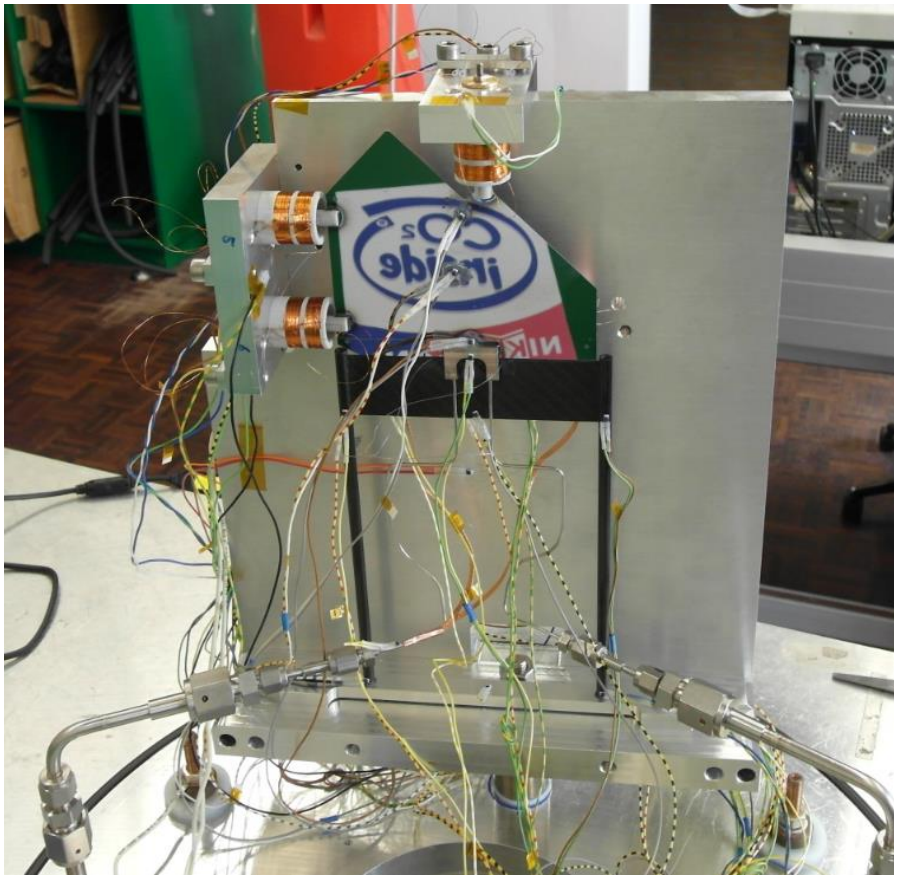
Nikhef VELO module measurement results



Contents

- Test setup
- Displacement results
  - Module I
  - Module II
  - Module III
- Thermal model
- Creep test results
- Conclusion

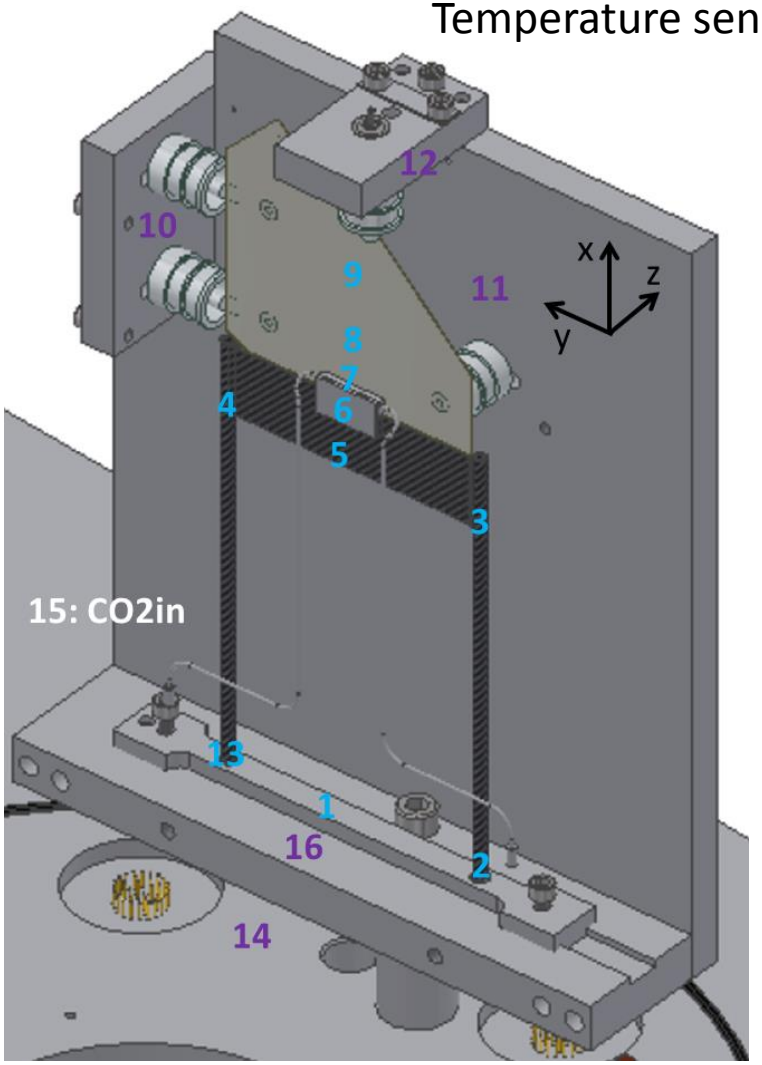
Test setup

- 6 LVDT sensors
- 16 temperature sensors PT100
- Temperature control for frame
- Vacuum pressure better than 10^{-4} mbar

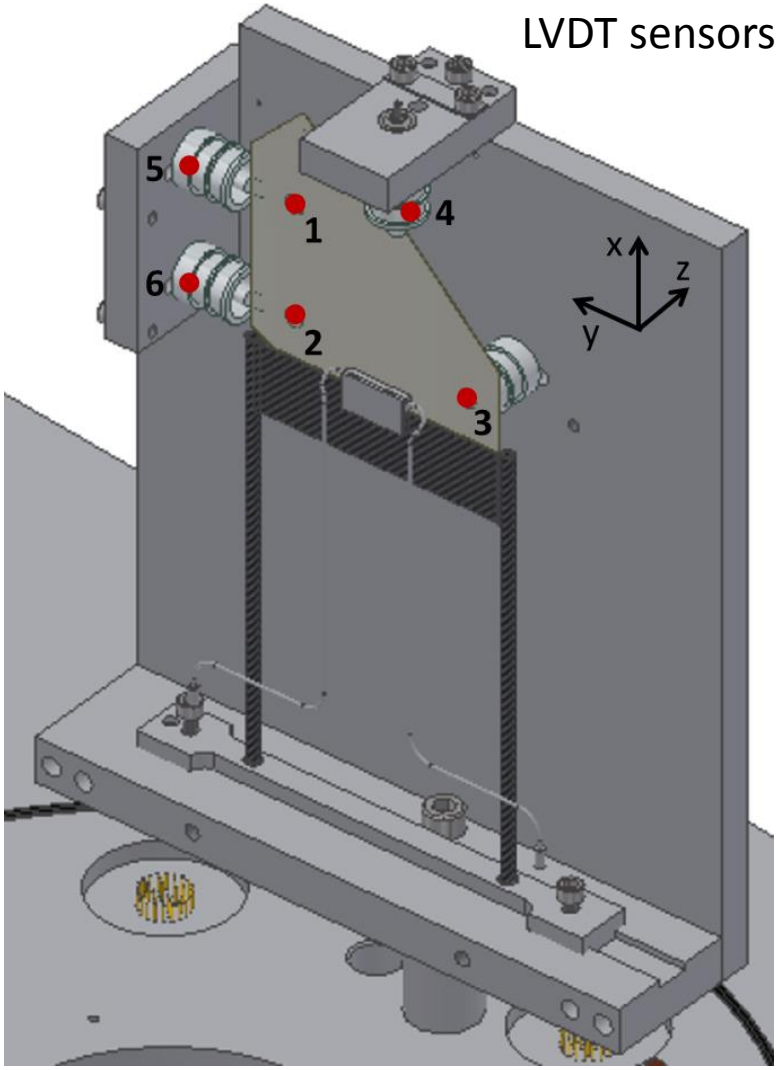
More info:
https://indico.cern.ch/event/364489/contribution/1/material/slides/1.pdf

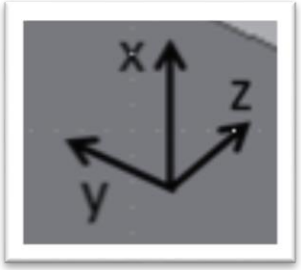
Location sensors

Temperature sensors



LVDT sensors



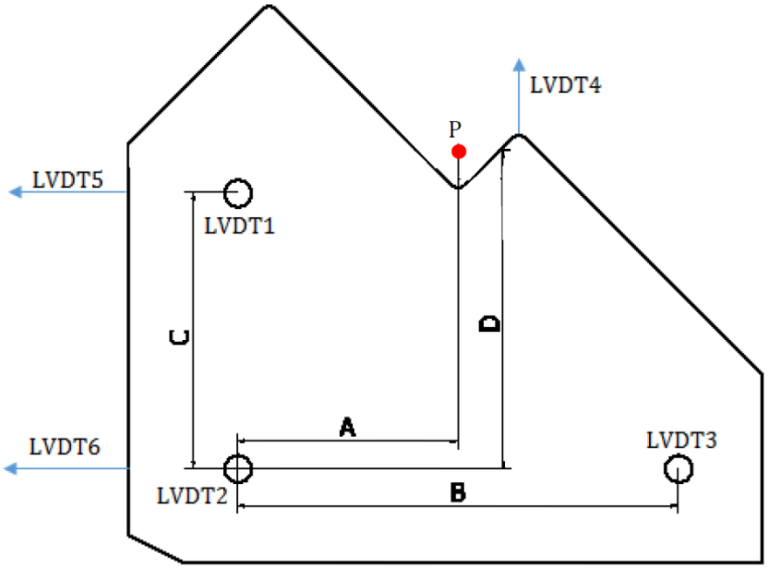


Measuring displacement

- Point **P** is the location of the proton-proton interaction point relative to the silicon, when the module is perfectly aligned i.e. (x,y)=(0,0)
- The measured values of the LVDTs are converted to a displacement of point **P**, by means of a transformation matrix

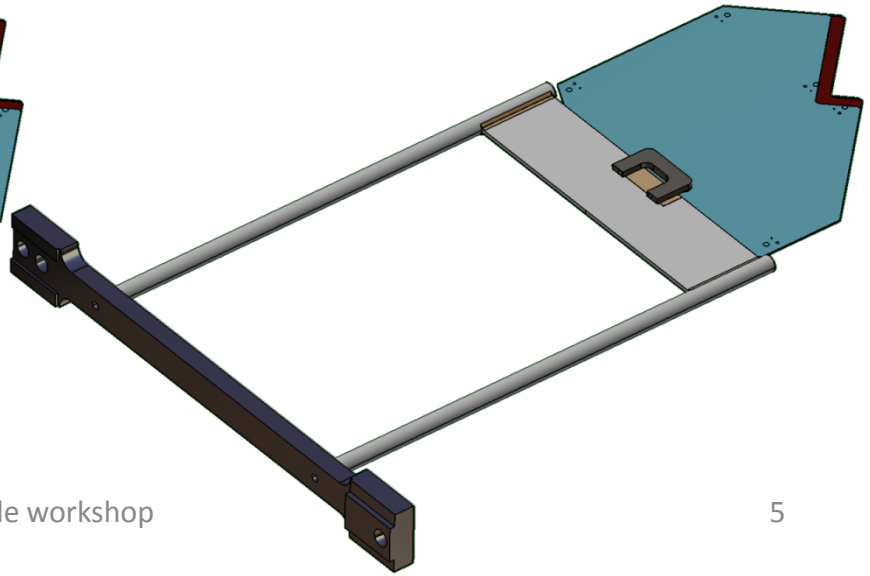
Displacement in X	LVDT 4
Displacement in Y	LVDT 5 & 6
Displacement in Z	LVDT 1, 2 & 3

Rotation X-axis	LVDT 2 & 3
Rotation Y-axis	LVDT 1 & 2
Rotation Z-axis	LVDT 5 & 6



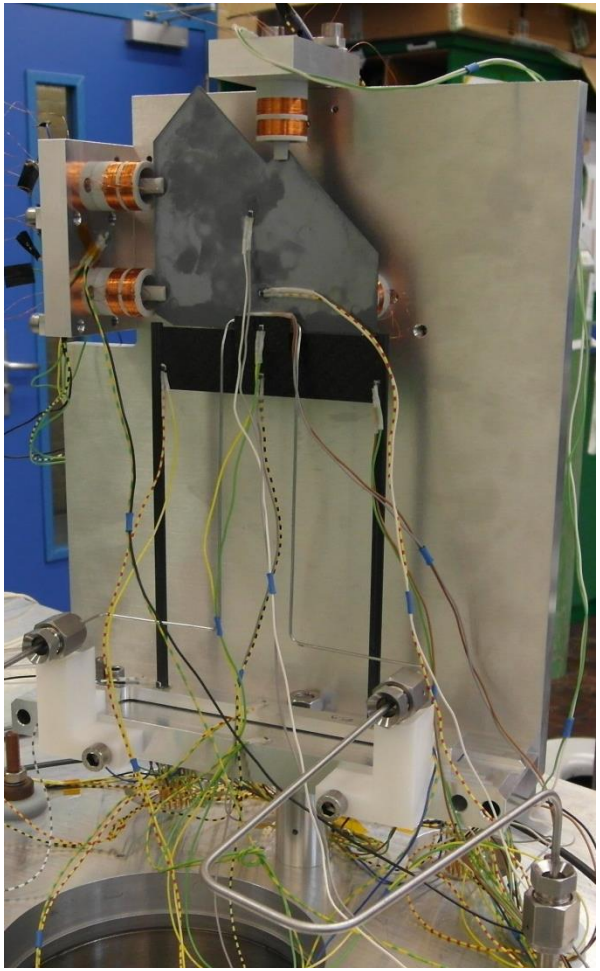
Nikhef modules

- Module I:
  - Cooling block **glued** to silicon
- Module II:
  - Cooling block **soldered** to silicon
  - Capillaries direct on CO2 in/outlet
- Module III:
  - Mustache shaped cooling block
  - Metalized layer came loose, thus cooling block **glued** to silicon
  - 1/8 inch VCR connector



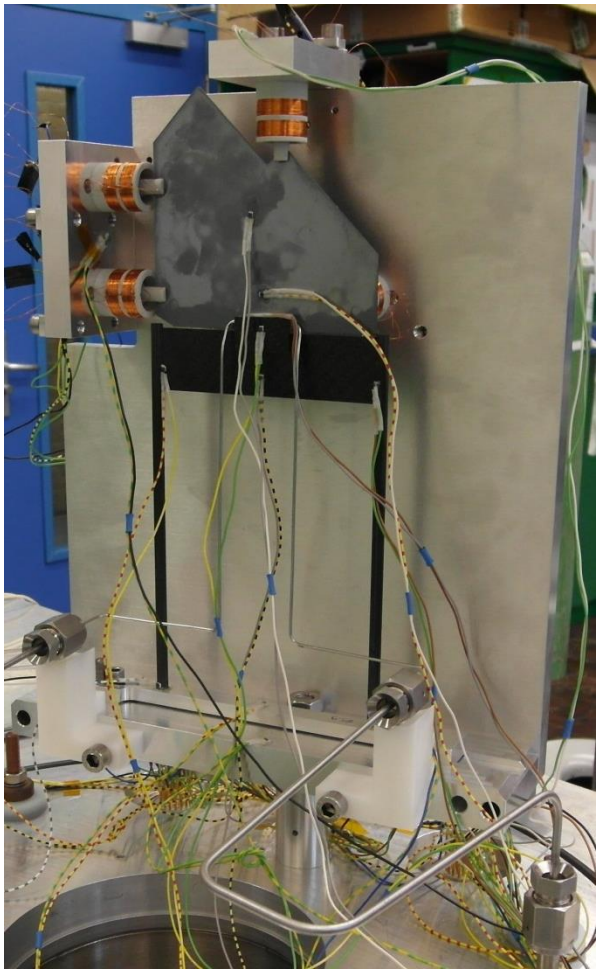
Nikhef module I

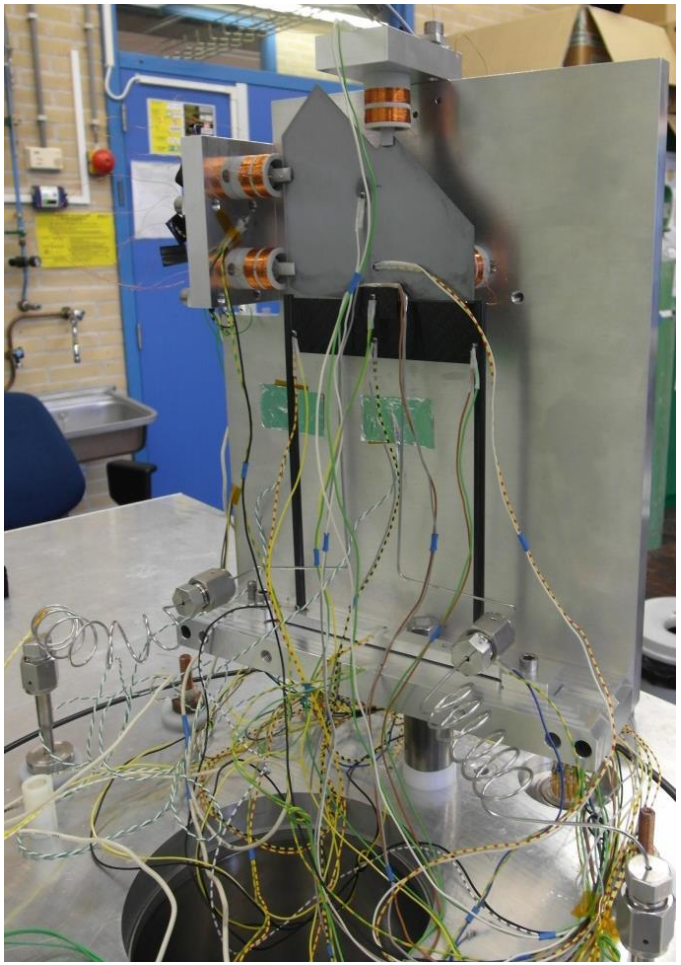
- Cooling block glued to the silicon
- Measurement 1 is with straight tubes connected to the capillaries of the module
- Measurement 2 is with pig-tail shaped tubes connected to the capillaries of the module



Nikhef module I

Straight tubes and pig-tail shaped tubes

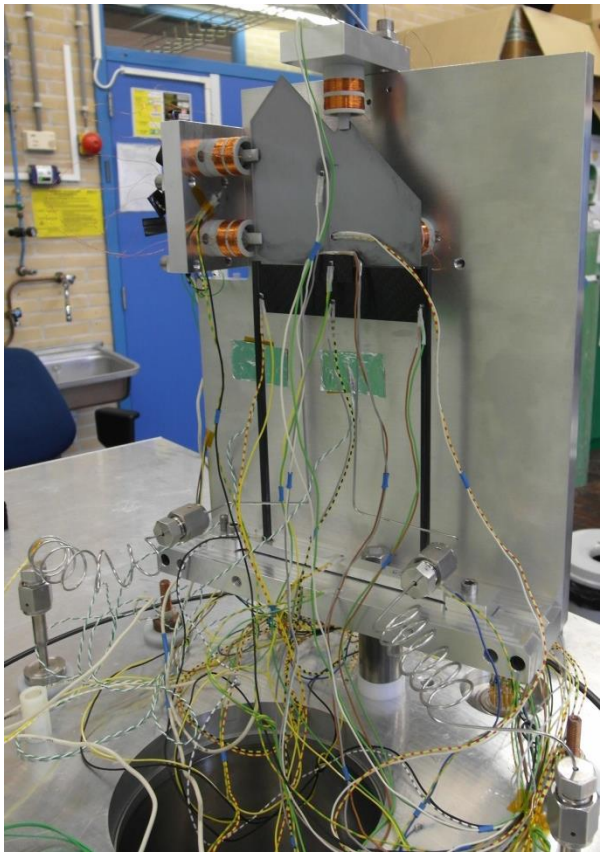




Displacement results

Nikhef module I

Sensor	Displacement (µm) Measurement 1	Displacement (µm) Measurement 2
LVDT 1	-17	-16
LVDT 2	-10	-11
LVDT 3	-2	-6
LVDT 4	-26	-27
LVDT 5	-8	-8
LVDT 6	-12	-12



Displacement of point **P**:

Displacement in X	-27 µm
Displacement in Y	-7 µm
Displacement in Z	-15 µm

Rotation X-axis	0.08 mrad
Rotation Y-axis	-0.12 mrad
Rotation Z-axis	0.08 mrad

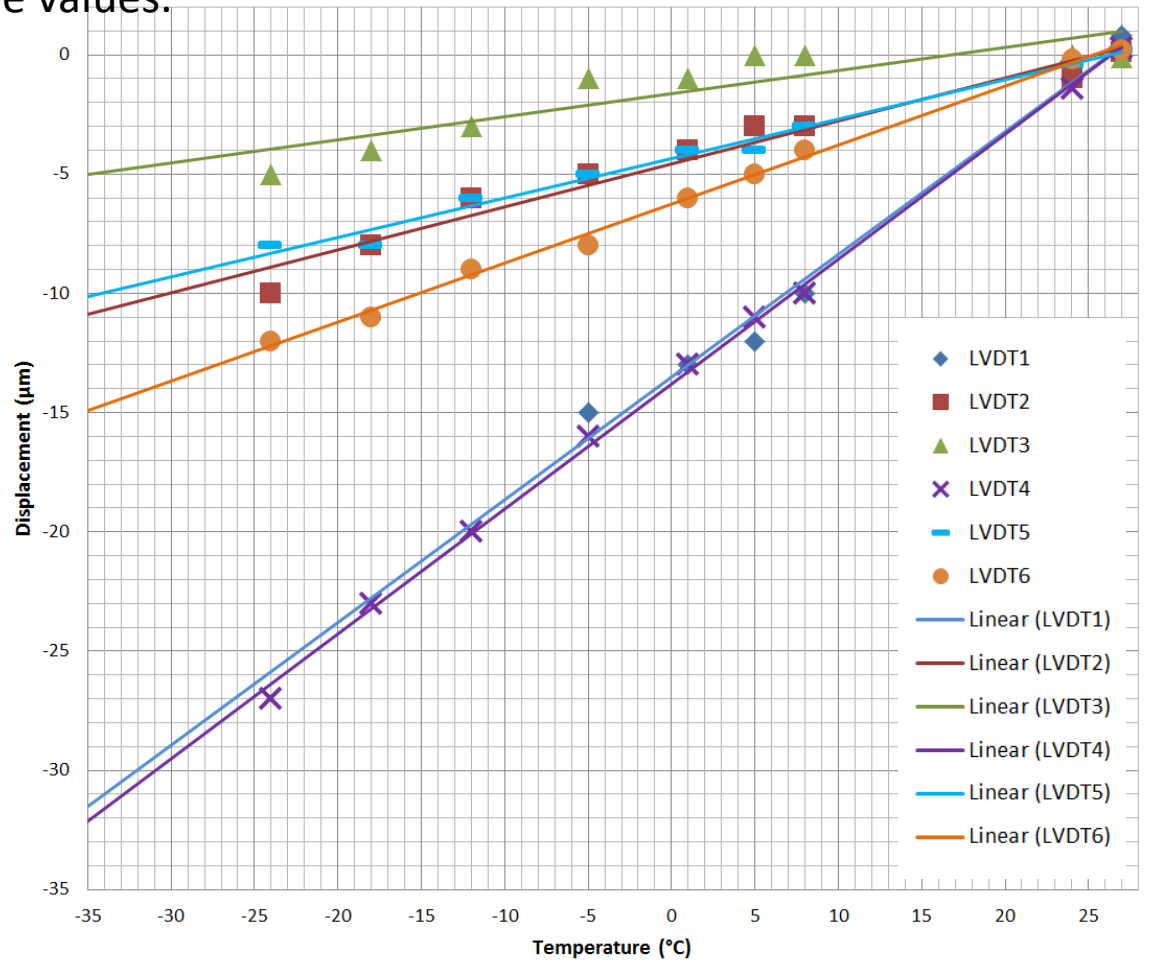
Conclusion: changing the cooling pipe lay out does not affect the measurements

Extrapolation to -35 °C

Nikhef module I

The cooling temperature is expected to be near -30 °C. A temperature of -35 °C is used for the extrapolation to find the extreme values.

Sensor	Displacement (µm)
LVDT 1	-33
LVDT 2	-11
LVDT 3	-5
LVDT 4	-33
LVDT 5	-10
LVDT 6	-15



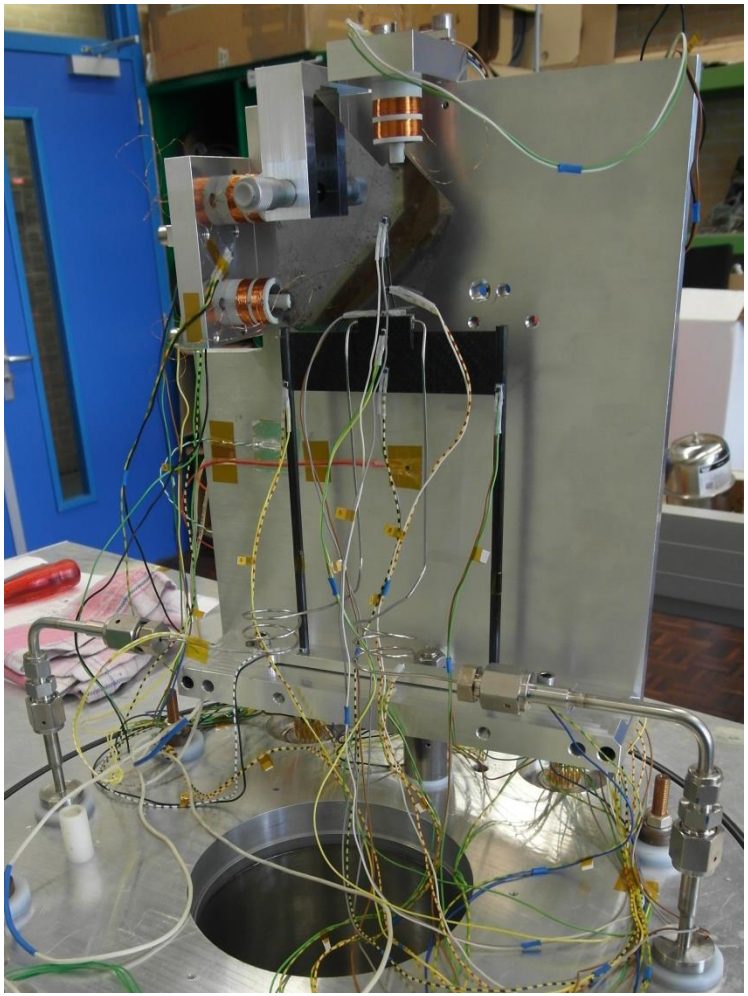
Displacement of point **P**:

Displacement in X	-33 µm
Displacement in Y	-9 µm
Displacement in Z	-36 µm

Rotation X-axis	0.08 mrad
Rotation Y-axis	-0.44 mrad
Rotation Z-axis	0.10 mrad

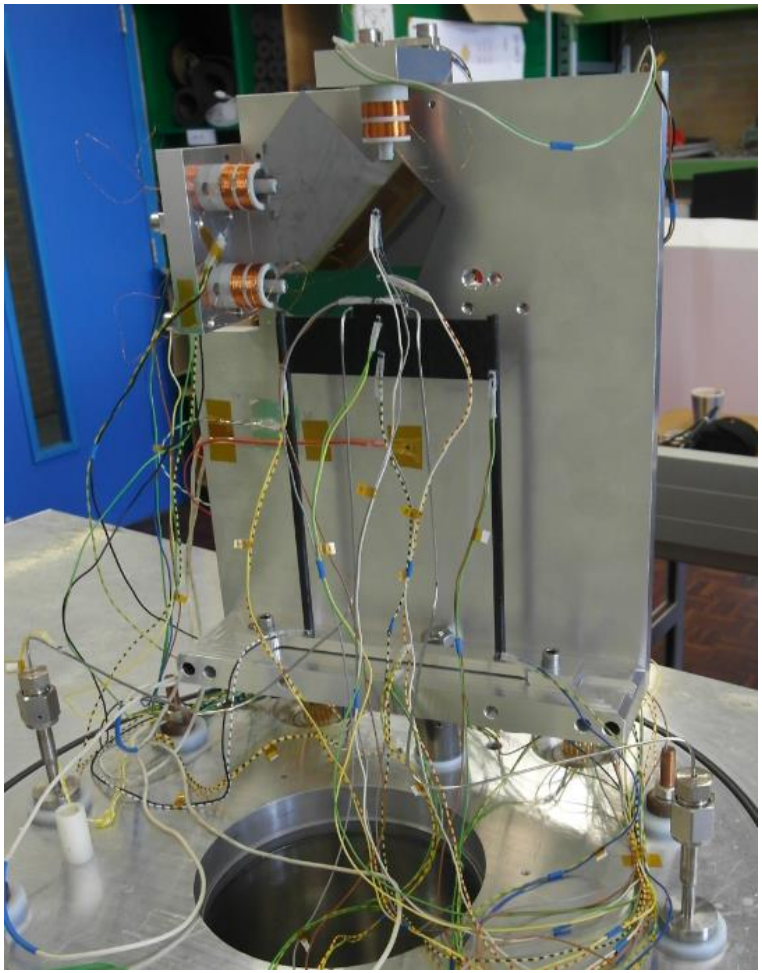
Nikhef module II

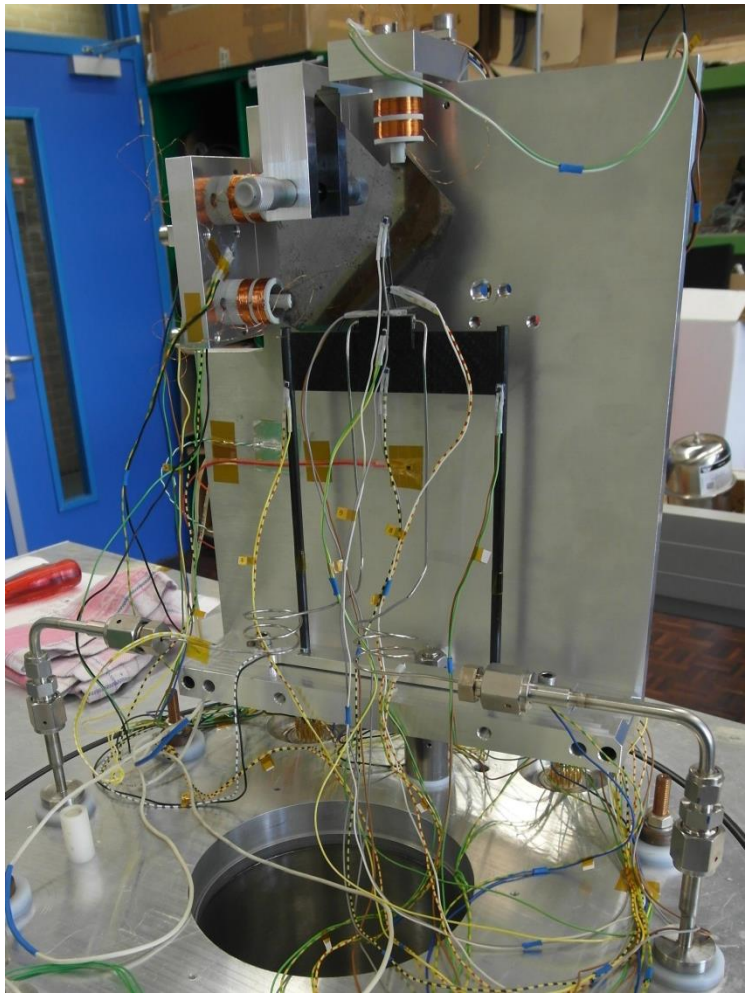
- Cooling block soldered on the silicon
- Silicon lost a ‘small’ corner due to handling the capillaries after bonding the silicon to the carbon hurdle →
- LVDT 3 can not be used for the measurement
- Measurement 1: capillaries connected to CO2 in/outlet
- Measurement 4: pig-tail shaped capillaries



Nikhef module II

Straight tubes and pig-tail shaped tubes

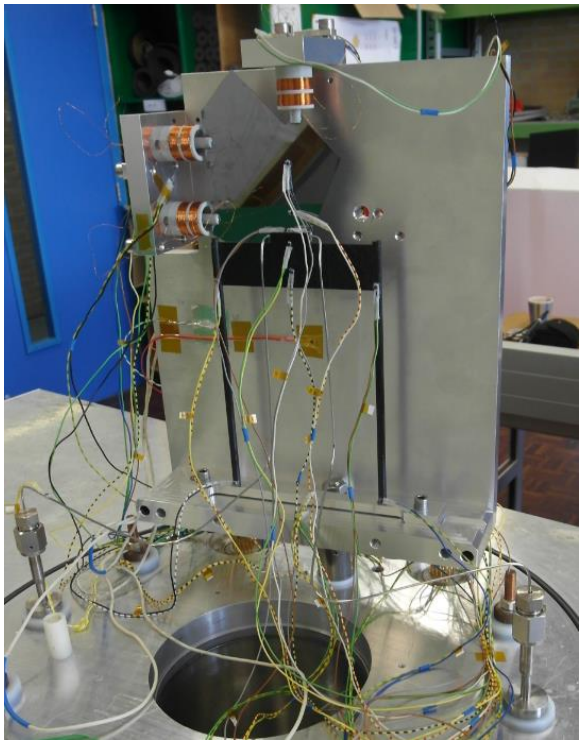




Displacement results

Nikhef module II

Sensor	Displacement (µm) Measurement 1 22-04-2015 -23.5 °C	Displacement (µm) Measurement 4 01-05-2015 -22.3 °C
LVDT 1	-162	-169
LVDT 2	-38	-38
LVDT 3	N/A	N/A
LVDT 4	-25	-26
LVDT 5	-10	-10
LVDT 6	-14	-14



Displacement of point **P**:

Displacement in X	-25 µm
Displacement in Y	~ -12 µm
Displacement in Z	~ -170 µm

Can not calculate the rotation, due to the missing LVDT 3

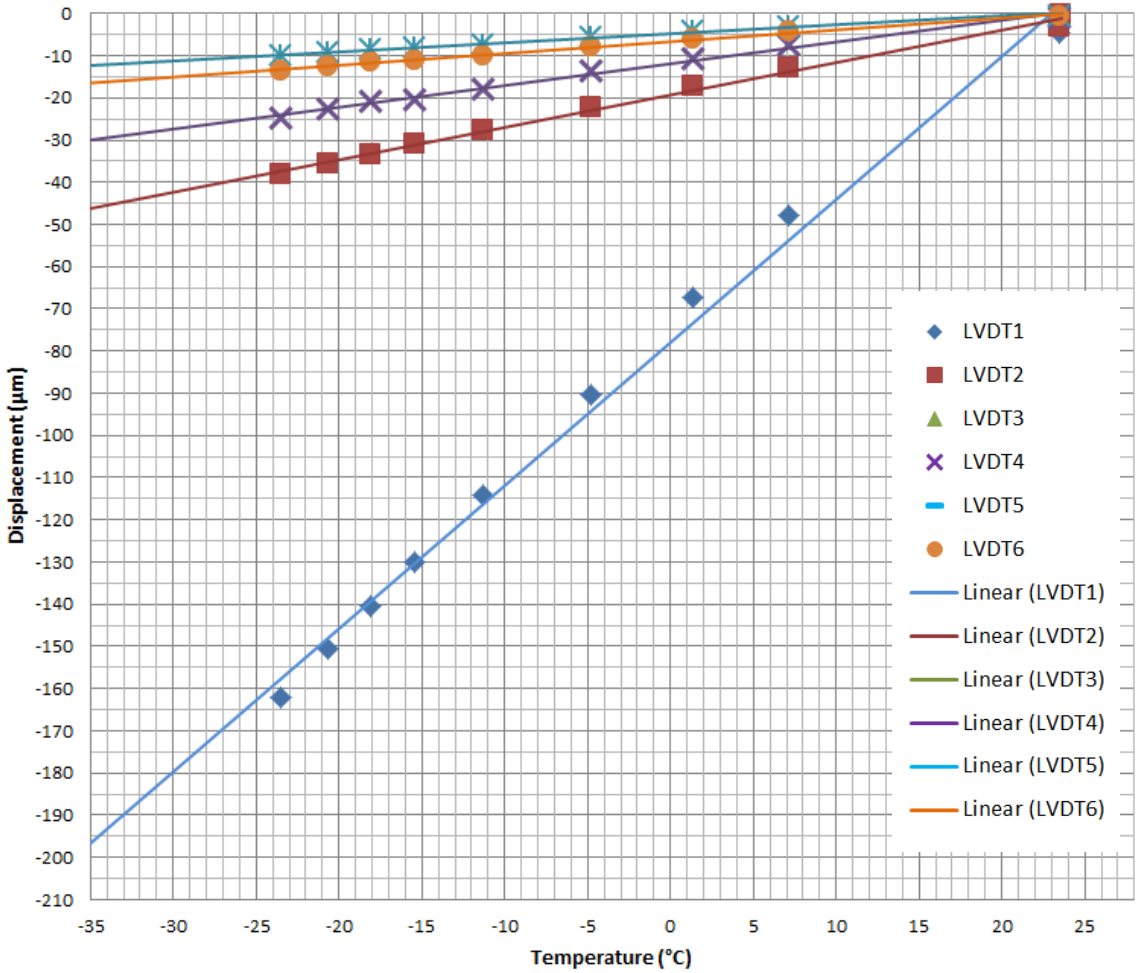
Extrapolation to -35 °C

Nikhef module II

Sensor	Displacement (µm) Measurement 1
LVDT 1	-197
LVDT 2	-56
LVDT 3	N/A
LVDT 4	-30
LVDT 5	-12
LVDT 6	-16

Displacement of point **P** :

Displacement in X	-30 µm
Displacement in Y	~ -14 µm
Displacement in Z	~ -200µm

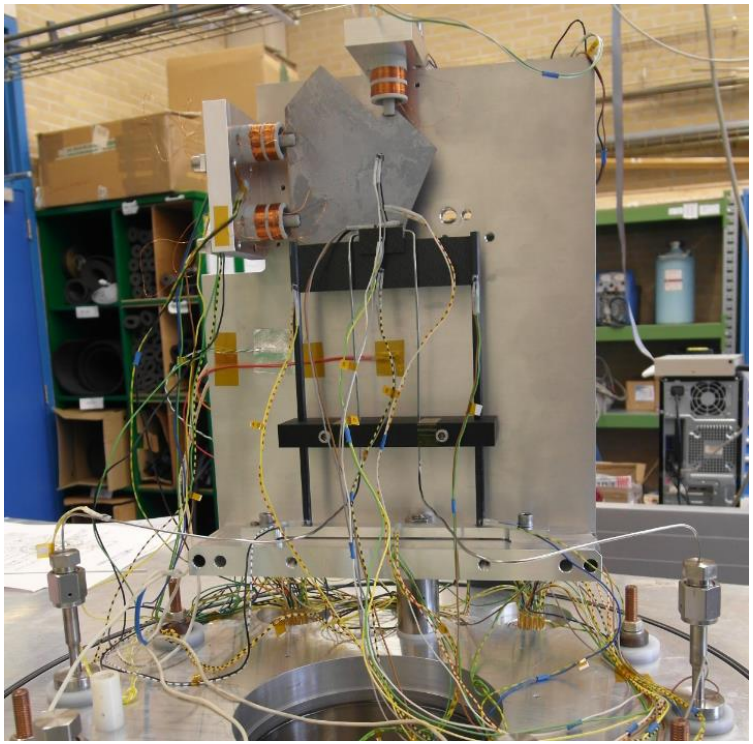


Extra measurements with constraint

Nikhef module II

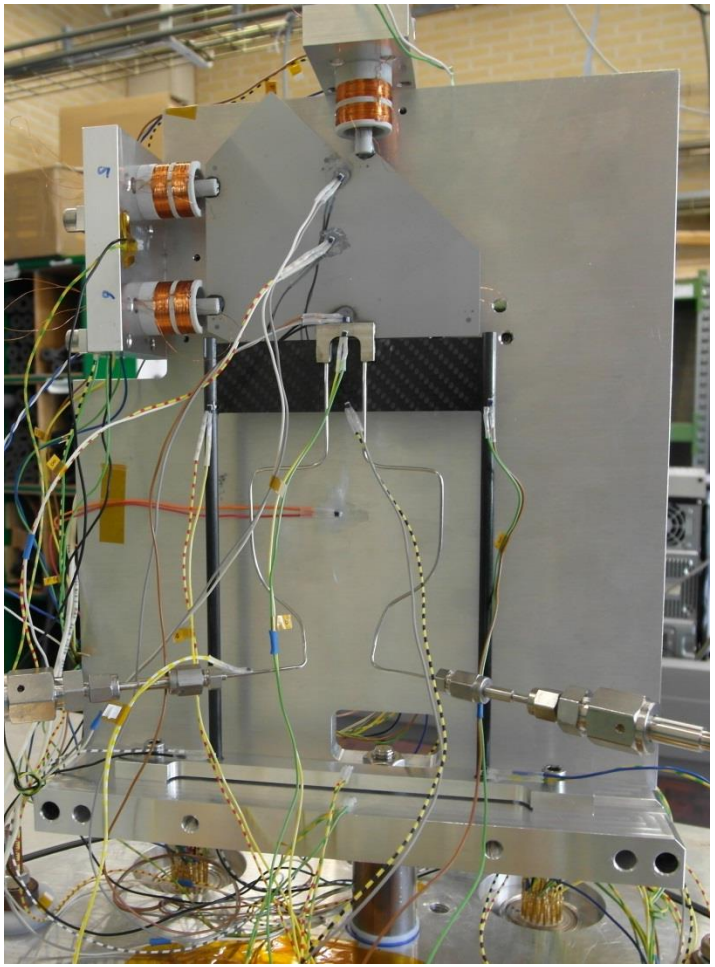
- Measurement 2: constrain capillaries, all directions
- Measurement 3: constrain in x & y direction
- The displacement for the module with an extra constraint is larger than without any constraint

Sensor	Displacement (µm) Measurement 2 24-04-2015 -24.1 °C	Displacement (µm) Measurement 3 29-04-2015 -23.2 °C
LVDT 1	-193	-243
LVDT 2	-47	-64
LVDT 3	N/A	N/A
LVDT 4	-27	-34
LVDT 5	-7	-6
LVDT 6	-10	-8



Nikhef module III

- Mustache shaped cooling block
- Cooling block glued to the silicon
- 1/8 inch VCR connector on the capillaries



Displacement results

Nikhef module III

Sensor	Displacement (µm) Measurement 1 21-05-2015 -26.8 °C
LVDT 1	-87
LVDT 2	-52
LVDT 3	-44
LVDT 4	-29
LVDT 5	-11
LVDT 6	-12

Displacement of point **P** for measurement 1:

Displacement in X	-29 µm
Displacement in Y	-11 µm
Displacement in Z	-93 µm

Rotation X-axis	0.10 mrad
Rotation Y-axis	-0.70 mrad
Rotation Z-axis	0.03 mrad

Displacement of point **P** for extrapolation to -35 °C :

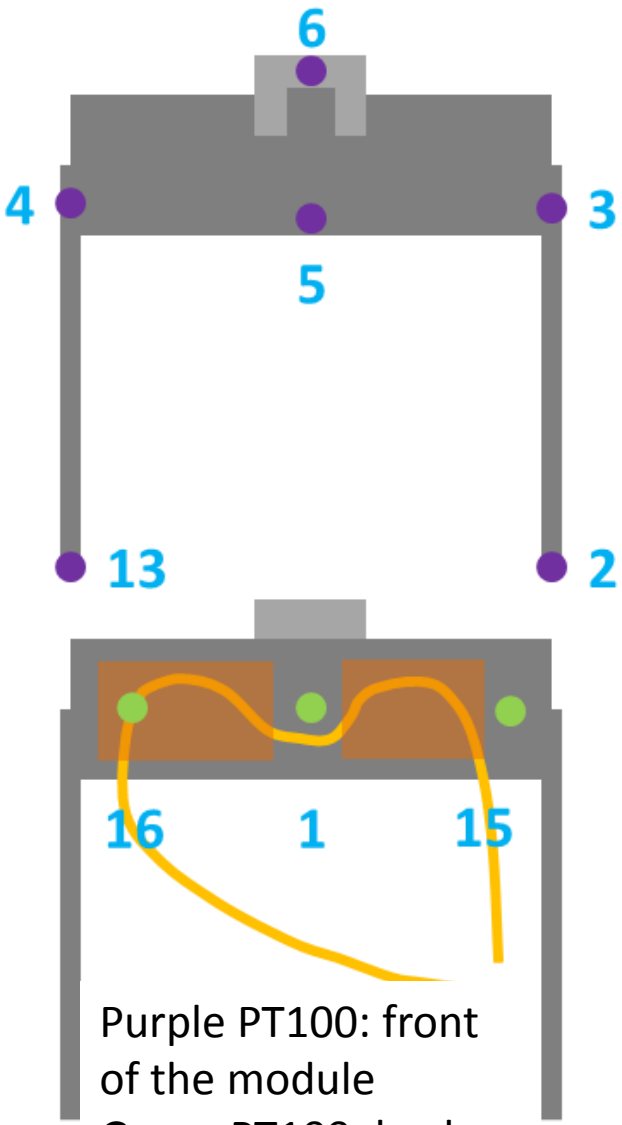
Displacement in X	-32 µm
Displacement in Y	-11 µm
Displacement in Z	-105 µm

Rotation X-axis	0.11 mrad
Rotation Y-axis	-0.72 mrad
Rotation Z-axis	0.04 mrad

Additional cooling midplate

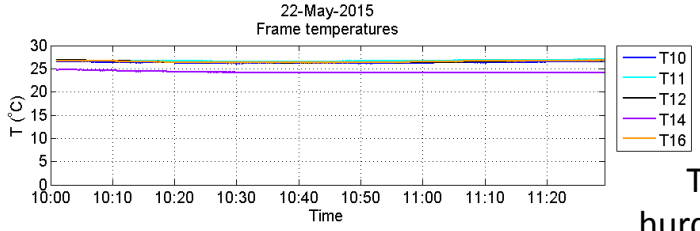
Nikhef module IIIb

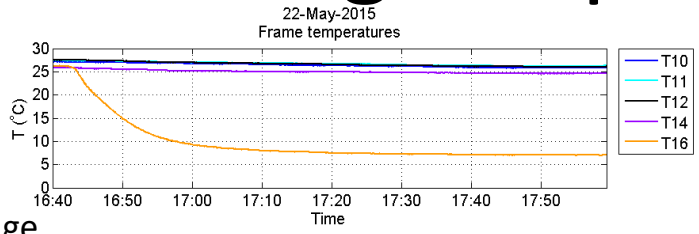
- From the LVDT1/LVDT2 ratio can be derived that the rotation point is situated at the height of the midplate
- Additional cooling on the back of the midplate for a more homogeneous temperature → less deformation
- Sensors T1, T15 & T16 are relocated to the back of the midplate for the second measurement



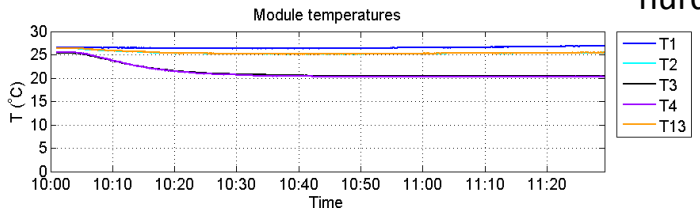
Purple PT100: front of the module
Green PT100: back side of the midplate

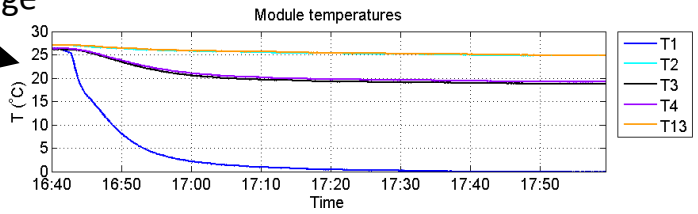
Results additional cooling midplate



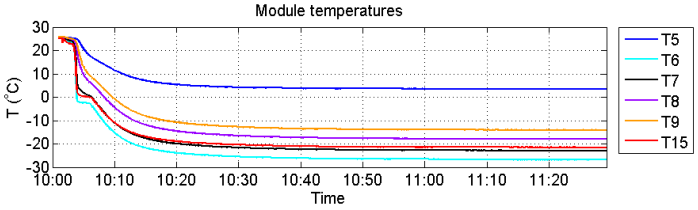


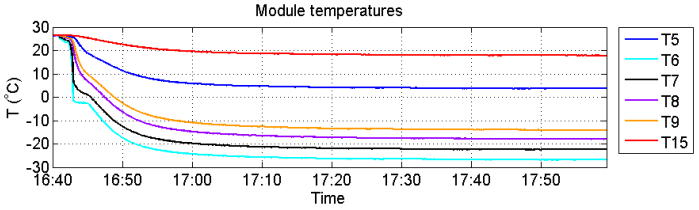
Temperatures hurdle don't change



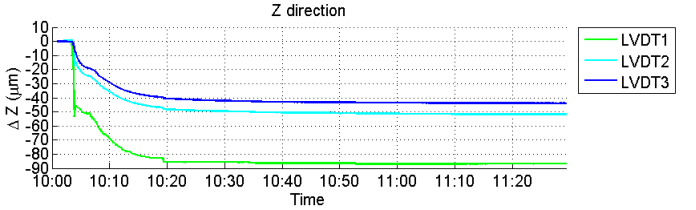


T1, T15 and T16 are relocated to the midplate!

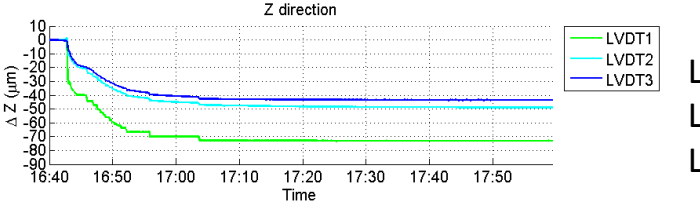




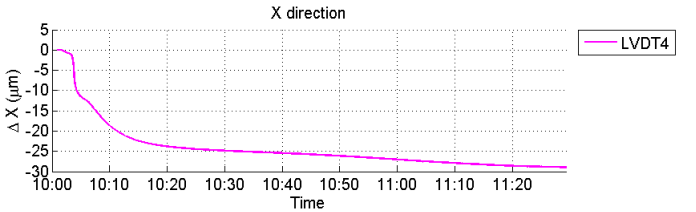
Makes a difference for LVDT 1, though not yet enough…



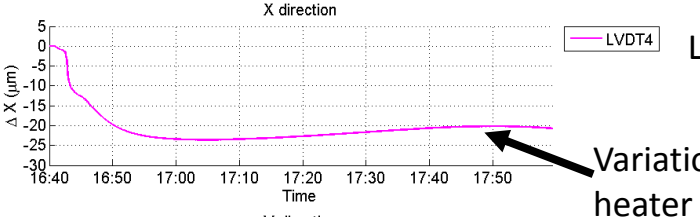
LVDT 1: -87
LVDT 2: -52
LVDT 3: -44



LVDT 1: -72
LVDT 2: -49
LVDT 3: -44

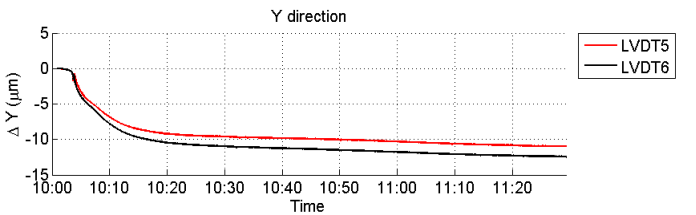


LVDT 4: -29

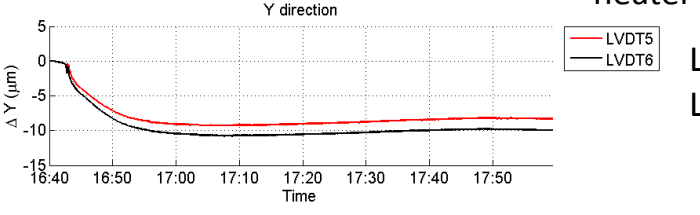


LVDT 4: -23

Variations due to heater control



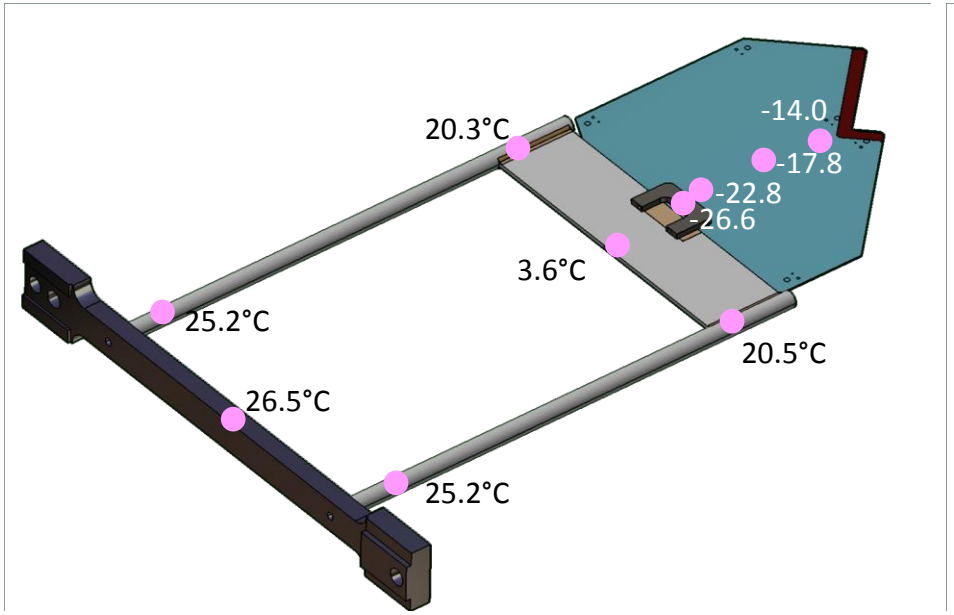
LVDT 5: -11
LVDT 6: -12



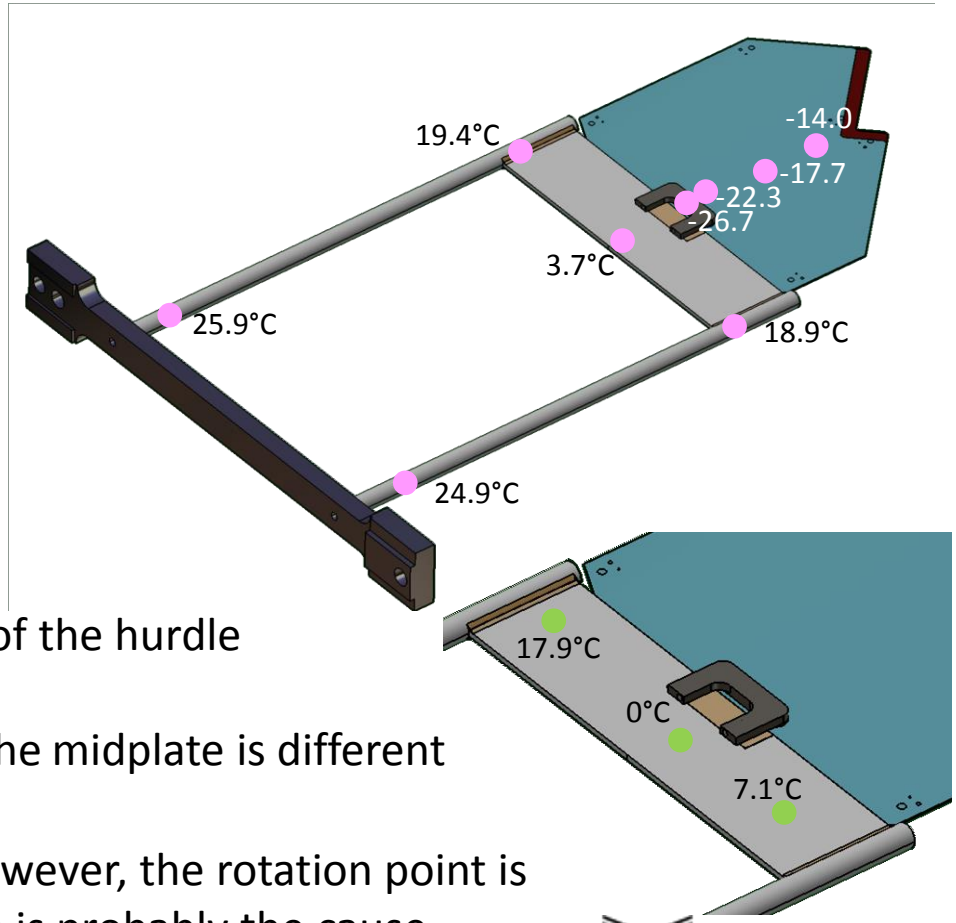
LVDT 5: -9
LVDT 6: -11

Comparison temperature IIIa and IIIb

Module IIIa



Module IIIb



There is a temperature gradient over the rods of the hurdle

$$\Delta T_{IIIa} \approx 5°\text{C} \;\&\; \Delta T_{IIIb} \approx 6°\text{C}$$

The temperature of the front and the back of the midplate is different

$$T_{front} = 3.7°\text{C} \;\&\; T_{back} = 0°\text{C}$$

Both can cause deformation of the module. However, the rotation point is located near the midplate → thus the midplate is probably the cause

Displacement results

Nikhef module IIIb

Sensor	Displacement (µm) Measurement 2 22-05-2015 -26.9 °C
LVDT 1	-72
LVDT 2	-49
LVDT 3	-44
LVDT 4	-23
LVDT 5	-9
LVDT 6	-11

Displacement of point **P** for measurement 1:

Displacement in X	-23 µm
Displacement in Y	-8 µm
Displacement in Z	-76 µm

Rotation X-axis	0.06 mrad
Rotation Y-axis	-0.46 mrad
Rotation Z-axis	0.04 mrad

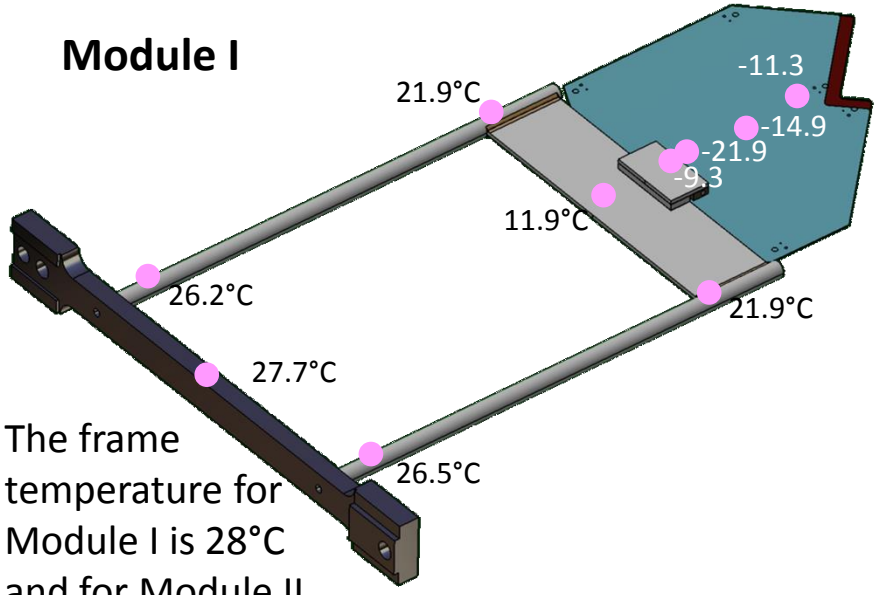
Displacement of point **P** for extrapolation to -35 °C :

Displacement in X	-27 µm
Displacement in Y	-11 µm
Displacement in Z	-90 µm

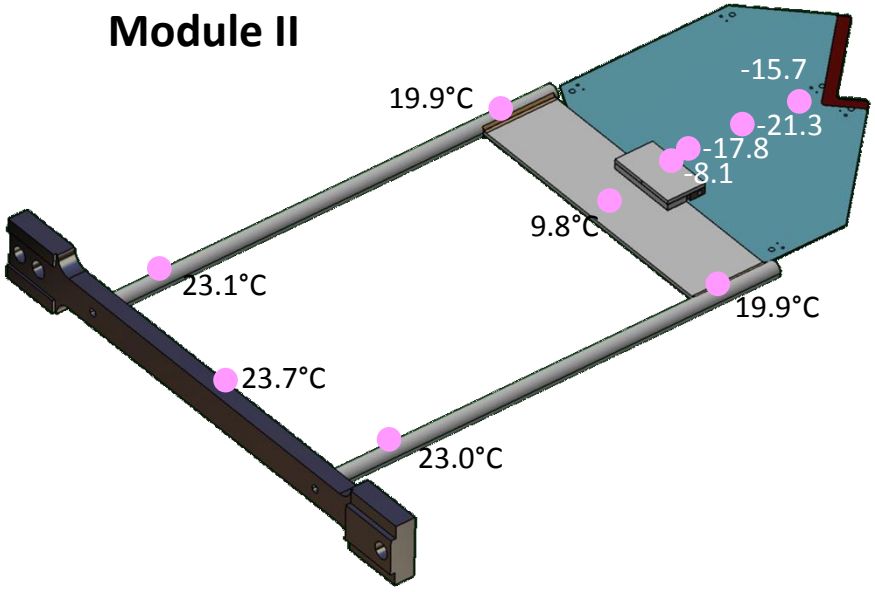
Rotation X-axis	0.08 mrad
Rotation Y-axis	-0.58 mrad
Rotation Z-axis	0.02 mrad

Comparison with thermal model

Module I



Module II



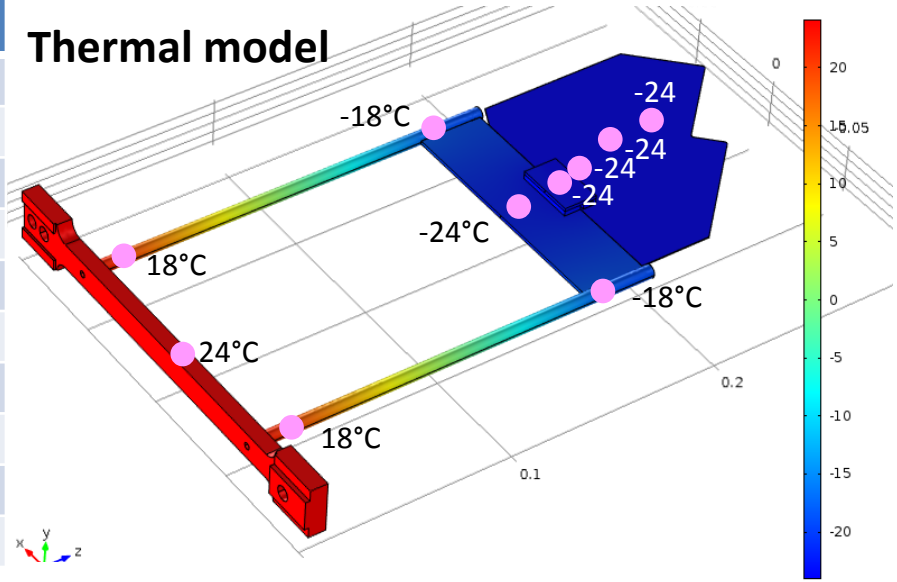
The frame temperature for Module I is 28°C and for Module II 23.9°C

The capillary temperature at the CO2 inlet side for Module I is -22.9°C and for Module II -23.4°C

Only a complete and detailed model can provide a good prediction

Module I 17-02-2015 14:00		Module II 22-04-2015 12:00		Thermal model	
T1	27.7	T1	23.7	T1	24
T2	**26.5**	T2	**23.0**	T2	**18**
T3	**21.9**	T3	**19.9**	T3	**-18**
T4	**21.9**	T4	**19.9**	T4	**-18**
T5	11.9	T5	9.8	T5	-24
T6	-9.3	T6	-8.1	T6	-24
T7	-21.9	T7	-17.8	T7	-24
T8	-14.9	T8	-21.3	T8	-24
T9	-11.3	T9	-15.7	T9	-24
T13	**26.2**	T13	**23.1**	T13	**18**
T15	-22.9	T15	-23.4		
T16	28.0	T16	23.9		

Thermal model

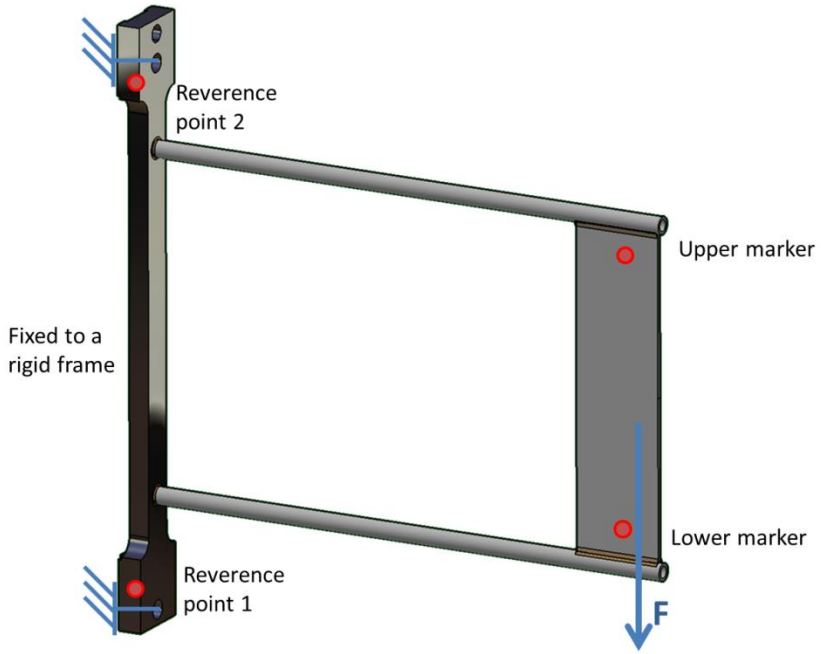


Cooling block temperature= -24°C

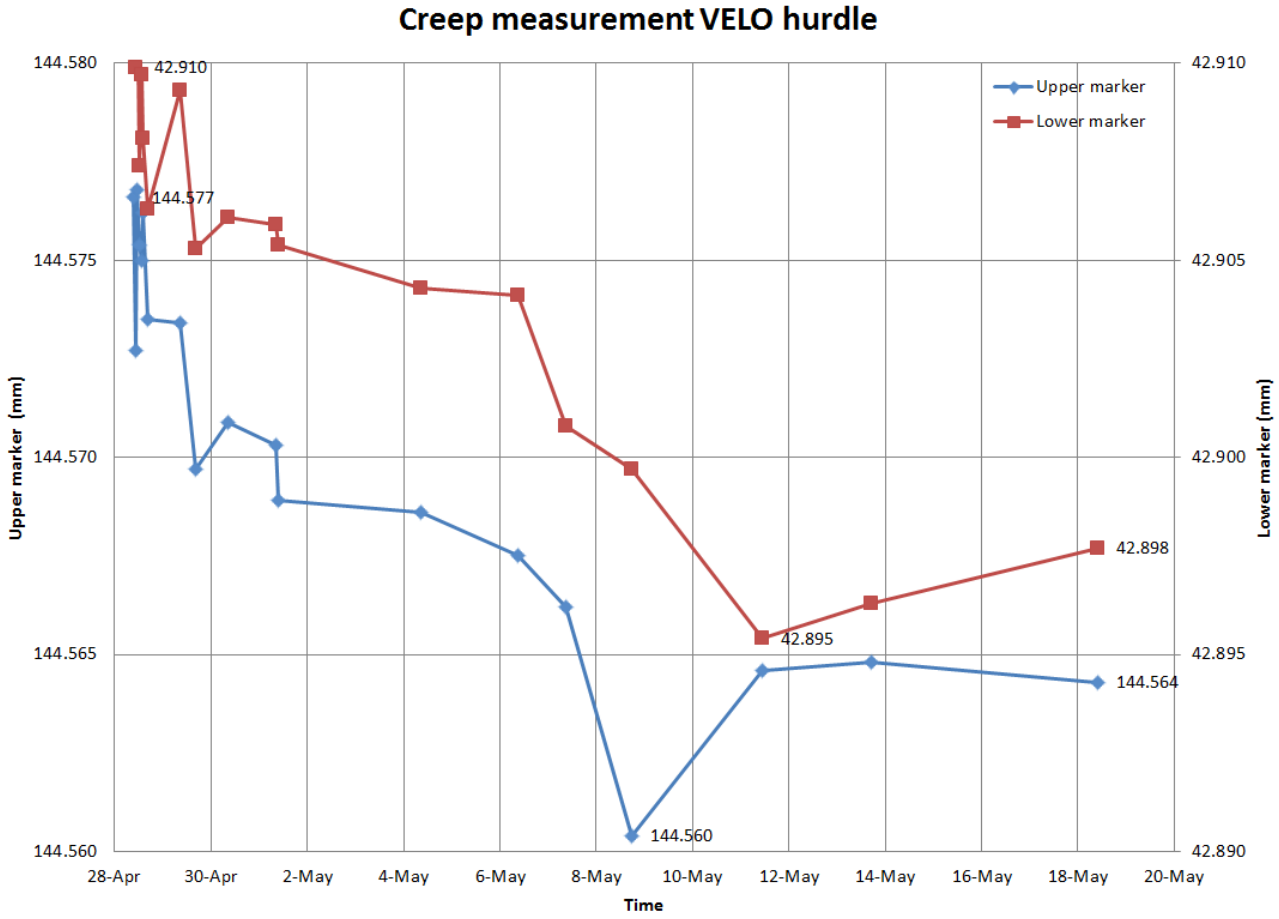
Thermal model by John Back, University of Warwick

Creep test VELO hurdle

- 3 weeks with a constant load of 420 grams
- Accuracy ± 4 µm



Creep test VELO hurdle results



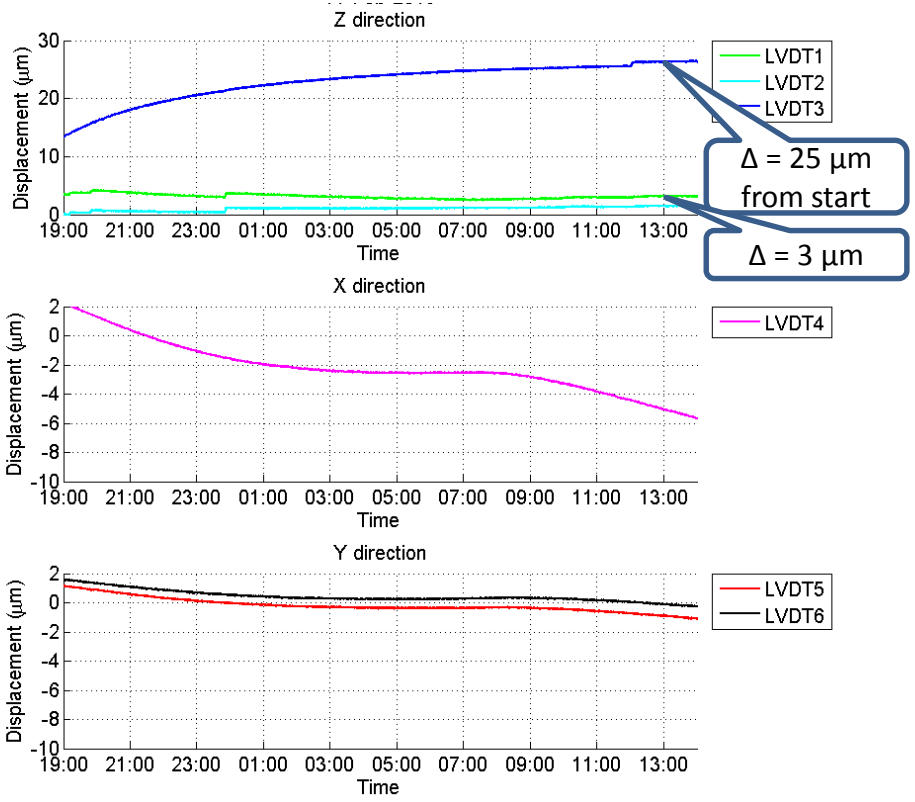
The lower marker moved down 12 µm
The upper marker moved down 15 µm
Creep is a significant effect thus creep test is ongoing

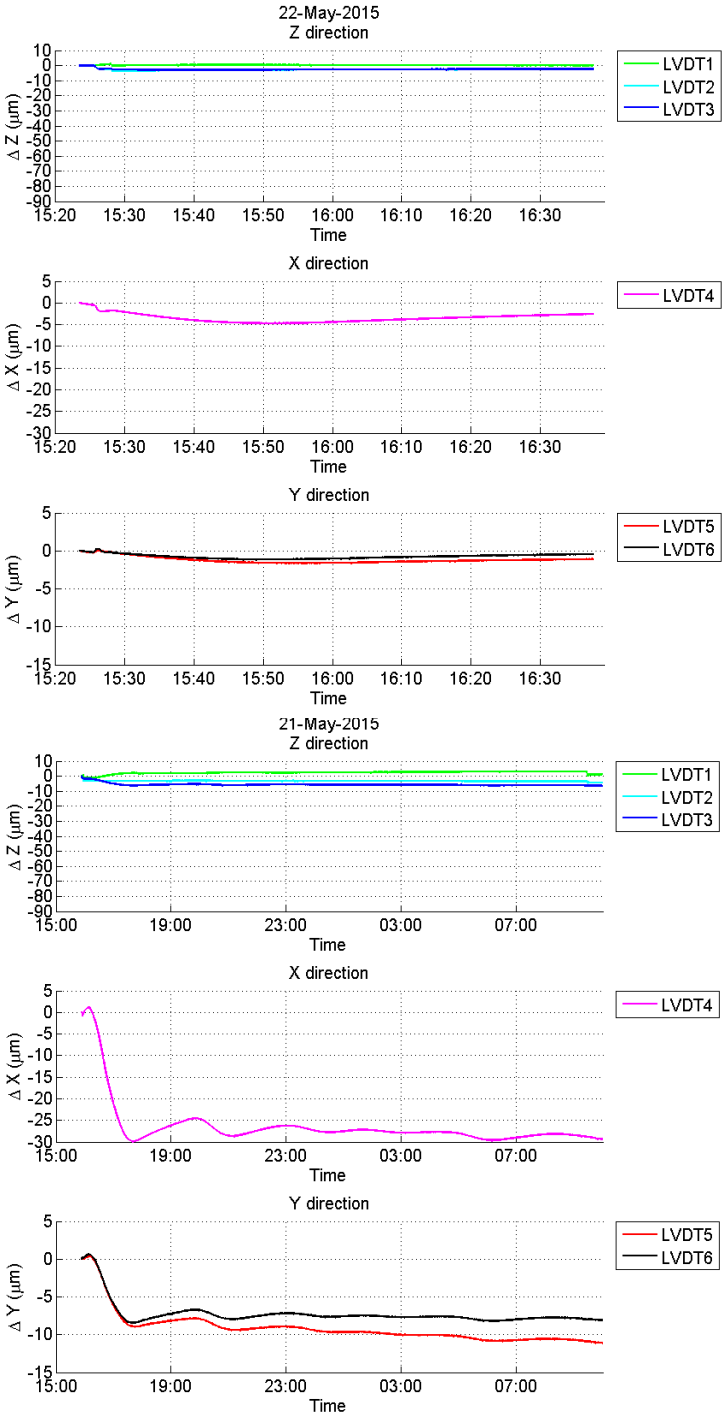
Conclusion

- The displacements at the "point **P**" as the result of a ΔT of 55°C (cooling temperature of -35°C) are
  - About -30 µm in X → predictable
  - About -10 µm in Y → small
  - About -36, -200 and -93 µm for module I, II and III, respectively in Z → requires further study
- Constraining the capillaries causes a larger displacement of the silicon and thus “point **P** "
- Additional cooling on backside of mid plane reduces displacement in Z
  - Rotation of the silicon may be caused by inhomogeneous temperature of midplate
  - Deformation of the midplate may be due to cooling, a possible solution is optimizing the midplate by:
    - differently ‘woven' carbon fiber?
    - temperature 'vias'?
  - Deformation of the hurdle may be due to radiation from the frame, a possible solution is optimizing the test setup by adding a heat shield
- It is difficult to predict the behavior of the module by means of a thermal model due to the many variables and uncertainties.
- There is an observable result in the creep test, when naively extrapolated there is a large effect (order 100 micron) → requires further study

Evacuate system

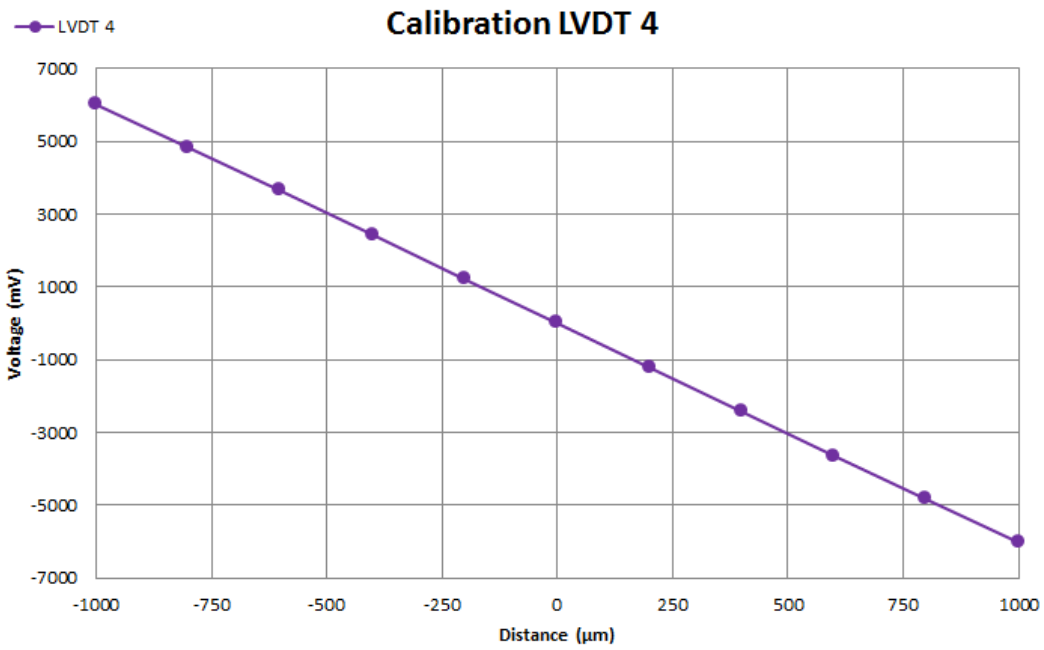
- For module I the displacement due to pump down is 25µm
- For module III, there is no significant movement due to pump down



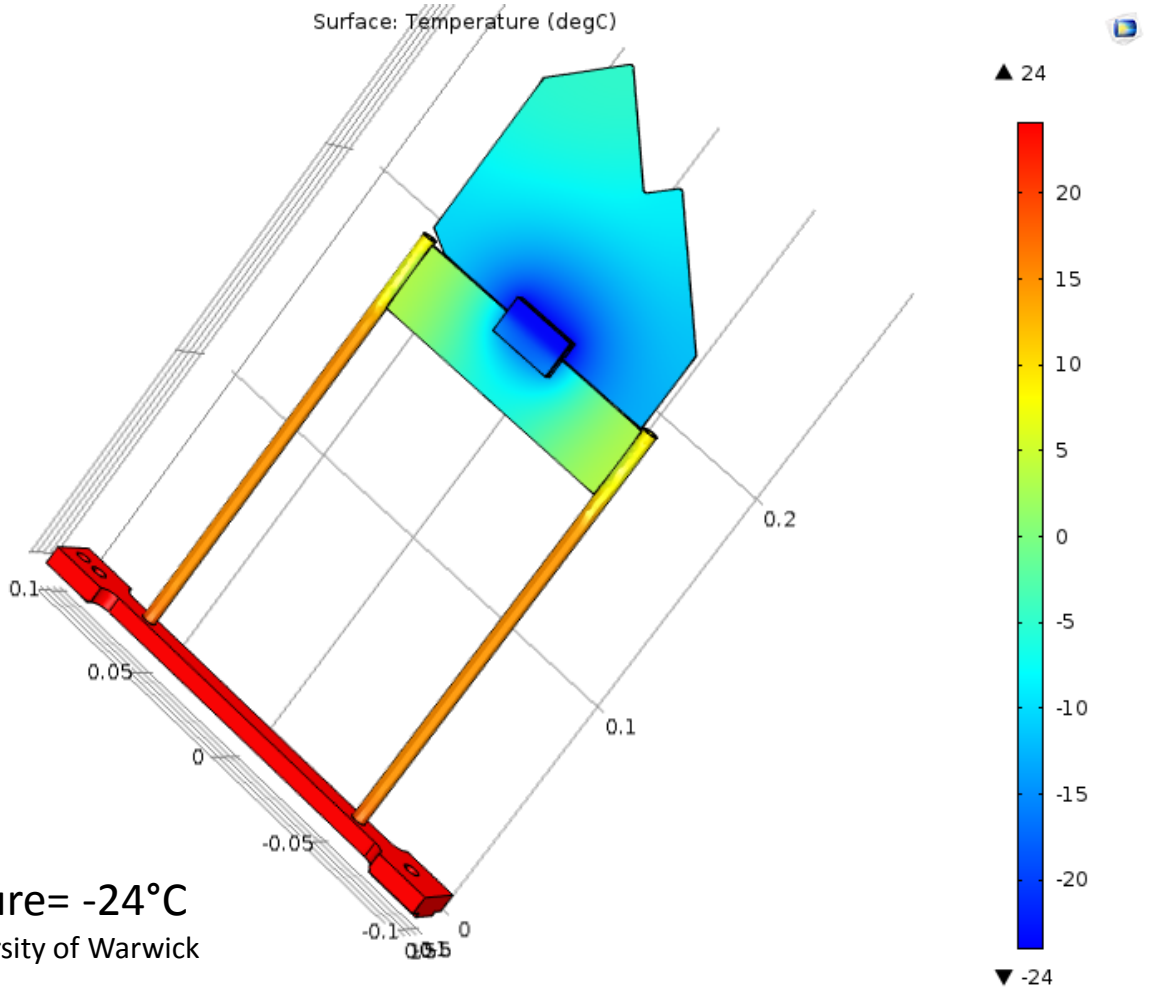


Calibration LVDT sensor

- Calibration of LVDT sensors in a range of -1000 to +1000 µm
- Small influence of eddy currents on LVDT signal
- Standard deviation for calibration better than 10^{-4} µm
- Radial tra



Thermal model with convection



Cooling block temperature= -24°C

Thermal model by John Back, University of Warwick