VELO module prototype III

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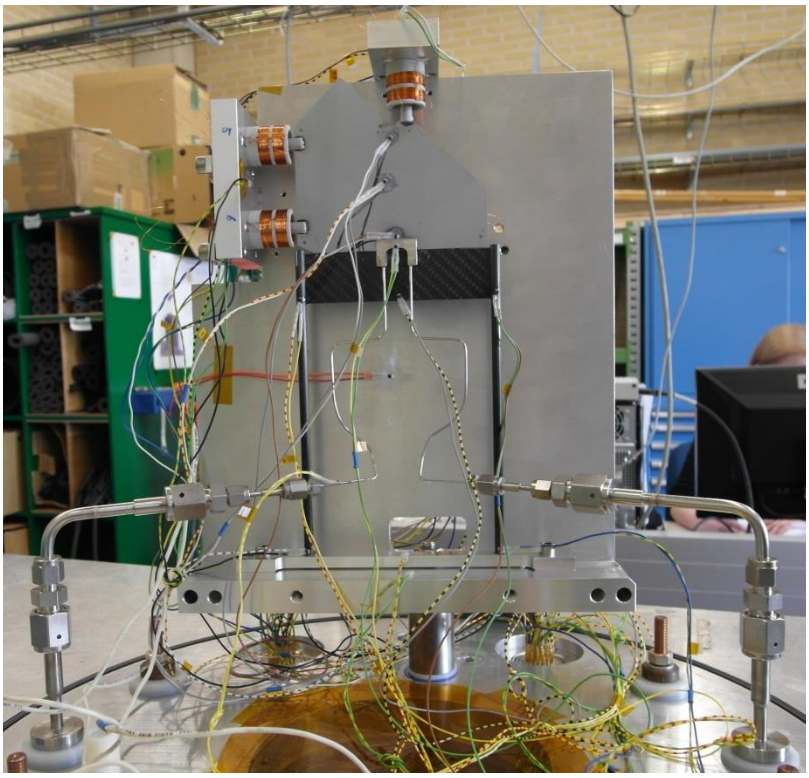

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1. Specifications VELO module prototype III

For this module the design of the cooling block has changed into a moustache shaped cooling block. The cooling block will be soldered to the silicon and glued on the carbon hurdle. A view of the moustache shaped cooling block is given in Figure 1.

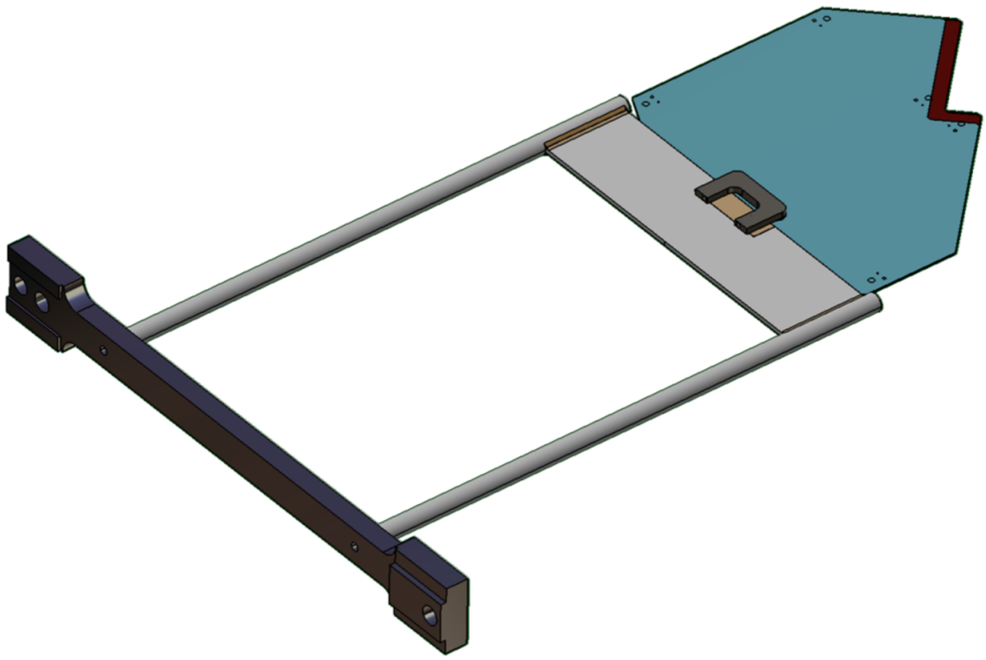


Figure 1: View of VELO module III with moustache shaped cooling block

While soldering the moustache shaped cooling block, the metalized surface on the silicon came loose. Therefore the moustache shaped cooling block is glued to the silicon. A schematic view of the bonding of the silicon to the carbon hurdle is given in Figure 2.

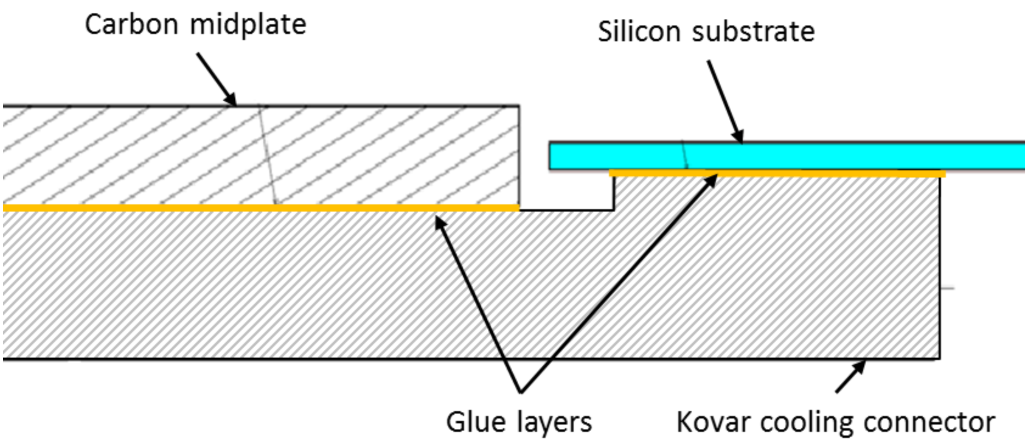
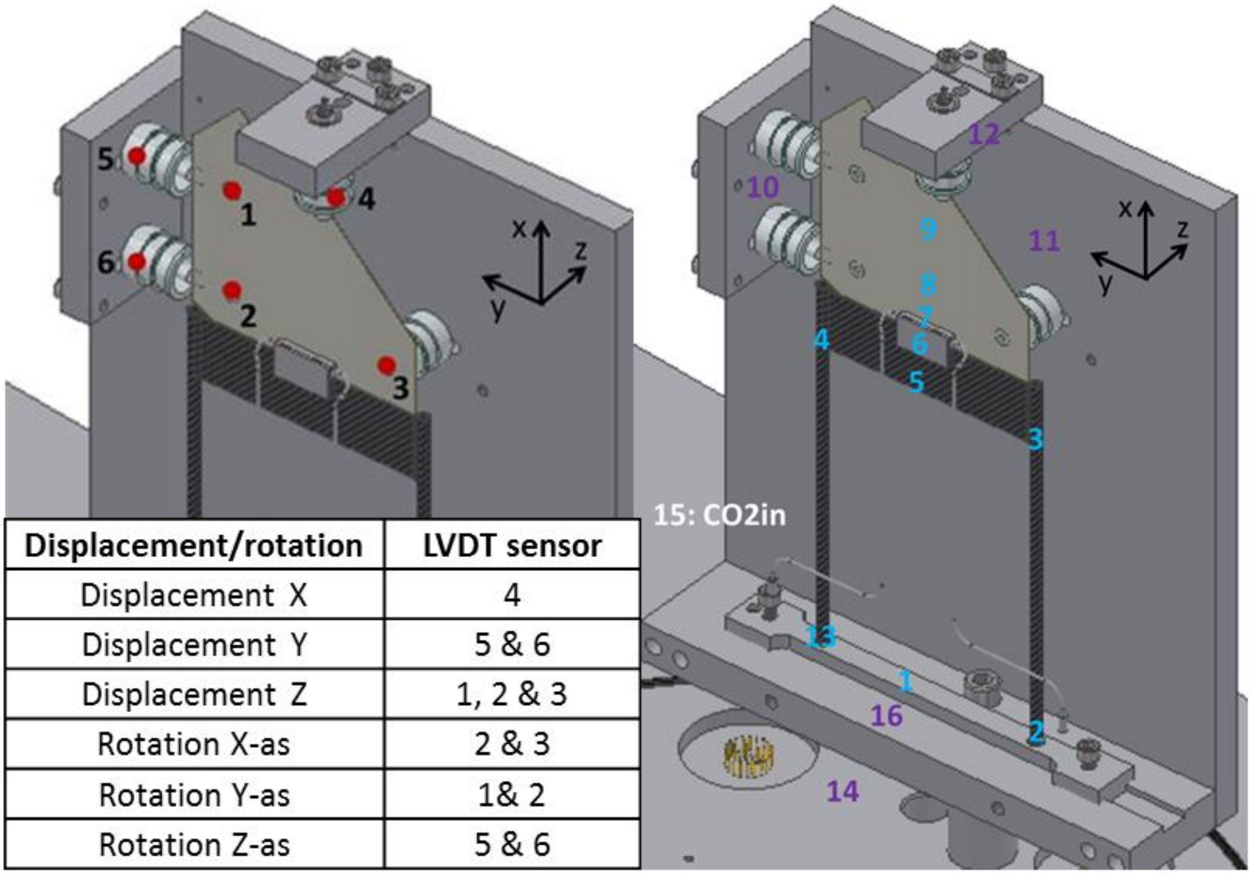


Figure 2: Section of VELO module III bonding between the silicon and the carbon hurdle

2. Measuring set up

For these measurements, the same frame and LVDT sensors are used as the in the previous measurements with VELO module prototype I. Figure 3 gives a view of the location of LVDT and temperature sensors.



Displacement/rotation	LVDT sensor
Displacement X	4
Displacement Y	5 & 6
Displacement Z	1, 2 & 3
Rotation X-as	2 & 3
Rotation Y-as	1& 2
Rotation Z-as	5 & 6

Figure 3: Location of the LVDT and temperature sensors

The coloured wires of the LVDT sensors are not connected exactly in the same way as before, therefore some pins are exchanged in the connector at the vacuum side.

The first results show that temperature T15 is warmer than expected, this is probably due to a thick glue layer between sensor 15 and the capillary. A view of the sensors from a cold temperature to warm is given below:

Module I	15	7	8	9	6	5
Module II	15	8	7	9	6	5
Module III	6	7	15	8	9	5

3. Results measurement 1: 22 May 2015

The following measurement is started with a frame temperature of 26.5 °C (Set Value 50) and under vacuum conditions. As temperature sensor T15 is warmer than expected, temperature sensor T6, cooling block, is used as an indication of the liquid CO_2 temperature. The module is cooled down with liquid CO_2 with a temperature of approximately -26 °C.

A summary of the settings of the cooling system follows:

- Temperature primary cooling = -50 °C
- Temperature Accumulator= -5 °C
- Cooling temperature CO2 = -26 °C
- Mass flow system = 5 g/s
- Mass flow module ≈ 2g/s
- Heater control: 26.5 °C

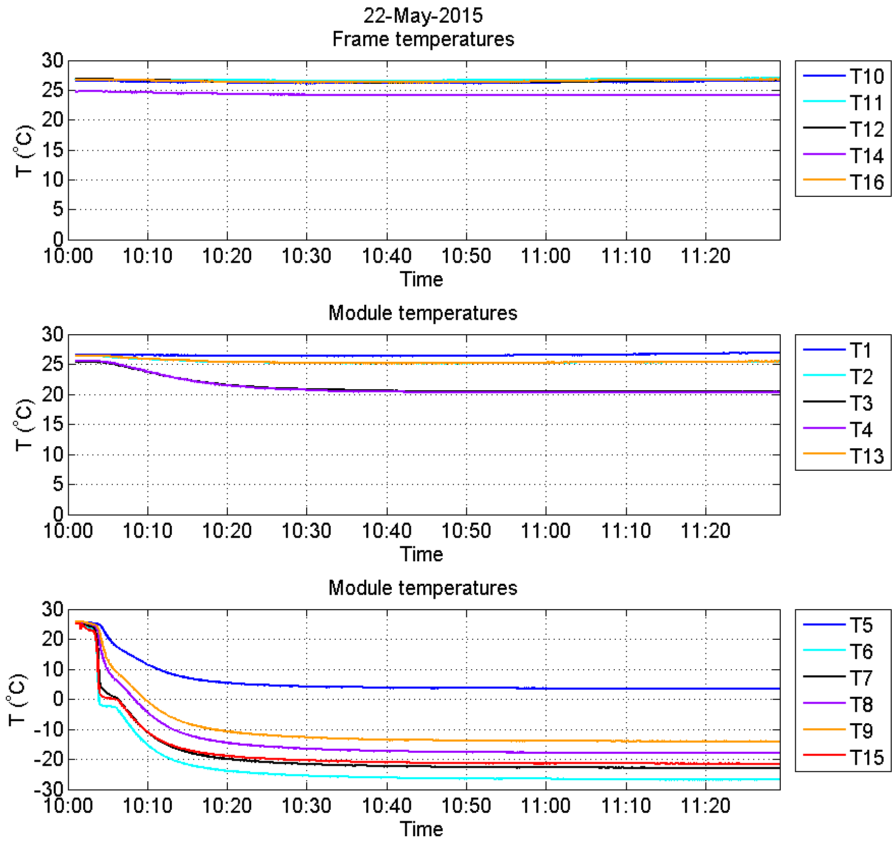


Figure 4: Temperature curve for cooling down of VELO module III

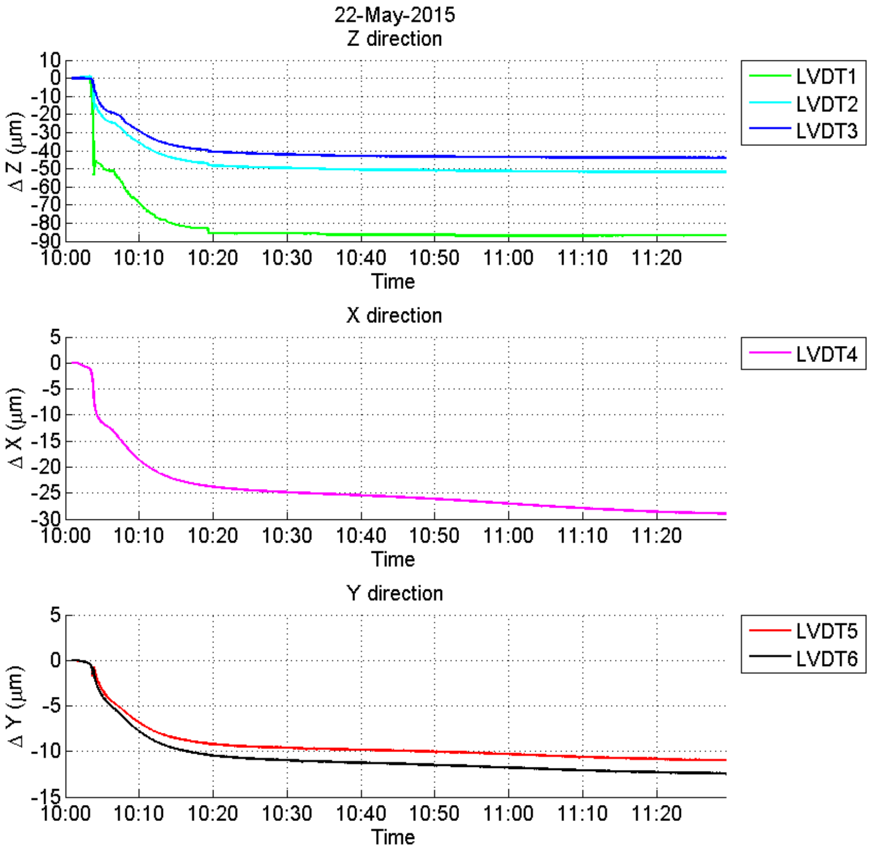


Figure 5: LVDT signal for cooling down of VELO module III

The displacement for the cooling down from 26 °C down to -26 °C per LVDT sensor is shown in the following table.

Table 1: Displacement for cool down from 26 °C down to -24 °C

Sensor	Displacement (µm)
LVDT 1	-87
LVDT 2	-52
LVDT 3	-44
LVDT 4	-29
LVDT 5	-11
LVDT 6	-12

The following figure shows the displacement versus the temperature of the kovar cooling block T6. The two phase temperature for this measurement is -5 °C, this explains the jump in the curves at approximately -5 °C.

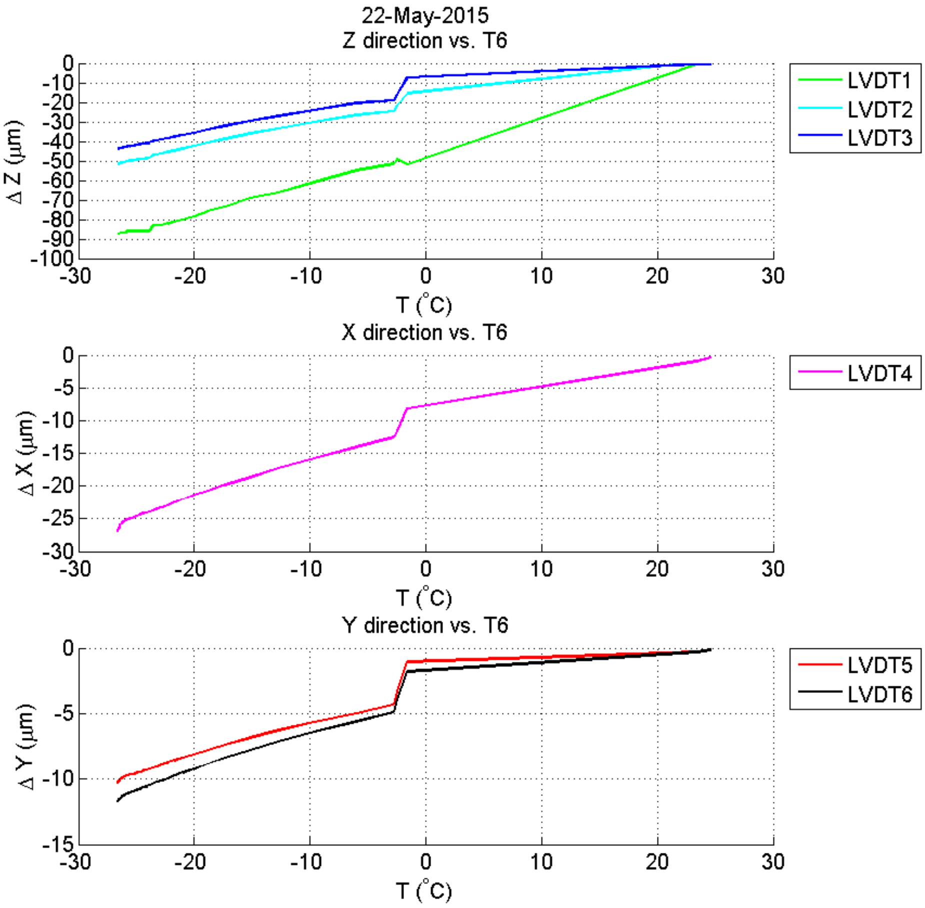


Figure 6: Displacement versus temperature sensor 6 for module III

4. Results measurement 2: 22 may 2015

For this measurement additional cooling is added on the backside of the midplate. Litze wire is connected to the CO2 inlet capillary and taped to the back of the midplate by means of copper tape. This adjusted module will be referred to as module IIIb.

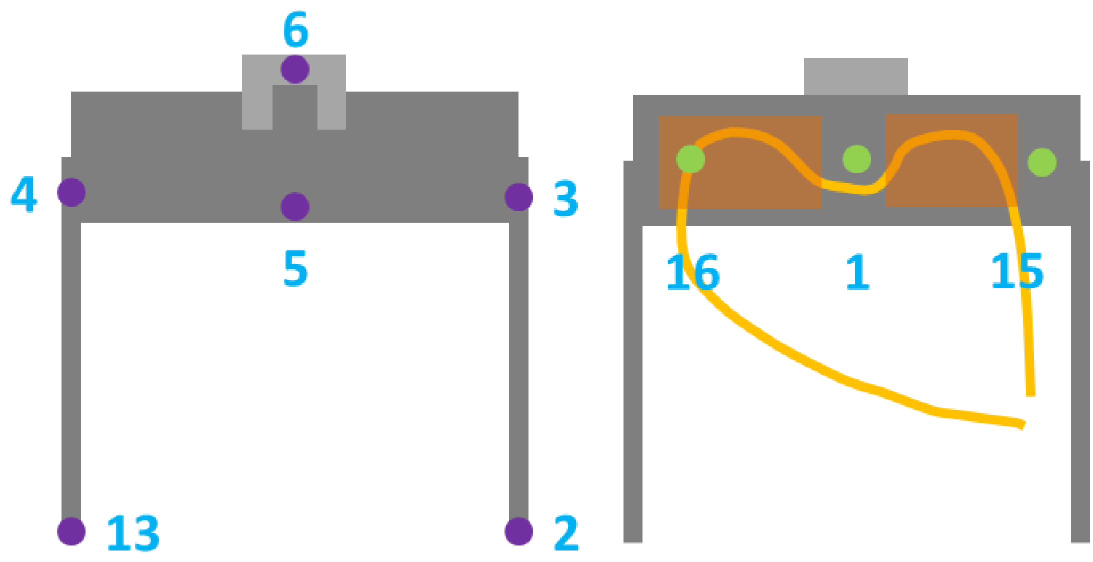


Figure 7: Schematic view additional cooling midplate

To monitor the temperature of the backside of the midplate, sensors T1, T15 and T16 are relocated to the midplate.

To measure the displacement when cooling down the module, the module is cooled down with liquid CO_2 with a temperature of approximately -26 °C.

A summary of the settings of the cooling system follows:

- Temperature primary cooling = -50 °C
- Temperature Accumulator= -5 °C
- Cooling temperature CO2 = -26 °C
- Mass flow system = 5 g/s
- Mass flow module ≈ 2g/s
- Heater control: 26.5 °C

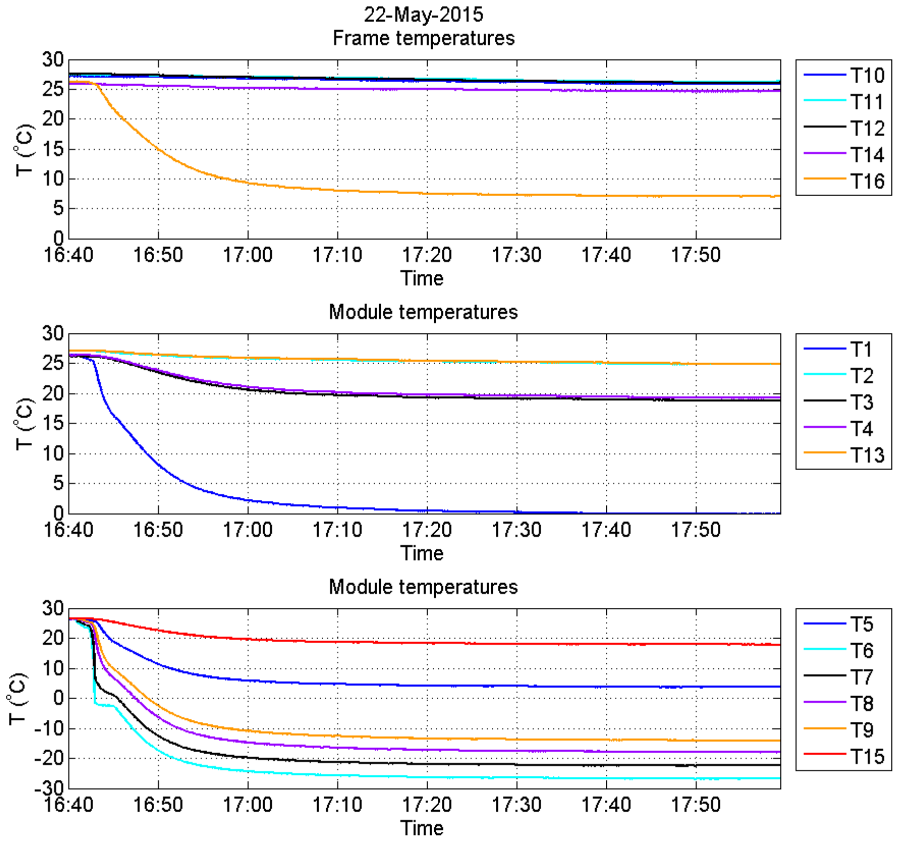


Figure 8: Temperature curve for cooling down of VELO module IIIb

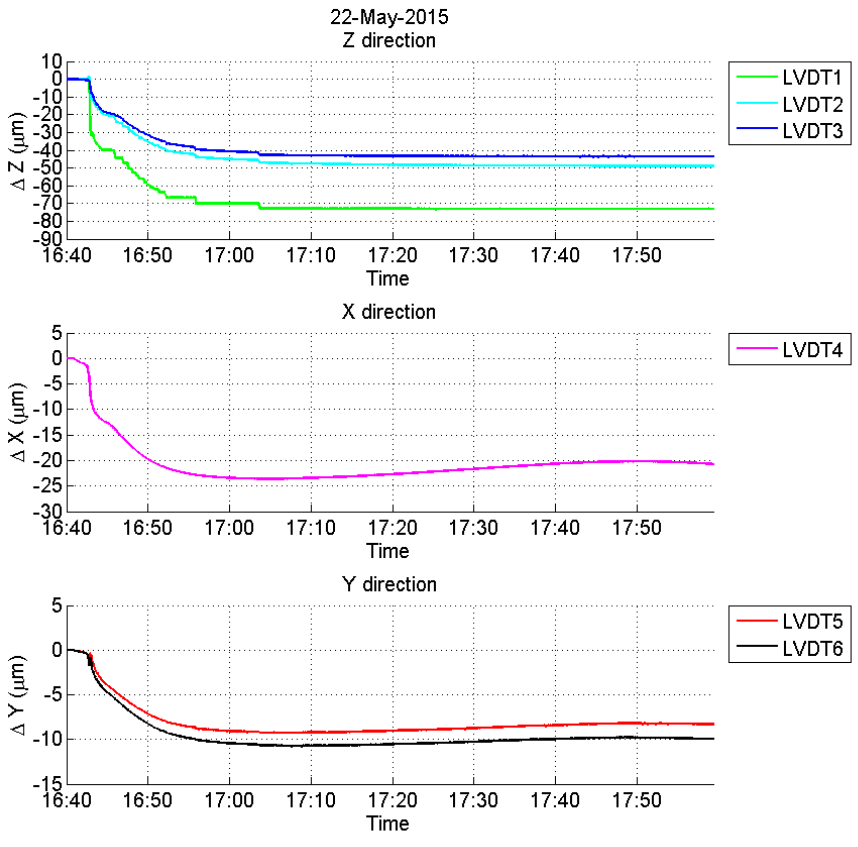


Figure 9: LVDT signal for cooling down of VELO module IIIb

The displacement for the cooling down from 26 °C down to -26 °C per LVDT sensor is shown in the following table.

Table 2: Displacement for cool down from 26 °C down to -24 °C

Sensor	Displacement (μm)
LVDT 1	-72
LVDT 2	-49
LVDT 3	-44
LVDT 4	-23
LVDT 5	-9
LVDT 6	-11

The temperatures of the hurdle don't change significantly due to the additional cooling on the backside of the midplate, see Figure 10. The temperature sensors on the backside of the midplate indicate that the temperature of the midplate is not homogeneous which can cause deformation of the midplate and thus displacement of the module.

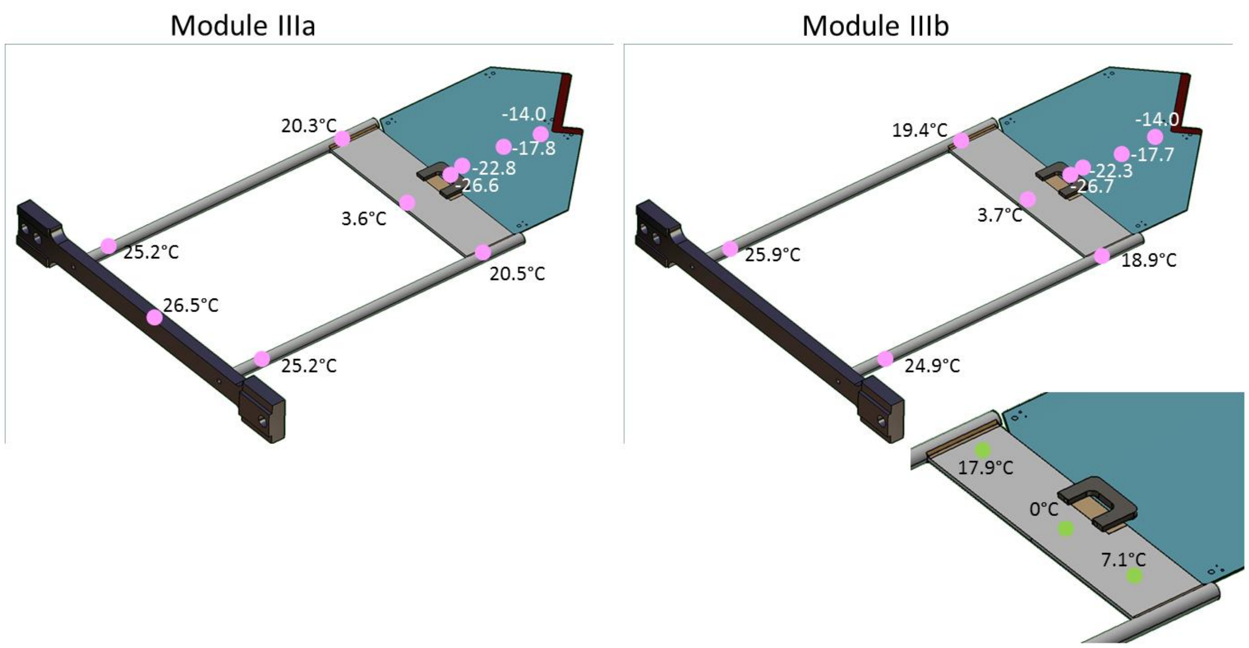


Figure 10: Temperature distribution of module III and module IIIb

The additional cooling does make a difference of approximately 15 μm in the signal of LVDT sensor 1. This suggests that cooling the backside of the midplate reduces deformation of the module.

5. Results measurement 3: 9 June 2015

The frame is heated to a temperature of approximately 26 °C, this can cause some heating by radiation. Therefore a radiation shield is added between the frame and the module and the additional cooling is removed from the backside of the midplate.

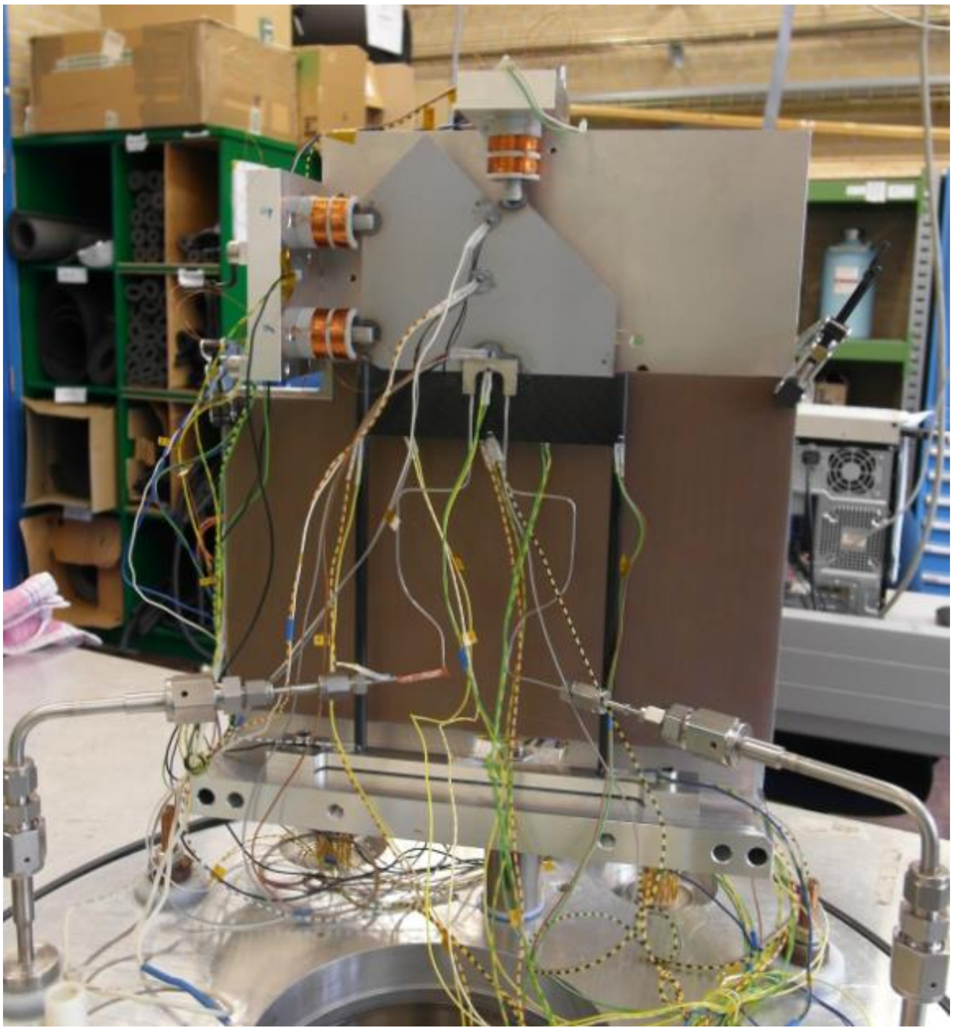


Figure 11: Test setup with radiation shield

To measure the displacement when cooling down the module, the module is cooled down with liquid CO_2 with a temperature of approximately -28 °C.

A summary of the settings of the cooling system follows:

- Temperature primary cooling = -50 °C
- Temperature Accumulator= -5 °C
- Cooling temperature CO2 = -28.5 °C
- Mass flow system = 5 g/s
- Mass flow module ≈ 2g/s
- Heater control: 26.5 °C

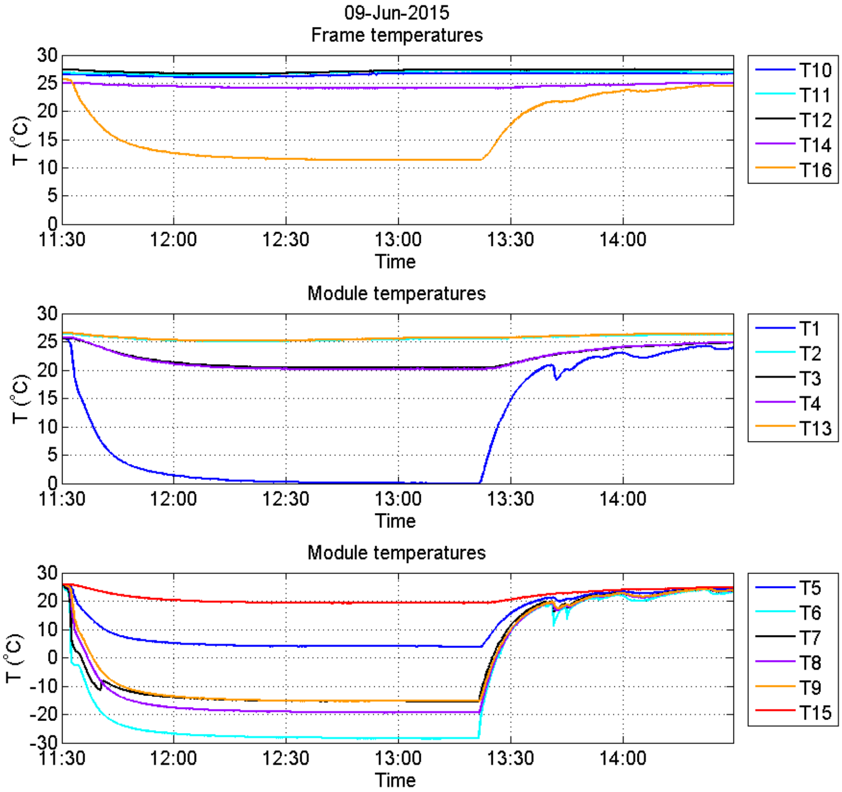


Figure 12: Temperature curve for cooling down and warm up of VELO module III with radiation shield

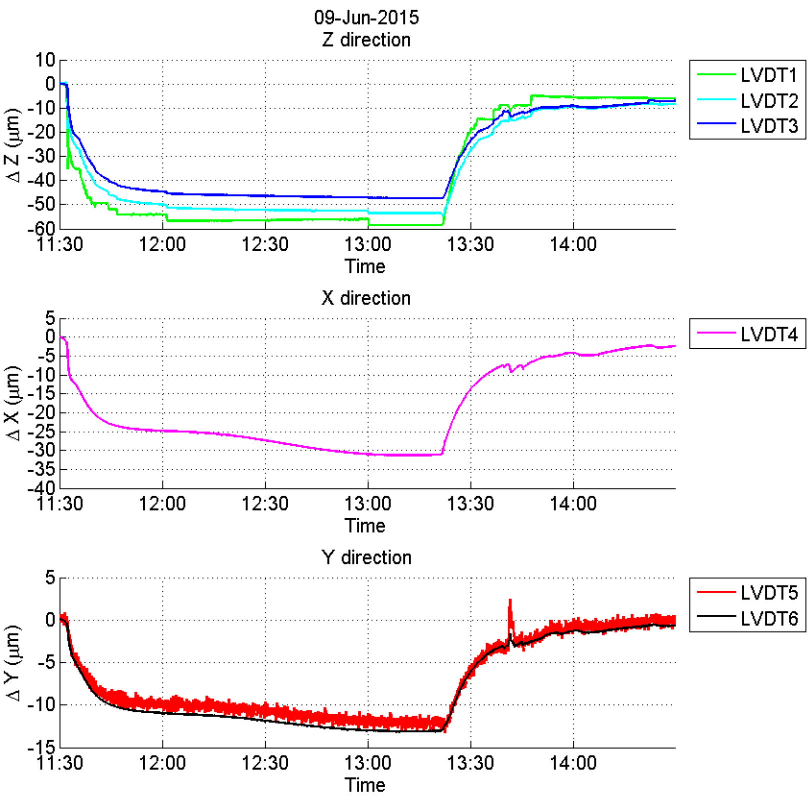


Figure 13: LVDT signal for cooling down and warm up of VELO module III with radiation shield

The displacement for the cooling down from 26 °C down to -28 °C per LVDT sensor is shown in the following table.

Table 3: Displacement for cool down from 26 °C down to -28 °C

Sensor	Displacement (μm)
LVDT 1	-58
LVDT 2	-54
LVDT 3	-47
LVDT 4	-31
LVDT 5	-11
LVDT 6	-13

6. Results measurement 4: 9 June 2015

The measurement with the radiation shield is repeated after checking that temperature sensor 7 is still connected and that the wires of LVDT 5 are free to move.

First the module is cooled down with liquid CO_2 with a temperature of approximately -28 °C. When the temperature is stable, the CO_2 is heated up in the following steps: -22, -15, and -8 °C. The module heats up to almost 26 °C when the CO_2 flow through the module is stopped.

A summary of the settings of the cooling system follows:

- Temperature primary cooling = -50 °C
- Temperature Accumulator= -5 °C
- Mass flow system = 5 g/s
- Mass flow module ≈ 2g/s
- Heater control: 26.5 °C

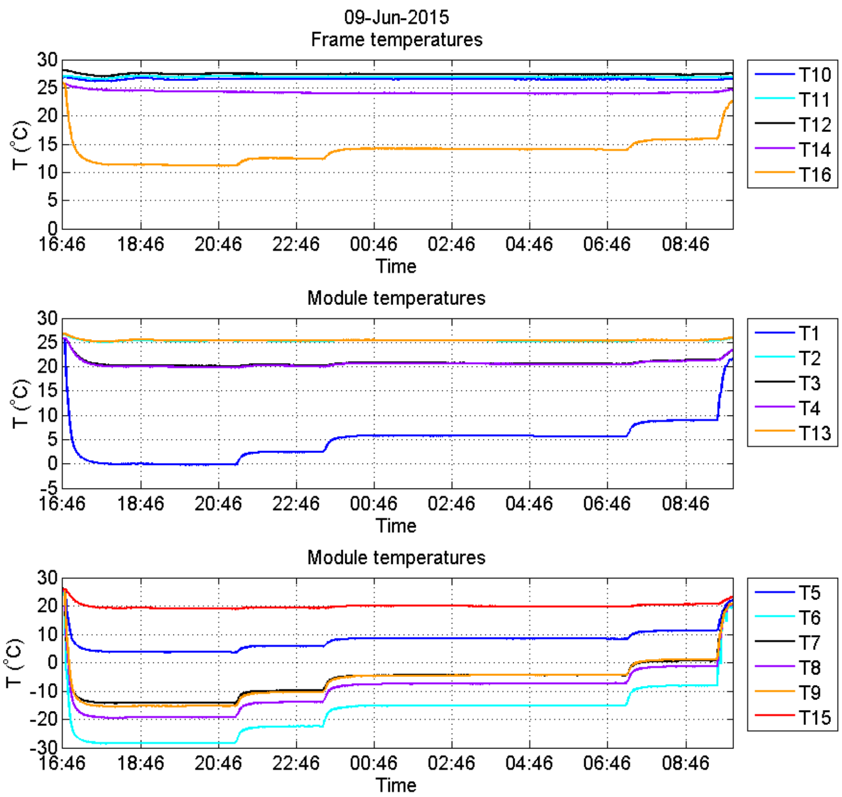


Figure 14: Temperature curve for cooling down and warm up of VELO module III with radiation shield

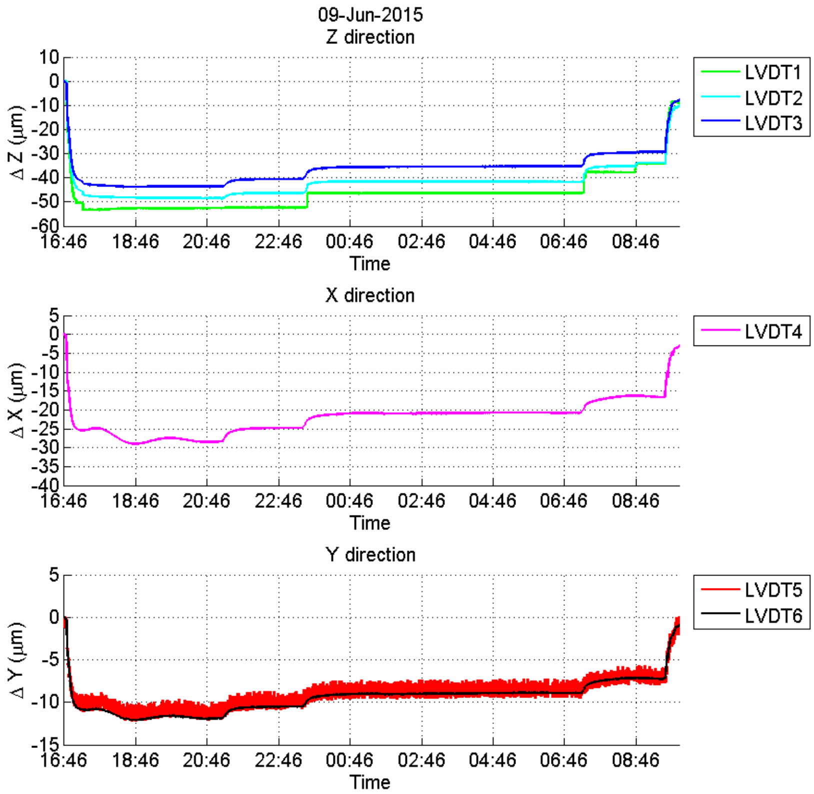
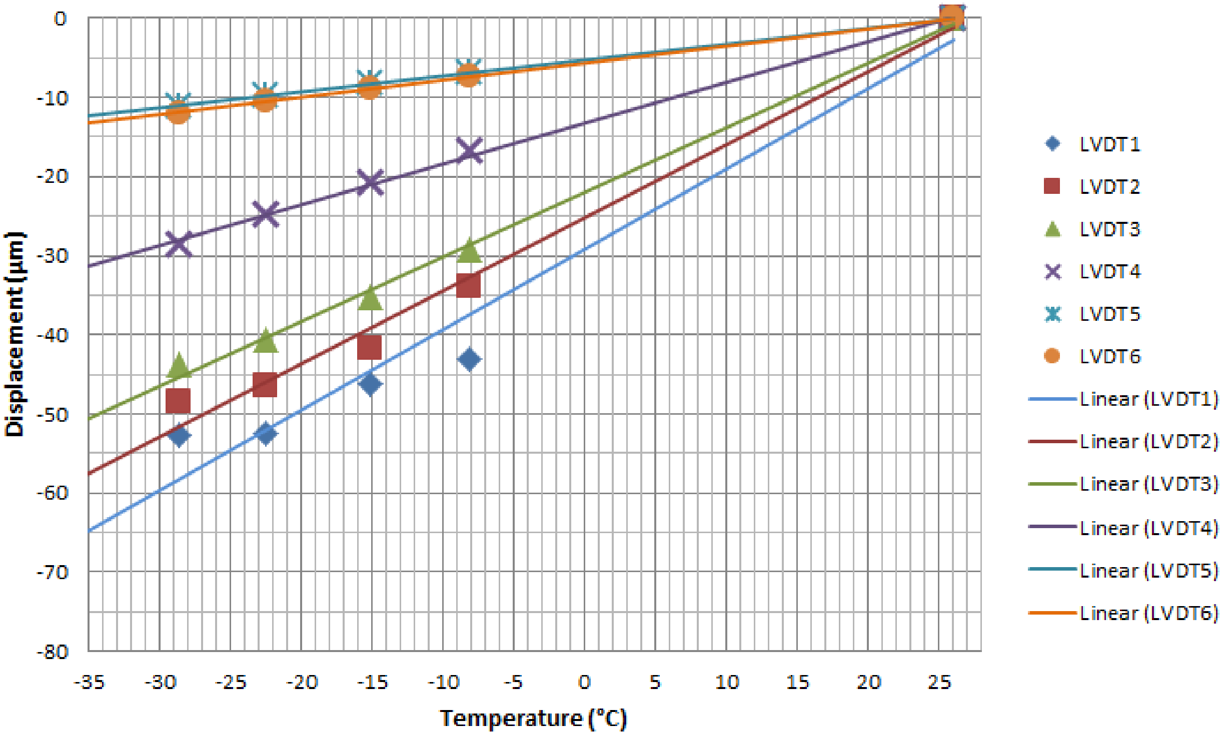


Figure 15: LVDT signal for cooling down and warm up of VELO module III with radiation shield

The displacement for the cooling down from 26 °C down to -28 °C per LVDT sensor is shown in the following table.

Table 4: Displacement for cool down from 26 °C down to -28 °C

Sensor	Displacement (μm)
LVDT 1	-53
LVDT 2	-48
LVDT 3	-44
LVDT 4	-28
LVDT 5	-11
LVDT 6	-12



0
-10
-20
-30
-40
-50
-60
-70
-80
Displacement (µm)
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
Temperature (°C)
LVDT1
LVDT2
LVDT3
LVDT4
LVDT5
LVDT6
Linear (LVDT1)
Linear (LVDT2)
Linear (LVDT3)
Linear (LVDT4)
Linear (LVDT5)
Linear (LVDT6)

7. Results measurement 5: 11 June 2015

From the previous measurement, it shows that het silicon moves evenly away from the frame. This behaviour is not seen before, thereby LVDT sensor 1 does not make a step at every temperature change. Therefore LVDT sensor 1 is checked with a micrometer which resulted in the conclusion that LVDT 1 might be outside its measuring range when the module is in 'neutral' position and only after cooling down comes within the measuring range.

Two spacers are added to the hurdle that force the silicon into a more centred position relative to the LVDT sensors on the silicon surface, see Figure 16. In this setup, the signal of LVDT 1 corresponds with the displacement caused by the micrometer.

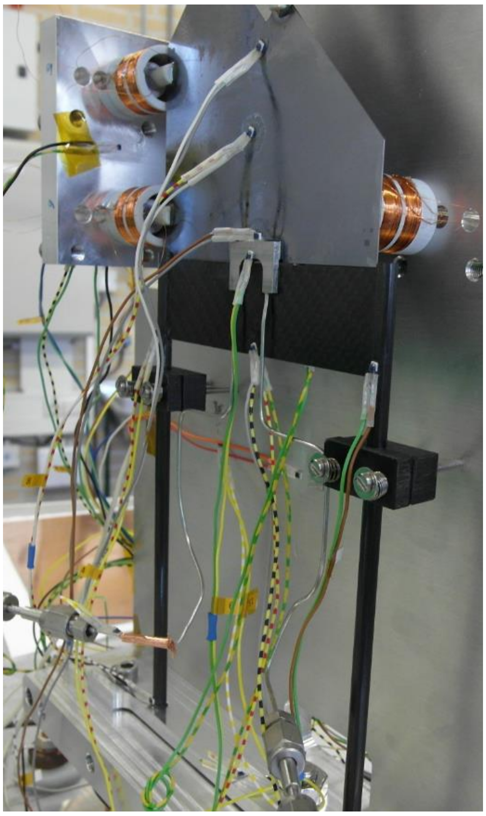


Figure 16: Hurdle with spacers

Temperature sensors T12 and T15 are relocated, a view of the location of the temperature sensors on the hurdle of the module is given in Figure 17.

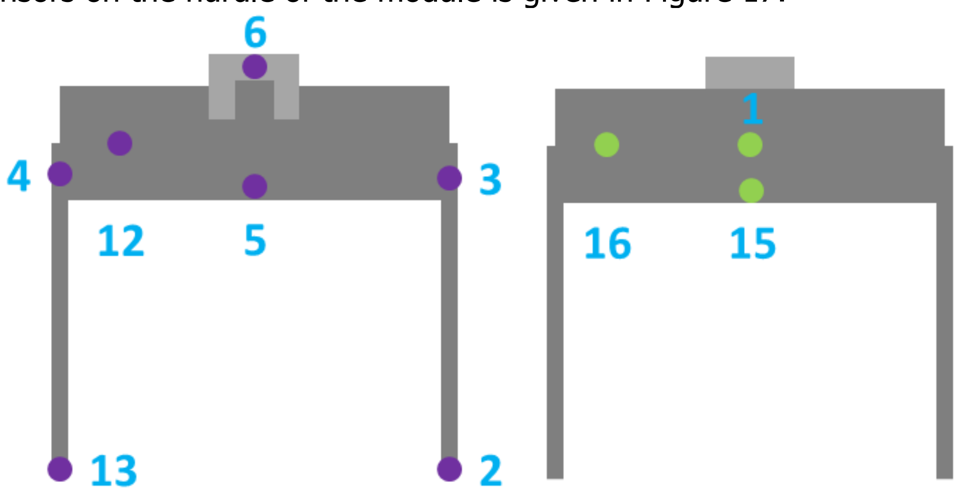


Figure 17: Temperature sensors on hurdle of module

To measure the displacement when cooling down the module, the module is cooled down with liquid CO_2 with a temperature of approximately -29 °C. Next the module is warmed up in the following steps -23 and -16 °C.

A summary of the settings of the cooling system follows:

- Temperature primary cooling = -50 °C
- Temperature Accumulator= -5 °C
- Mass flow system = 5 g/s
- Mass flow module ≈ 2g/s
- Heater control: 26.5 °C

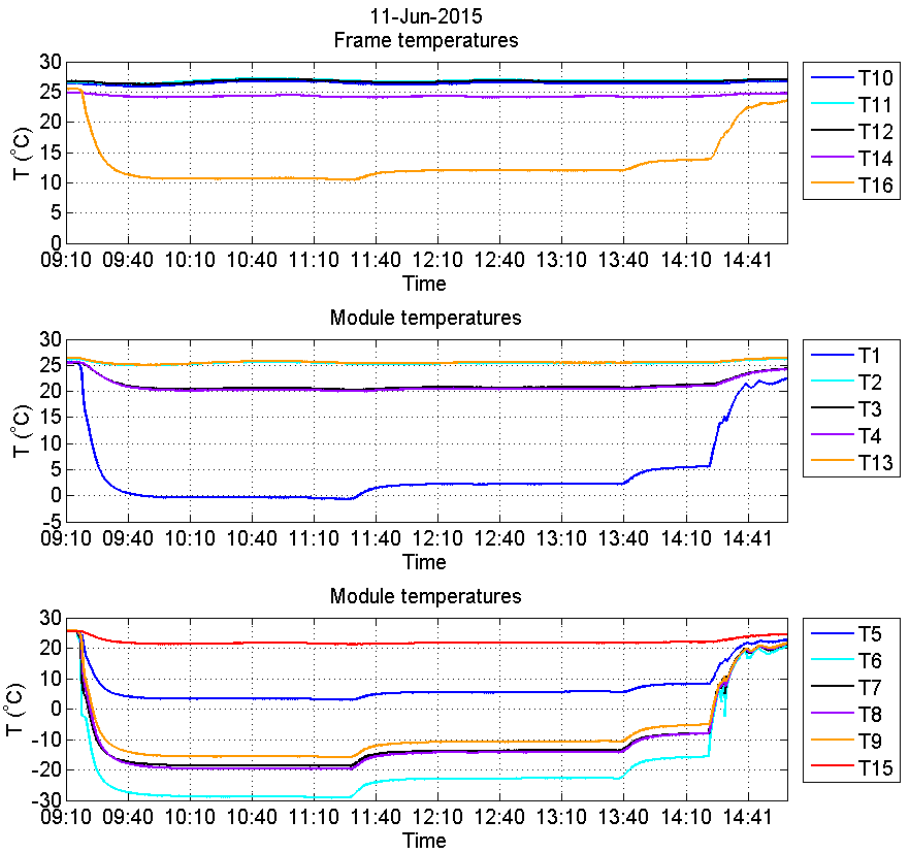


Figure 18: Temperature curve for cooling down and warm up of VELO module III with spacers

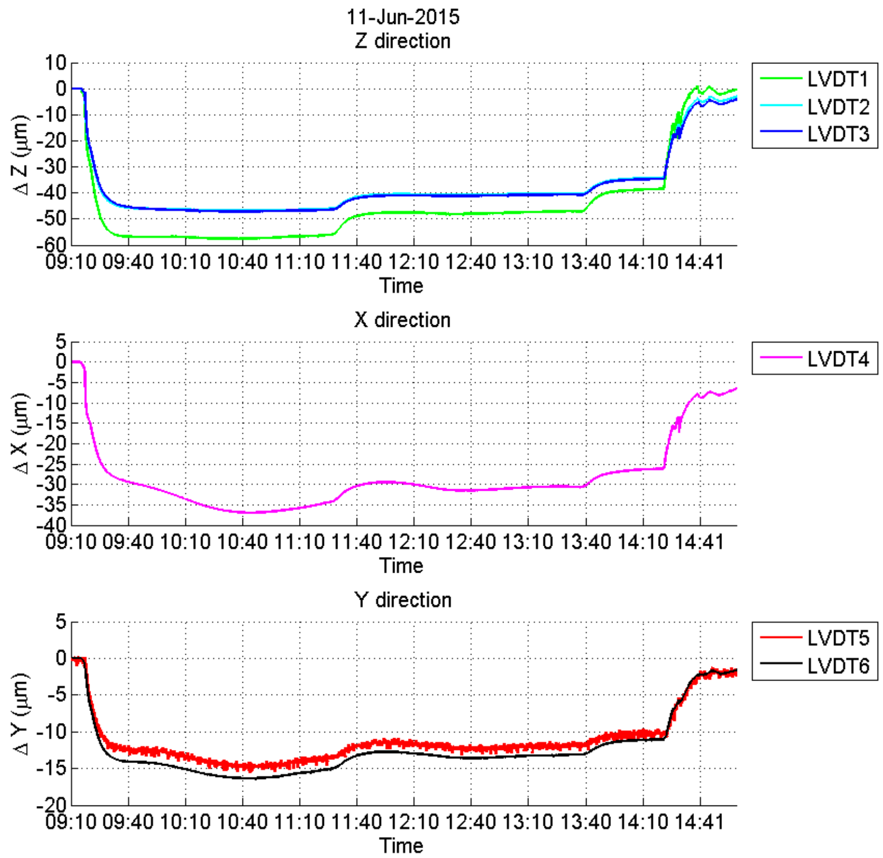


Figure 19: : LVDT signal for cooling down and warm up of VELO module III with spacers

The displacement for the cooling down from 26 °C down to -28 °C per LVDT sensor is shown in the following table.

Table 5: Displacement for cool down from 26 °C down to -29 °C

Sensor	Displacement (µm)
LVDT 1	-57
LVDT 2	-46
LVDT 3	-47
LVDT 4	-36
LVDT 5	-14
LVDT 6	-16

The displacement for various temperatures is shown in Figure 20. A regression line is fitted for the measurement points of each LVDT sensor.

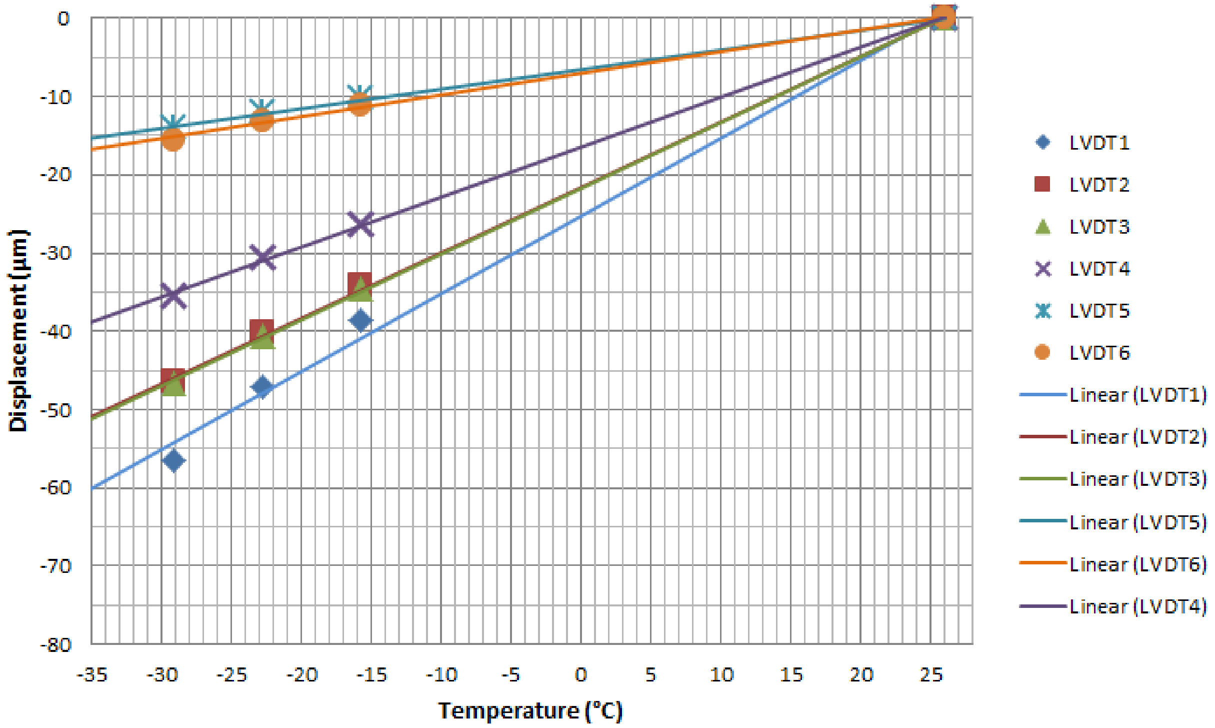


Figure 20: Displacement versus temperature for VELO module III with hurdle spacers

8. Results measurement 6 & 7: 12 June 2015

From the previous measurements it shows that the spacers on the hurdle have influence on the measurement. Therefore the back plate of the LVDT frame is moved 1 mm from the module, so that the primary coils 1, 2 and 3 are better aligned within the secondary coil.

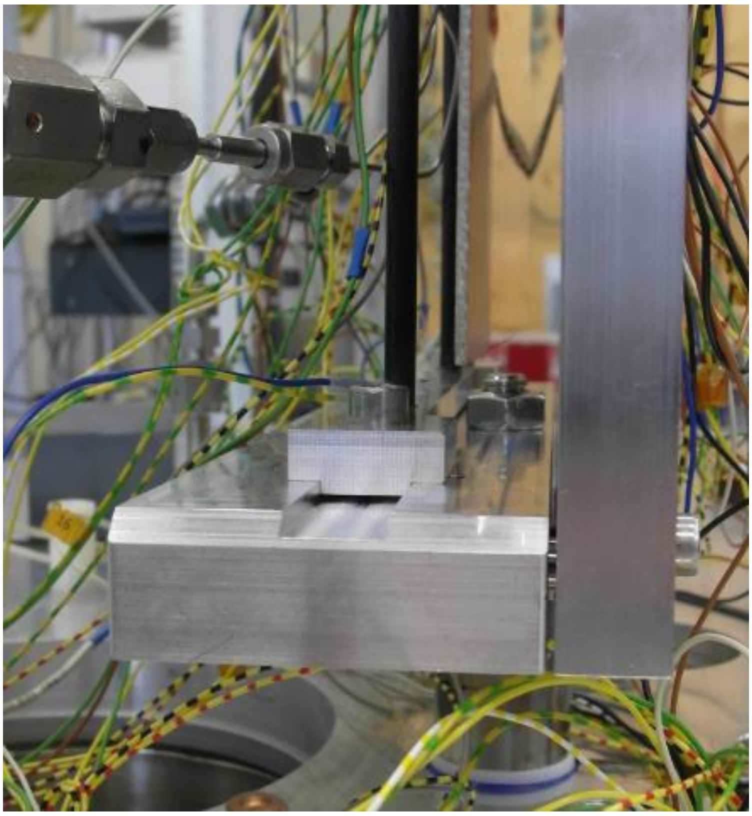


Figure 21:Frame with spacer

LVDT4 is not used during this measurement. Temperature sensors T15 and T12 are relocated. T15 is in the centre of the midplate (other side of T1) and T12 is on the right of the midplate (other side of T16).

To measure the displacement when cooling down the module, the module is cooled down with liquid CO_2 with a temperature of approximately -28 °C.

A summary of the settings of the cooling system follows:

- Temperature primary cooling = -50 °C
- Temperature Accumulator= -5 °C
- Cooling temperature CO2 = -28.5 °C
- Mass flow system = 5 g/s
- Mass flow module ≈ 2g/s
- Heater control: 26.5 °C

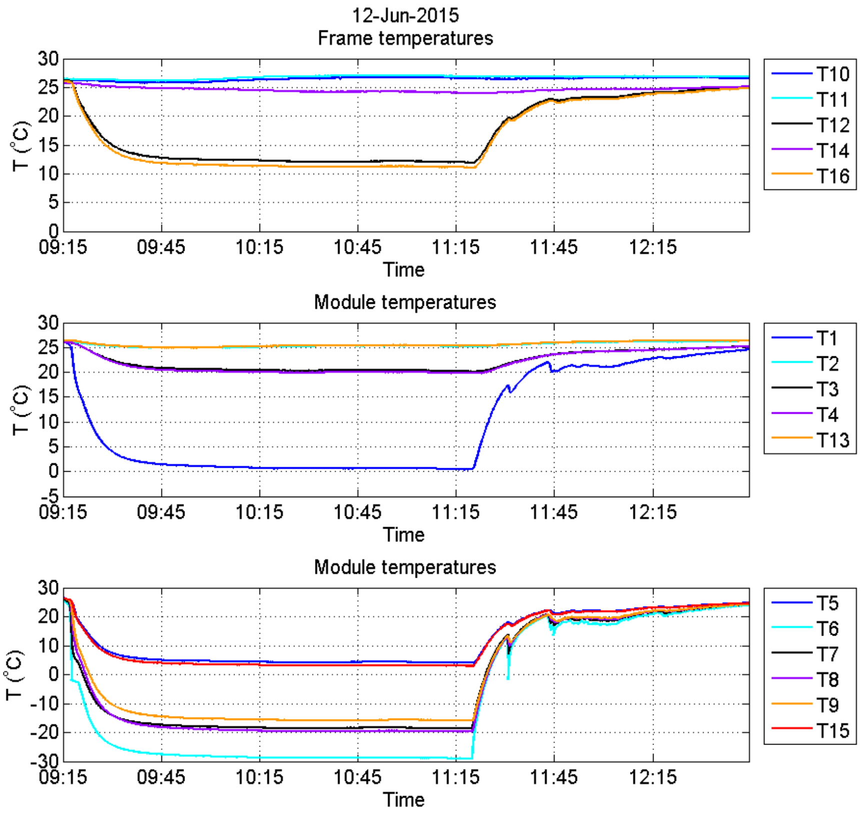


Figure 22: Temperature curve for cooling down and warm up of VELO module III with frame spacer

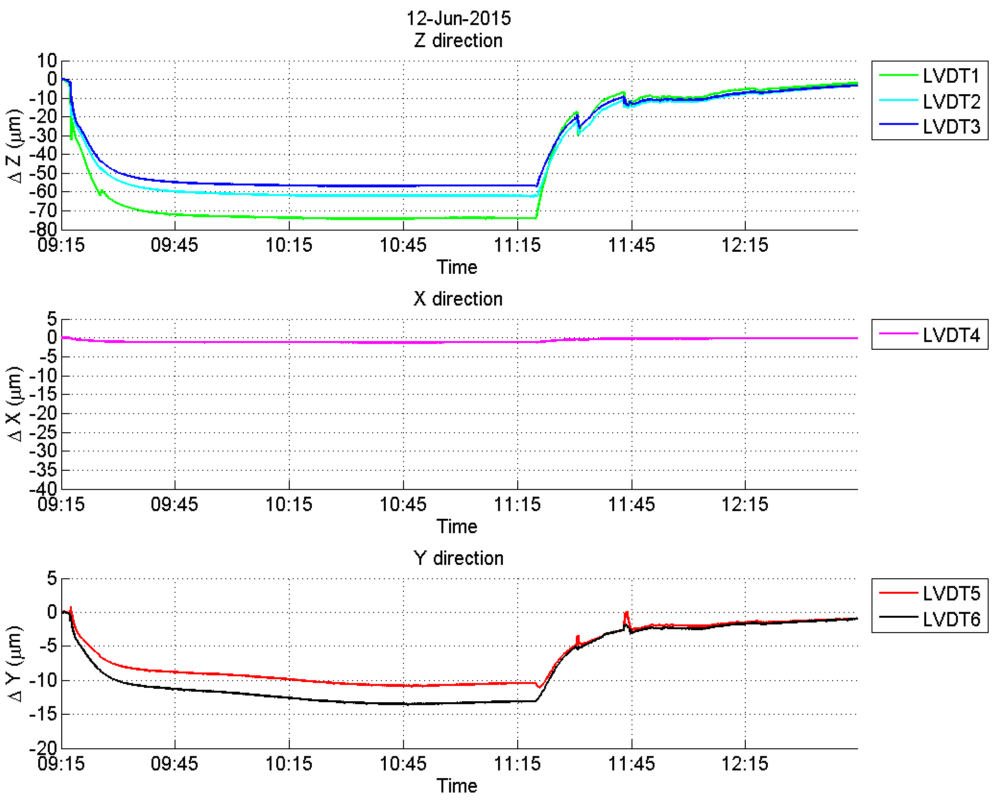


Figure 23: : LVDT signal for cooling down and warm up of VELO module III with frame spacer

The following results are with equal system settings. After that the module is cooled down with liquid CO_2 with a temperature of approximately -29 °C, the CO_2 is heated up in the following steps: -23, -15, -8 and -3 °C. After several days, the module is cooled down again to a temperature of -29°C.

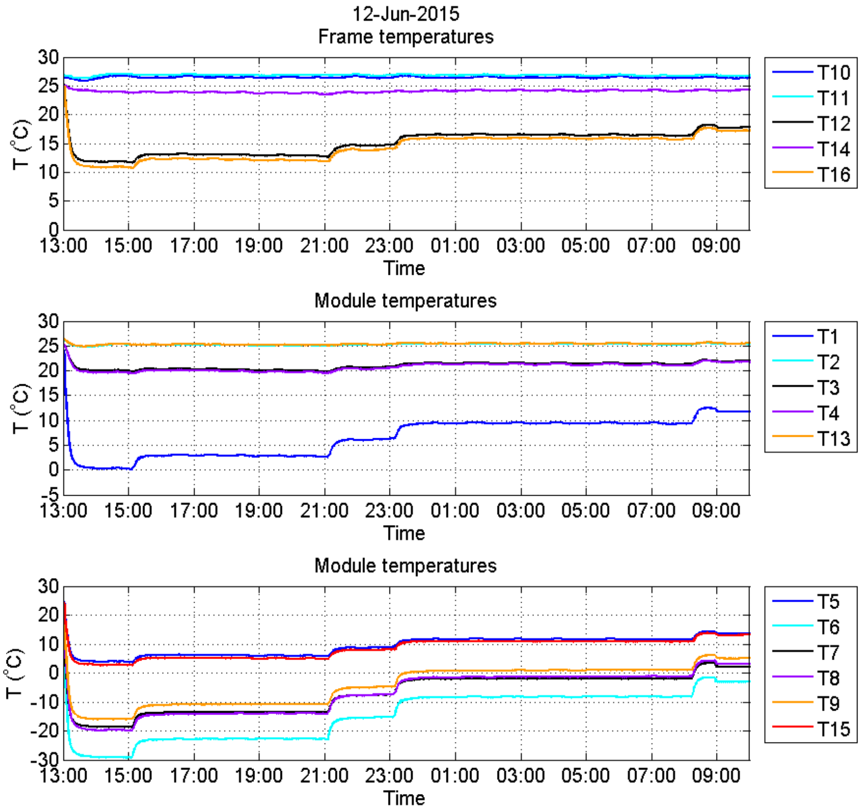


Figure 24: Temperature curve for cooling down of VELO module III with frame spacer

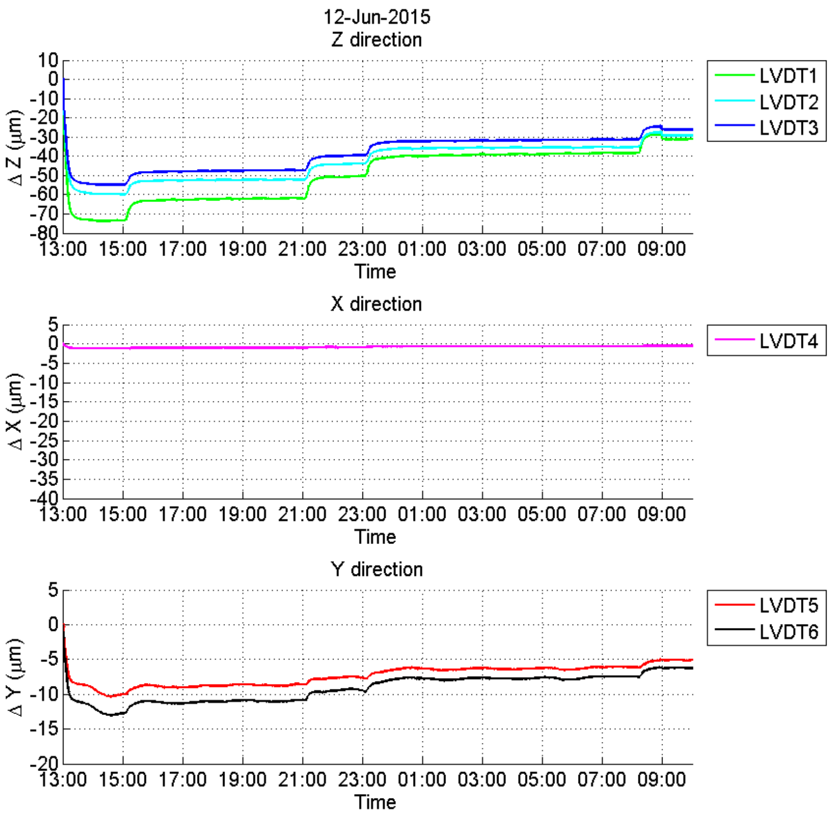


Figure 25: : LVDT signal for cooling down of VELO module III with frame spacer

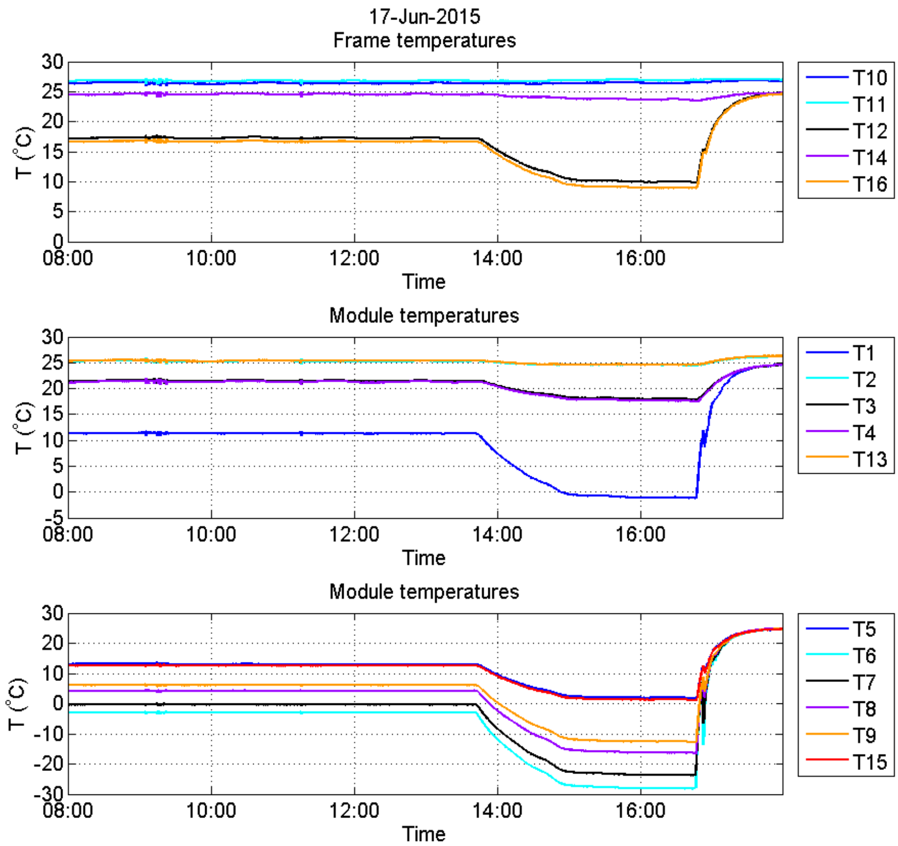


Figure 26: Temperature curve for cooling down back to -29°C of VELO module III with frame spacer

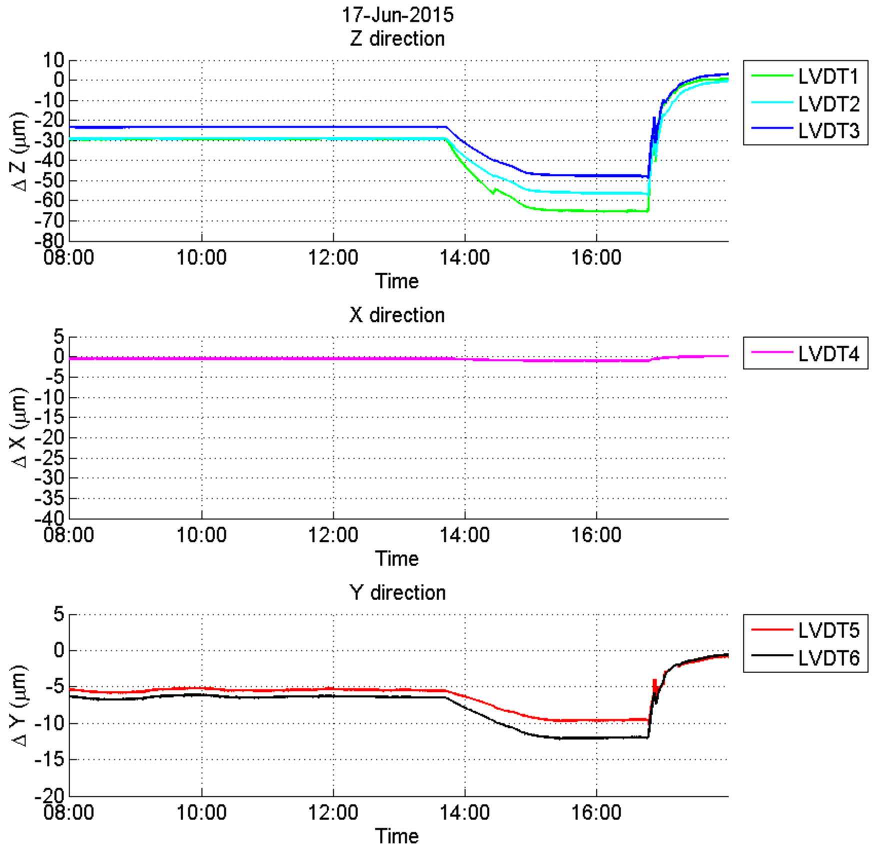


Figure 27: LVDT signal for cooling down back to -29°C of VELO module III with frame spacer

During this measurement, this module is cooled down three times. The table below shows the displacement of the module at -28°C with respect to the start temperature of approximately 26°C.

Table 6: Displacement for cool down from 26 °C down to -28 °C

Sensor	Displacement (µm)	Displacement (µm)	Displacement (µm)
LVDT 1	-73	-74	-65
LVDT 2	-62	-60	-57
LVDT 3	-57	-55	-47
LVDT 4	N/A	N/A	N/A
LVDT 5	-10	-10	-10
LVDT 6	-13	-13	-12

The displacement for various temperatures is shown in Figure 28. A regression line is fitted for the measurement points of each LVDT sensor. LVDT sensors 1, 2 and 3 show a deviation at the start point at a temperature of 25°C.

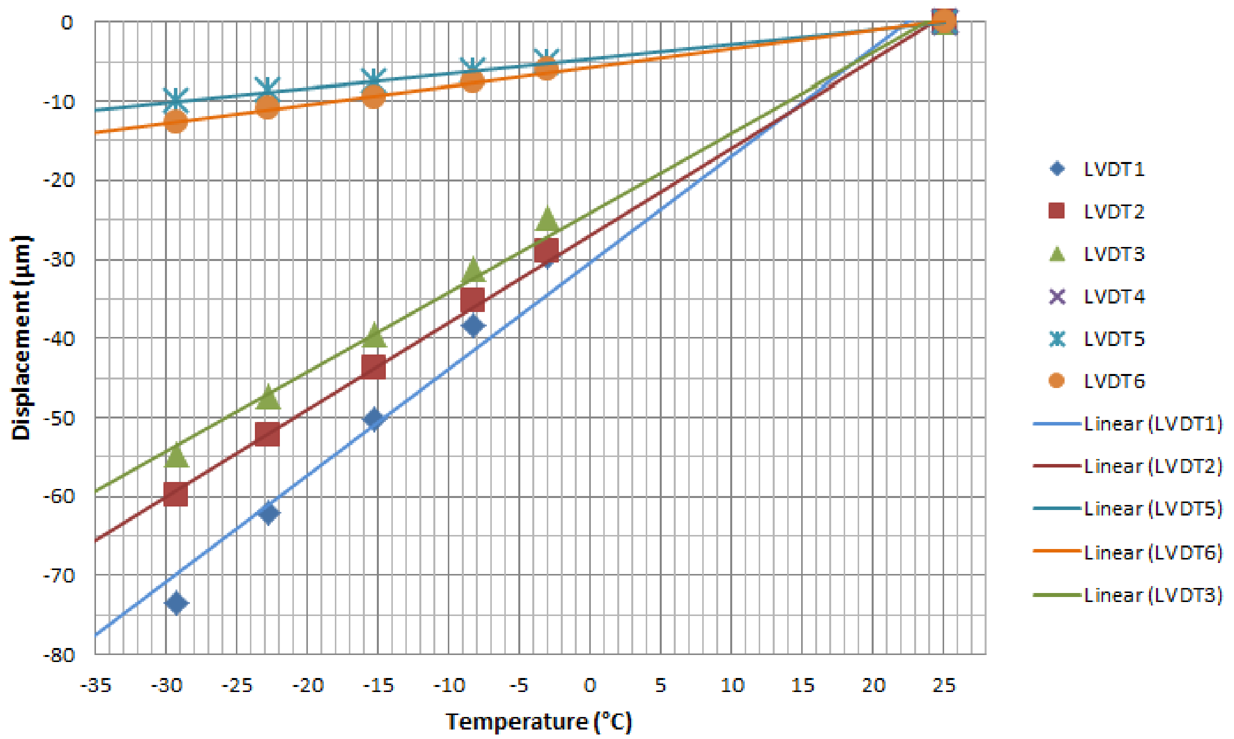


Figure 28: Displacement versus temperature for VELO module III with frame spacer

9. Results measurement 8: 19 June 2015

This measurement is done with an offset of 1 mm of the back plate of the frame and a radiation shield between the module and the frame.

To measure the displacement when cooling down the module, the module is cooled down with liquid CO_2 with a temperature of approximately -28 °C. Next the module is warmed up in steps up to -3.0 °C and cooled back down to -28 °C. Followed by a warm up and cool down in steps.
Cooling temperatures in chronological order: -28.5, -22.4, -14.9, -8.0, -3.0, -28.4, -22.4, -14.9, -8.0, -14.7, -22.2 and -28.3 °C.

A summary of the settings of the cooling system follows:

- Temperature primary cooling = -50 °C
- Temperature Accumulator= -5 °C
- Mass flow system = 5 g/s
- Mass flow module ≈ 2g/s
- Heater control: 26.5 °C

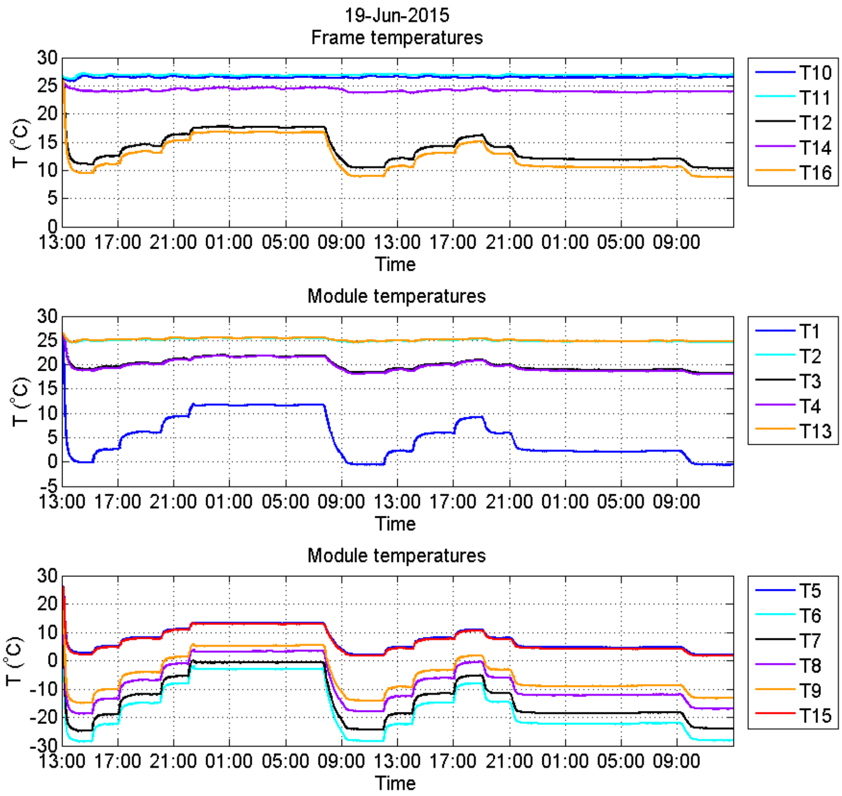


Figure 29: Temperature curve for cooling down of VELO module III with frame spacer and radiation shield

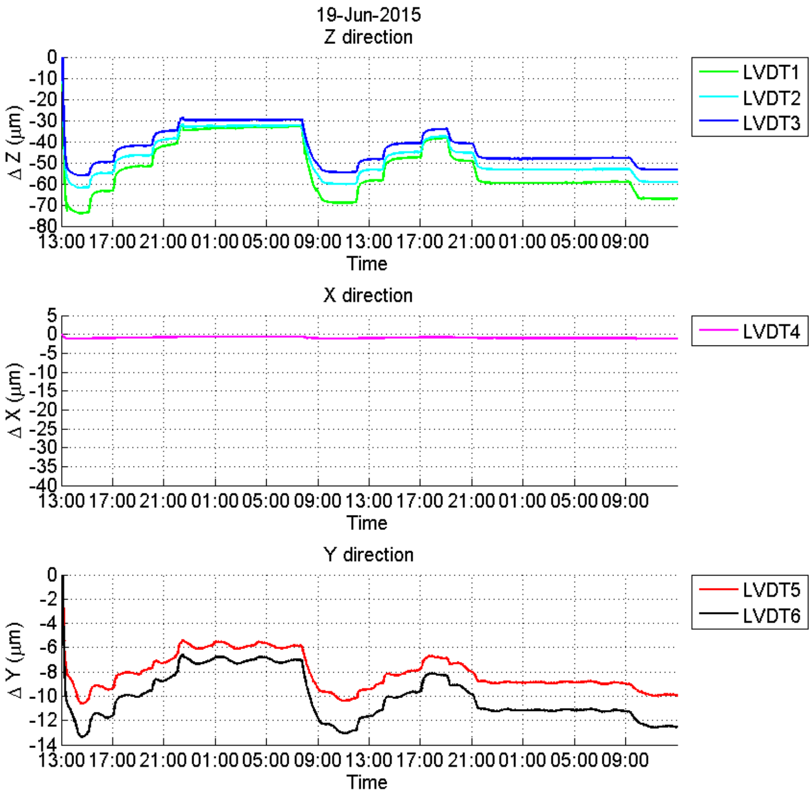


Figure 30: LVDT signal for cooling down of VELO module III with frame spacer and radiation shield

During this measurement, this module is cooled down three times. The table below shows the displacement of the module at -28°C with respect to the start temperature of approximately 26°C.

Table 7: Displacement for cool down from 26 °C down to -28 °C

Sensor	Displacement (μm)	Displacement (μm)	Displacement (μm)
LVDT 1	-74	-69	-67
LVDT 2	-62	-60	-59
LVDT 3	-56	-55	-53
LVDT 4	N/A	N/A	N/A
LVDT 5	-10	-10	-10
LVDT 6	-13	-13	-13
T6	-28.5 °C	-28.4 °C	-28.3 °C

The displacement for various temperatures is shown in Figure 31. A regression line is fitted for the measurement points of each LVDT sensor.

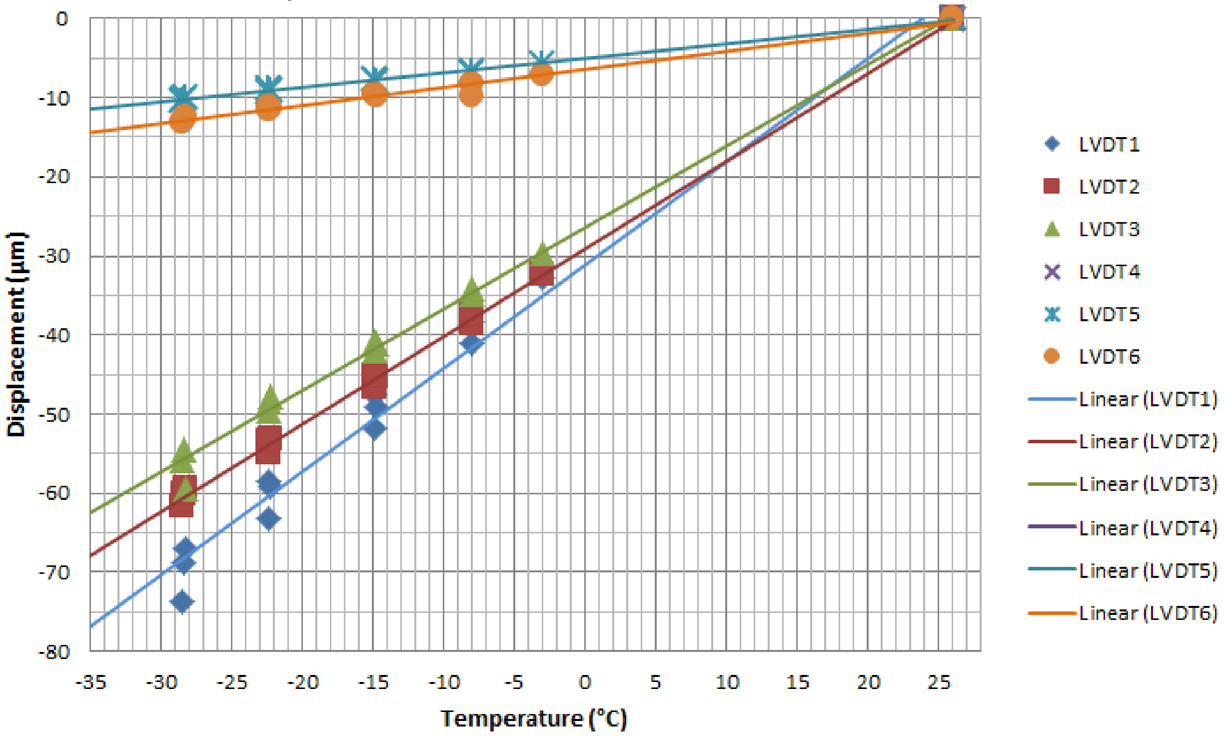


Figure 31: Displacement versus temperature for VELO module III with frame spacer with radiation shield

10. Results measurement 9: 25 June 2015

This measurement is done with an offset of 1 mm of the back plate of the frame and a modified cooling block (Figure 32). Two kovar blocks are glued to the back of the midplate, the blocks are connected to the capillaries with copper blocks and Litze wire.

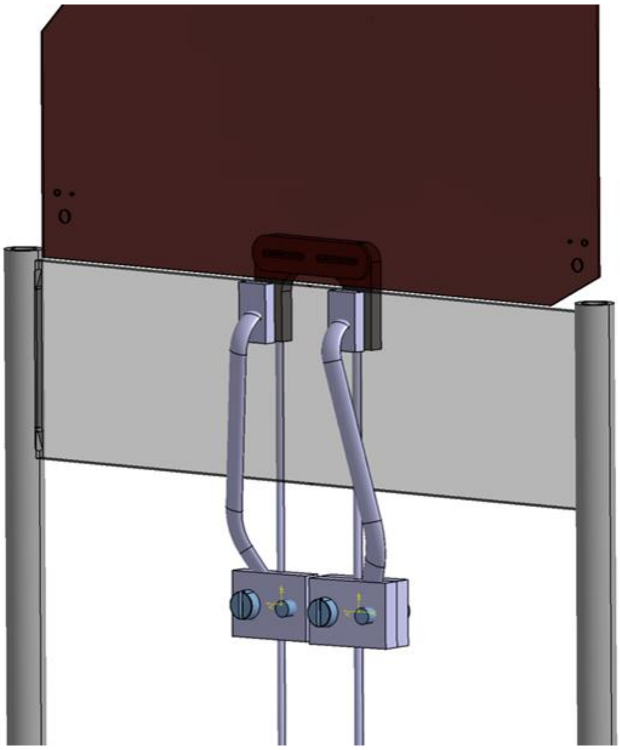


Figure 32: A view of the upgraded cooling block

To measure the displacement when cooling down the module, the module is cooled down with liquid CO_2 with a temperature of approximately -29 °C. Next the module is warmed up in steps up to -8.0 °C and cooled down again in steps.
Cooling temperatures in chronological order: -28.7, -14.7, -8.2, -14.8, -21.8 and -27.6 °C.

A summary of the settings of the cooling system follows:

- Temperature primary cooling = -50 °C
- Temperature Accumulator= -5 °C
- Mass flow system = 5 g/s
- Mass flow module ≈ 2g/s
- Heater control: 26.5 °C

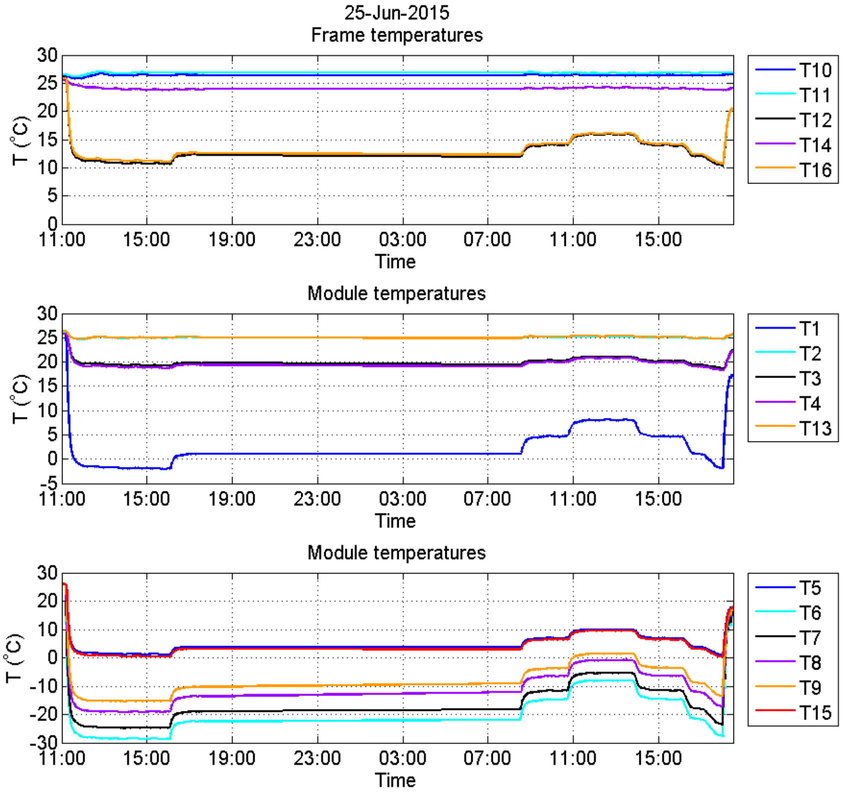


Figure 33: : Temperature curve for cooling down of VELO module III with modified cooling block

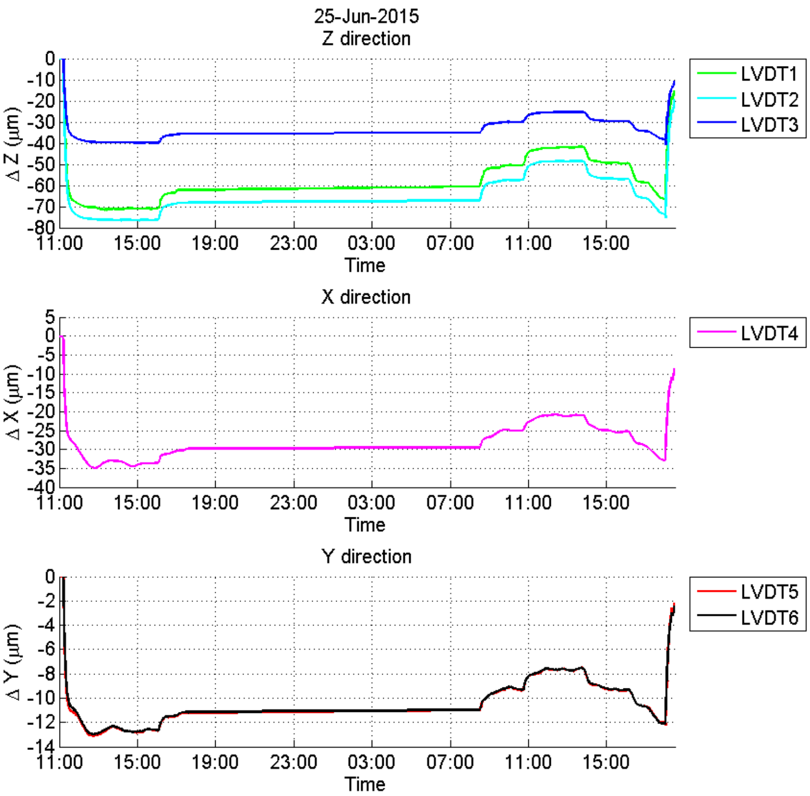


Figure 34: LVDT signal for cooling down of VELO module III with modified cooling block

During this measurement, this module is cooled down two times. The table below shows the displacement of the module at -28°C with respect to the start temperature of approximately 26°C.

Table 8: Displacement for cool down from 26 °C down to -28 °C

Sensor	Displacement (μm)	Displacement (μm)
LVDT 1	-71	-66
LVDT 2	-76	-74
LVDT 3	-40	-38
LVDT 4	-34	-33
LVDT 5	-13	-12
LVDT 6	-13	-12
T6	-28.7	-27.6

The displacement for various temperatures is shown in Figure 31. A regression line is fitted for the measurement points of each LVDT sensor.

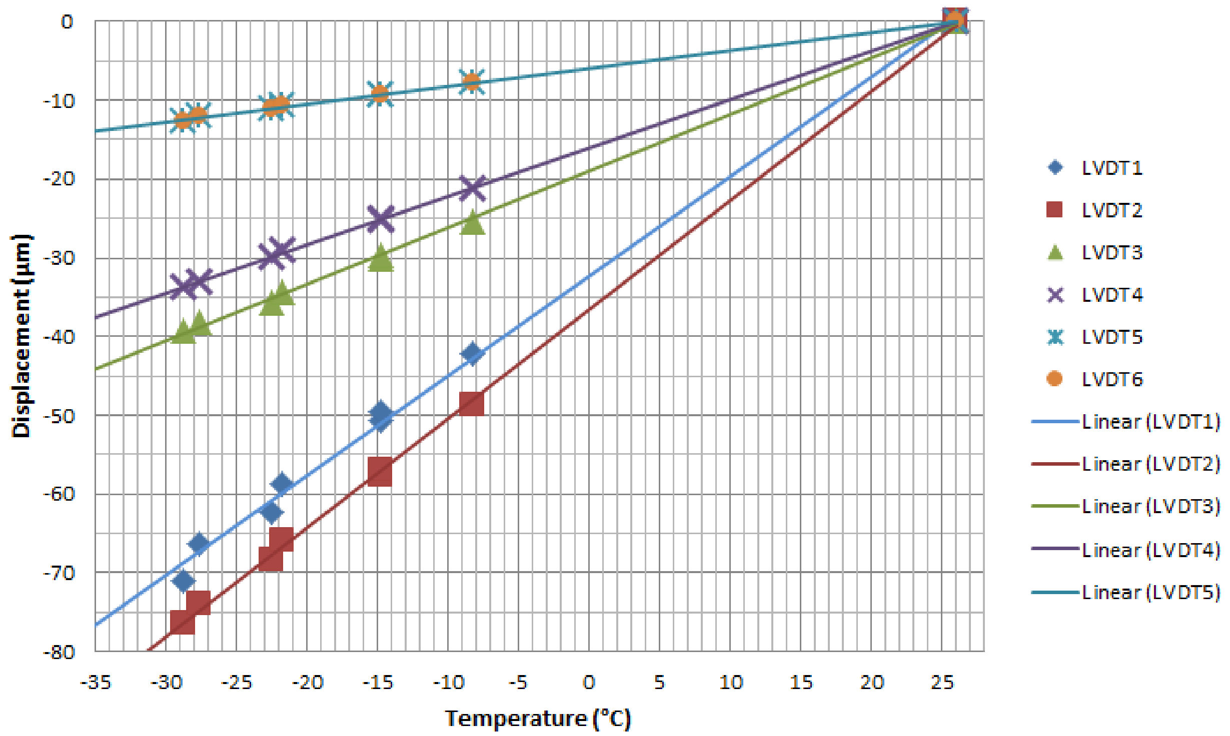


Figure 35: Displacement versus temperature for VELO module III with modified cooling block

11. Results measurement 10: 25 June 2015

From the previous measurement follows that the displacement of LVDT 2 is larger than LVDT 1. This might be an effect due too little space for movement of the module. Therefore LVDT 4 is removed from the frame and the module is cooled down again.

A summary of the settings of the cooling system follows:

- Temperature primary cooling = -50 °C
- Temperature Accumulator= -5 °C
- Cooling temperature CO_2 = -28.7 °C
- Mass flow system = 5 g/s
- Mass flow module ≈ 2g/s
- Heater control: 26.5 °C

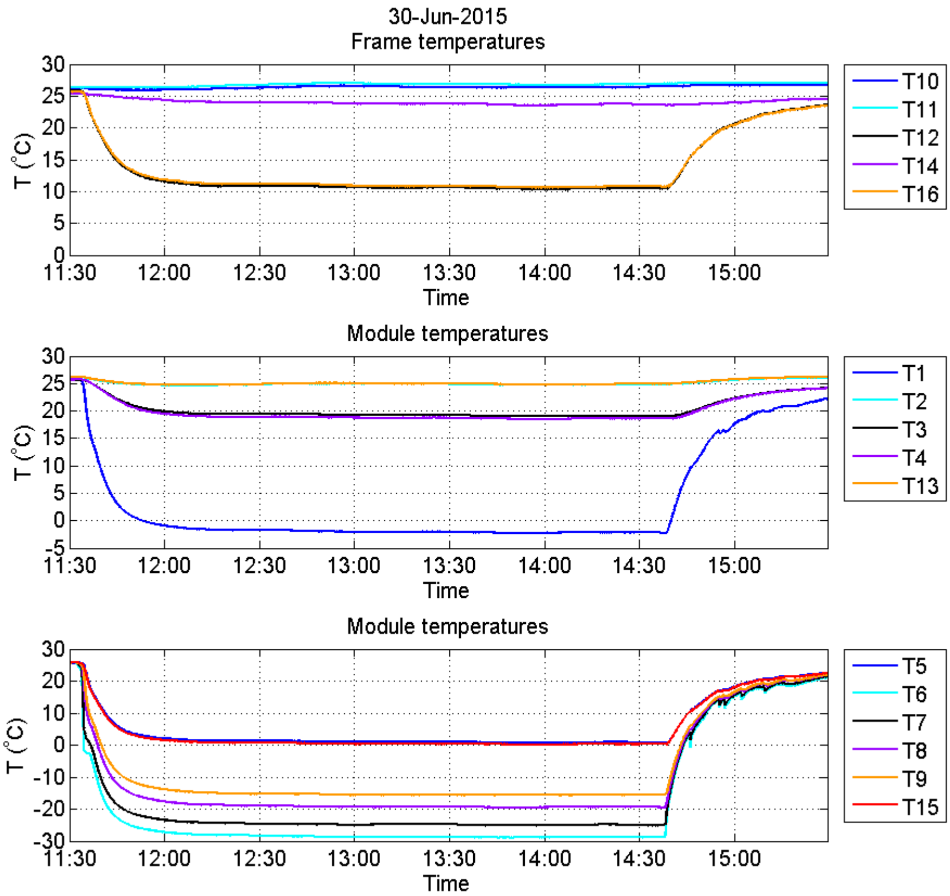


Figure 36: Temperature curve for cooling down of VELO module III with modified cooling block and without LVDT4

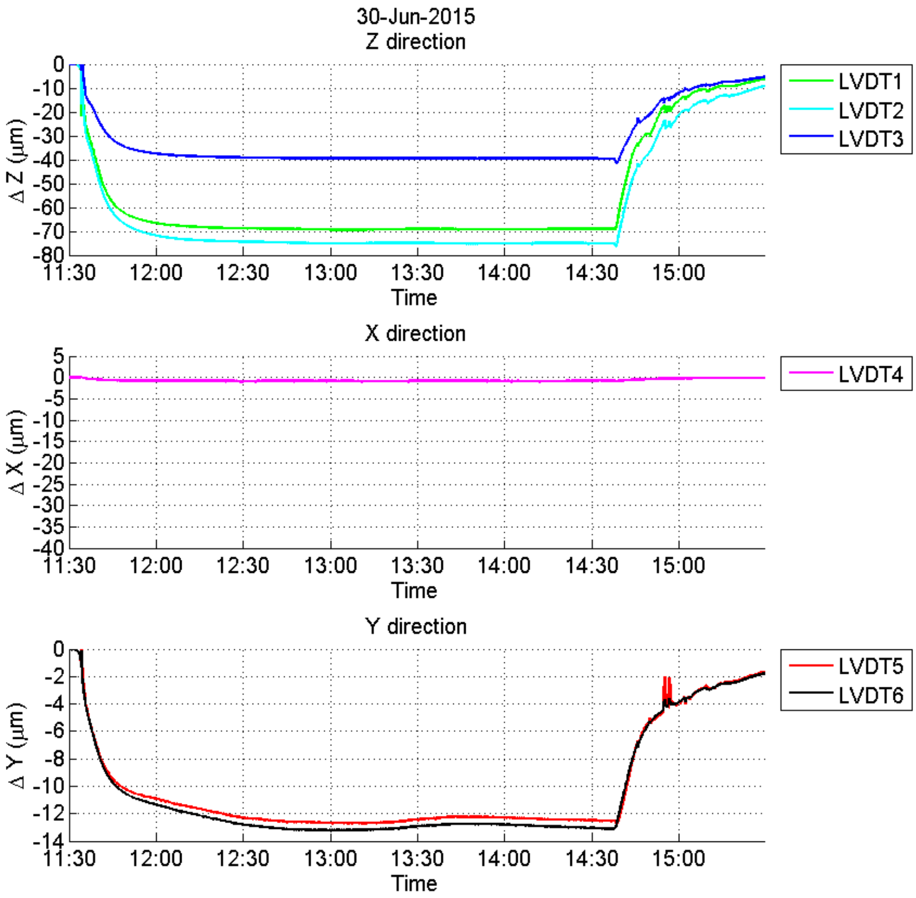


Figure 37: LVDT signal for cooling down of VELO module III with modified cooling block and without LVDT4

The table below shows the displacement of the module at -29°C with respect to the start temperature of approximately 26°C.

Table 9: Displacement for cool down from 26 °C down to -29 °C

Sensor	Displacement (µm)
LVDT 1	-69
LVDT 2	-75
LVDT 3	-39
LVDT 4	N/A
LVDT 5	-12
LVDT 6	-13
T6	-28.7

From the table above can be seen that the signal of LVDT 2 is still larger than the signal of LVDT 1, when cooling down. Thus this isn't an effect of a lack of space for the movement of the module.

12. Conclusion

The repeatability of the displacement of the module is good. The difference in LVDT signal between measurement 6, 7 and 8 is approximately 2 μm. For measurement 9 and 10 the difference in LVDT signal is also approximately 2 μm.

Adding a radiation shield in the test setup does not make a significant difference in the displacement of the module, when cooling down.

An estimation of the displacement of point P at a CO2 temperature of -28 °C, for module III with a moustache shaped cooling block is given below:

Displacement in X	-34 μm	Rotation X-as	0.07 mrad
Displacement in Y	-9 μm	Rotation Y-as	-0.24 mrad
Displacement in Z	-74 μm	Rotation Z-as	0.06 mrad

An estimation of the displacement of point P at a CO2 temperature of -28 °C, for module III with the modified moustache shaped cooling block with additional cooling on the back side of the midplate is given below:

Displacement in X	-34 μm	Rotation X-as	0.45 mrad
Displacement in Y	-13 μm	Rotation Y-as	-0.11 mrad
Displacement in Z	-51 μm	Rotation Z-as	0.02 mrad

The modified cooling block, with cooling on the back of the midplate, does give a significant difference in the displacement of the module. This behaviour is not well understood.

13. Summary results module III

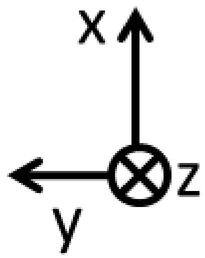
M1: Plain (fast)
M2: Additional cooling on back side midplate (fast)
M3: Radiation shield (fast)
M4: Radiation shield
M5: Hurdle with spacers
M6: Frame moved 1 mm
M7: Frame moved 1 mm and radiation shield
M8: Frame moved 1 mm and radiation shield (continued M6)
M9: Modified cooling block with additional cooling on back side midplate
M10: Modified cooling block with additional cooling on back side midplate, without LVDT 4

Sensor	Module III M1 22-05-2015 10:00	Module III M2 22-05-2015 16:30	Module III M3 9-06-2015 11:30	Module III M4 9-06-2015 16:45	Module III M5 11-06-2015 09:15	Module III M6 12-06-2015 09:10	Module III M7 12-06-2015 13:00	Module III M8 19-06-2015 13:00	Module III M9 25-06-2015 11:00	Module III M10 30-06-2015 11:30
1	26.5	0	0.2	0.1	-0.5	0.7	0.3	0.2	-1.4	-2.1
2	25.2	24.9	25.1	25.0	25.4	25.0	24.9	24.6	24.6	24.9
3	20.5	18.9	20.4	20.5	20.5	20.4	20.0	19.4	19.7	19.2
4	20.3	19.4	20.2	20.2	20.1	20.0	19.6	19.1	19.2	18.7
5	3.5	3.7	4.0	3.9	3.2	4.3	3.9	3.0	1.7	1.0
6	-26.6	-26.7	-28.2	-28.5	-29.1	-28.7	-29.1	-28.2	-27.9	-28.7
7*	-22.8	-22.3	-15.2	-14.2	-18.8	-18.4	-18.6	-24.4	-24.1	-24.9
8	-17.8	-17.7	-19.1	-19.4	-19.7	-19.4	-19.8	-18.4	-18.6	-19.3
9	-14.0	-14.0	-15.2	-15.4	-15.8	-15.6	-16.0	-14.6	-14.8	-15.5
13	25.2	25.1	25.2	25.1	25.6	25.2	25.0	24.7	24.7	24.9
15	-21.4	17.9	19.3	19.3	21.5	3.3	2.8	2.5	1.1	0.3
16	26.5	7.1	11.5	11.5	10.6	11.3	10.9	9.8	11.7	10.9
12	-	-	-	-	-	12.3	11.8	11.4	11.3	10.6

*Temperature sensor T7 doesn't always indicate the expected temperature
T15, T16 and T12 are relocated before starting measurement 6, see Figure 17 at page 17.

Sensor	Module III M1 22-05-2015 10:00	Module III M2 22-05-2015 16:30	Module III M3 9-06-2015 11:30	Module III M4 9-06-2015 16:45	Module III M5 11-06-2015 09:15	Module III M6 12-06-2015 09:10	Module III M7 12-06-2015 13:00	Module III M8 19-06-2015 13:00	Module III M9 25-06-2015 11:00	Module III M10 30-06-2015 11:30
LVDT 1	-87	-72	-58	-53	-57	-73	-73	-74	-71	-69
LVDT 2	-52	-49	-54	-48	-46	-62	-60	-62	-76	-75
LVDT 3	-44	-44	-47	-44	-47	-57	-55	-56	-40	-39
LVDT 4	-29	-23	-31	-28	-36	N/A	N/A	N/A	-34	N/A
LVDT 5	-11	-9	-11	-11	-14	-10	-9	-10	-13	-12
LVDT 6	-12	-11	-13	-12	-16	-13	-12	-13	-13	-13

	Module III M1 22-05-2015 10:00	Module III M2 22-05-2015 16:30	Module III M3 9-06-2015 11:30	Module III M4 9-06-2015 16:45	Module III M5 11-06-2015 09:15	Module III M6 12-06-2015 09:10	Module III M7 12-06-2015 13:00	Module III M8 19-06-2015 13:00	Module III M9 25-06-2015 11:00	Module III M10 30-06-2015 11:30
X	-29	-23	-31	-28	-36	N/A	N/A	N/A	-34	N/A
Y	-11	-8	-10	-11	-13	-9	-8	-9	-13	-12
Z	-93	-76	-56	-52	-61	-74	-74	-74	-52	-49
$X_{rotation}$	0.10	0.06	0.09	0.05	-0.01	0.06	0.06	0.08	0.45	0.45
$Y_{rotation}$	-0.70	-0.46	-0.08	-0.10	-0.22	-0.22	-0.26	-0.24	0.10	0.12
$Z_{rotation}$	0.02	0.04	0.04	0.02	0.04	0.06	0.06	0.06	0	0.02



14. LVDT signal before zeroing

Before the LVDT values are set to zero, the positions of the LVDT sensors and temperature T6 are measured under vacuum conditions seconds before starting the measurement.

	Module III M1 22-05-2015 10:00	**Module III M2** 22-05-2015 16:30	**Module III M3** 9-06-2015 11:30	**Module III M4** 9-06-2015 16:45	**Module III M5** 11-06-2015 09:15	**Module III M6** 12-06-2015 09:10	**Module III M7** 12-06-2015 13:00	**Module III M8** 19-06-2015 13:00	**Module III M9** 25-06-2015 11:00	**Module III M10** 30-06-2015 11:30
LVDT 1	1704.8	1688.5	1691.3	1685.3	513.5	644.8	644.0	643.5	638.5	628.4
LVDT 2	934.2	910.6	908.2	909.2	-41.1	252.6	-254.63	-261.9	-256.2	-261.0
LVDT 3	1076.1	1075.9	1074.5	1076.5	-46.8	16.3	14.1	6.5	17.2	12.1
LVDT 4	-120.4	-123.1	-119.8	-117.1	-129.3	N/A	N/A	N/A	-180.6	N/A
LVDT 5	794.0	798.5	819.2	819.9	878.2	855.3	854.8	854.8	839.3	846.8
LVDT 6	657.0	663.9	661.5	662.2	715.2	727.7	727.1	727.8	722.9	725.4
T6	25.6	26.3	25.7	25.5	25.5	26.0	24.7	25.9	25.9	25.6