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Mechanical and thermal tests on the BIL MDT chamber prototype "Calypso"

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Abstract

Tests have been done on the first full-scale BIL MDT chamber prototype "Calypso" to investigate the deformations produced both by loading the chamber and by varying the temperature of one multilayer with respect to the other. The chamber deflections were monitored by the RASNIK systems that served for the in-plane alignment and by dial gauges.

1. Introduction

The drift tube prototype chamber "Calypso" has been assembled in the University of Rome in June 1996, with a technique proposed by the Seattle Group, using tubes and end-plugs built by the Pavia Group [1].

The chamber has been tested on the H8 test-beam at CERN in July '96 [2]. Then in September and October, tests on the mechanical behaviour under load and under temperature gradients have been done (Test-1 and test-2 refer to different experimental conditions). The mechanical effects were measured both by the RASNIK systems [3] and by a set of dial gauges.

This note presents a short description of the mechanical structure of "Calypso" (a detailed presentation is given in Ref. 1) and the results of the mechanical and thermal tests.

The purpose of the study presented here is to understand any effect on MDT chambers due to both weight and temperature. As an example, we recall that a heat dissipation is expected from RPC chambers that, in the muon detection system, will be located very close to the MDT chambers.

2. “Calypso” mechanical structure

For the mechanical and thermal tests, the chamber was set in a horizontal plane, as shown in Fig. 1. Two stainless-steel cylindrical rods of 40 mm diameter were supporting “Calypso” by means of three mounts, two on the “high voltage” side and one on the “signal” side (see Fig. 2). Each rod was set on two concrete blocks, 1.8 m apart, by means of two plates with 3 screws allowing for a planar position of the plate itself. As the support rods were mounted far outboard, they allowed for a rather large deflection. Hence in considering the flexibility of the chamber, the rods' deflection must be taken into account.

We call Calypso-1 (Calypso-2) the first (second) multilayer exposed to the H8 beam. During the mechanical and thermal tests the chamber was upside-down, i.e. Calypso-1 (Calypso-2) was below (above).

2.1 Mechanical monitoring of the chamber

A double monitoring system has been used. The main system was based on RASNIK-CCD systems [3]. The RASNIK devices are mounted directly on the mechanical structure of “Calypso” (see Fig. 2). Hence, it is independent of the support rods' deflection mentioned before.

The second system was made of five or three dial gauges which were located under the chamber, first along one long side and then along the opposite long side (see Fig. 1). The dial gauges precision is ± 5 µm. (Only three dial gauges were used during part of the September tests and during the October temperature gradient tests.)

2.2 Thermal monitoring of the chamber

The temperature monitoring system was based on 48 thermal probes [4]: 24 for each of the two multilayers. In a multilayer, the probes were located into two horizontal planes 26 mm apart. The probes were inserted between the tubes. The electrical signal was read out and converted to a temperature through a dedicated Macintosh.

As a further control, a mercury thermometer was used, which had a precision of 0.5 ˚C.

3. Mechanical tests

The tests performed consisted in loading “Calypso” with different weights in its centre and in measuring the deflection both with the RASNIK and with the five or three dial gauges (see Fig. 1, 2 and 3).

However, the RASNIK systems measure the deformation of the chamber itself, while the set of dial gauges measures the deflection of the whole system “chamber + support rods”. Therefore the contribution of the rods to the total deflection measured by the dial gauges must be subtracted. This has been done by subtracting the average displacement measured by the two end dial gauges.

Moreover, to investigate for a reduction of the chamber deformation, a test was done by stretching two steel rods across the two cross-plates (see Fig. 3).

3.1 Flexibility test

One $(5 \times 10 \times 20)\ cm^3$ lead block has been put in the chamber centre interposing a wood plate to distribute the load (ca. 12 kg total weight) along the whole chamber width (1 m). In a further measurement, two blocks were used (ca. 24 kg).

Fig. 4 shows the “absolute” deflection measured by the dial gauges with a 12 kg load (upper part). Subtracting the deviation measured by the two end dial gauges, the “relative” deviation is obtained, which gives the “true” chamber deflection (Fig. 4 lower part).

Fig. 5 shows the deflections for 12 and 24 kg. The results obtained with the RASNIK is in good agreement with the one obtained with the dial gauges (see Table 1). The finite element analysis (FEA) prediction for a 24 kg load is –108 μm.

When the load is taken away, the deformation disappeared.

3.2 Flexibility test with stretching rods

The 12 kg load test was repeated when a torque was applied to 2 additional rods of 4 mm diameter in such a way as to compensate for the deflection. This operation was done “by hand” and no torque wrench has been used to monitor the torque value.

As shown in Fig. 6, a deflection of the chamber of 80 μm can be easily recovered by means of steel rods stretched with a convenient torque.

This method could be improved: (i) the torque could be monitored by means of a torque wrench; (ii) the maximum torque could be increased (moreover controlled better) by using rods with a larger diameter. Nevertheless, as the two cross-plates have a thickness of 5 mm that reduces to 1 mm in a special thin zone, a high torque may only deflect the cross-plates without compensating the deflection of the chamber.

4. Thermal tests

The main thermal test consisted in heating only one multilayer, to produce a temperature gradient between the two multilayers, and in measuring the deflection both with the RASNIK and with three dial gauges.

The chamber heating was done by covering Calypso-2 with four electric blankets. These are commercial blankets that dissipate a maximum power of 55 W each; a 10 steps' potentiometer allowed for heating regulation. The full coverage area of the blankets $(1.5 \times 3.2\ m^2)$ is larger than the Calypso-2 surface (ca. $1 \times 2.6\ m^2$). Calypso-1 was kept at room temperature (i.e. at 20 to 22 ˚C).

To diminish the heating time of Calypso-2 and to reach a thermal equilibrium in a reasonable time (typically about 2 hours), the blankets were covered by a black cloth and a layer of thermal insulator (plastic foam ca. 10 cm thick).

To stabilise the Calypso-2 temperature (typically from 29 to 32 ˚C), the blanket potentiometers were switched to step 6. In such a condition, the total dissipated power was ca. 130 W for the four blankets.

Under these conditions, the chamber heating resulted in a thermal difference between Calypso-2 and Calypso-1.

4.1 Test-1

In this test, the temperature probes were not operating. Thus the temperature was measured by a mercury thermometer that was placed on the drift tubes in three different positions: above Calypso-2, below Calypso-2 (the thermometer was fixed with scotch) and above Calypso-1.

The test-1 was done with Calypso-1 at 22 ˚C and Calypso-2 at 29/27 ˚C (above/below Calypso-2 respectively). Hence, the temperature gradient was ranging from 5 to 7 ˚C (see Fig. 7 solid lines). The deflection is about 100 μm with a good agreement between the RASNIK and the dial gauges (see Table 2). In Fig. 7 upper part, the dotted line corresponds to the chamber sag after we have turned the heating off and waited until the temperature gradient was lowered to 1 to 2 ˚C.

4.2 Test-2

An eventual thermal effect due to chamber self-heating when all the read-out and HV cards are switched on has been investigated. As shown in Fig. 8, no deformation is found.

Fig. 9 and 10 show the measured temperature for the two planes of probes in Calypso-1 (which is at room temperature) and in Calypso-2 before and after two hours of heating.

The heat transmission from one multilayer to the other was negligible for the purposes of our tests, as can be seen by comparing Calypso-1 temperature map in Fig. 9 and 10. This is due to the low conductivity of heat through the thin layer of glue between tubes and cross-plates.

The upper part of Fig. 11 shows the deflection as a function of 4 gradient values, and the lower part shows the same deformation represented as a function of the temperature of Calypso-2. The line represented on the lower part of Fig. 11 is a fit made on the 5 points. The relation between deformation and temperature is linear and is of 18 μm per ˚C. Note that the deformation is perfectly recovered when Calypso-2 temperature comes back to room temperature.

The test-2 results give us a full confirmation of the conclusions of test-1.

In a further test, the Calypso-2/Calypso-1 gradient was combined with a gradient along Calypso-2 tubes. Namely, the heating of Calypso-2 was done by turning on only the two blankets that were on the signal side of the multilayer. The results shown in Fig. 12 after three different periods of time indicate that a deflection of about 100 μm is reached once the chamber has stabilised, after ca. 6 hours. Figs 13, 14 and 15 show the temperature maps after 2, 4, and 6 hours of heating.

For all the measurements discussed above, a good agreement between the RASNIK and the dial gauges has been found (see Table 2).

5. Conclusions

A summary of the results is given in Tables 1 and 2. The agreement between the RASNIK systems and the dial gauges in measuring the chamber deformation is very good. The difference is contained within the dial gauges precision of ±5 μm.

The mechanical tests have shown that the deformation of our BIL MDT chamber prototype, both under loads and temperature gradients, turns out to be always elastic.

The deflection produced by a load of 24 kg in the central area of the chamber is of the order of 150 μm. A partial compensation of this deflection (ca. 80 μm) may be achieved by stretching rods.

A temperature difference between the two multilayers of about 10 ˚C produces a deflection of the order of 180 μm. A temperature gradient that combines a difference of temperature between the multilayers and along the tubes produces a deflection similar to the previous one. The chamber heating due to the electronic cards is negligible.

Acknowledgements

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References

[1] A. Biscossa et al.: The first full-scale prototype of a BIL MDT chamber for the ATLAS muon spectrometer. ATLAS Internal Note MUON-NO-136, January 1997.

[2] ATLAS internal note on test beam results: in preparation.

[3] P. Oberson : Note in preparation.

[4] According to the manufacturer, a temperature probe has a precision of 0.1 ˚C and a reproducibility of 0.2 ˚C. The systematic error is 1 ˚C at the 3 σ level on a sample of 1000 probes.

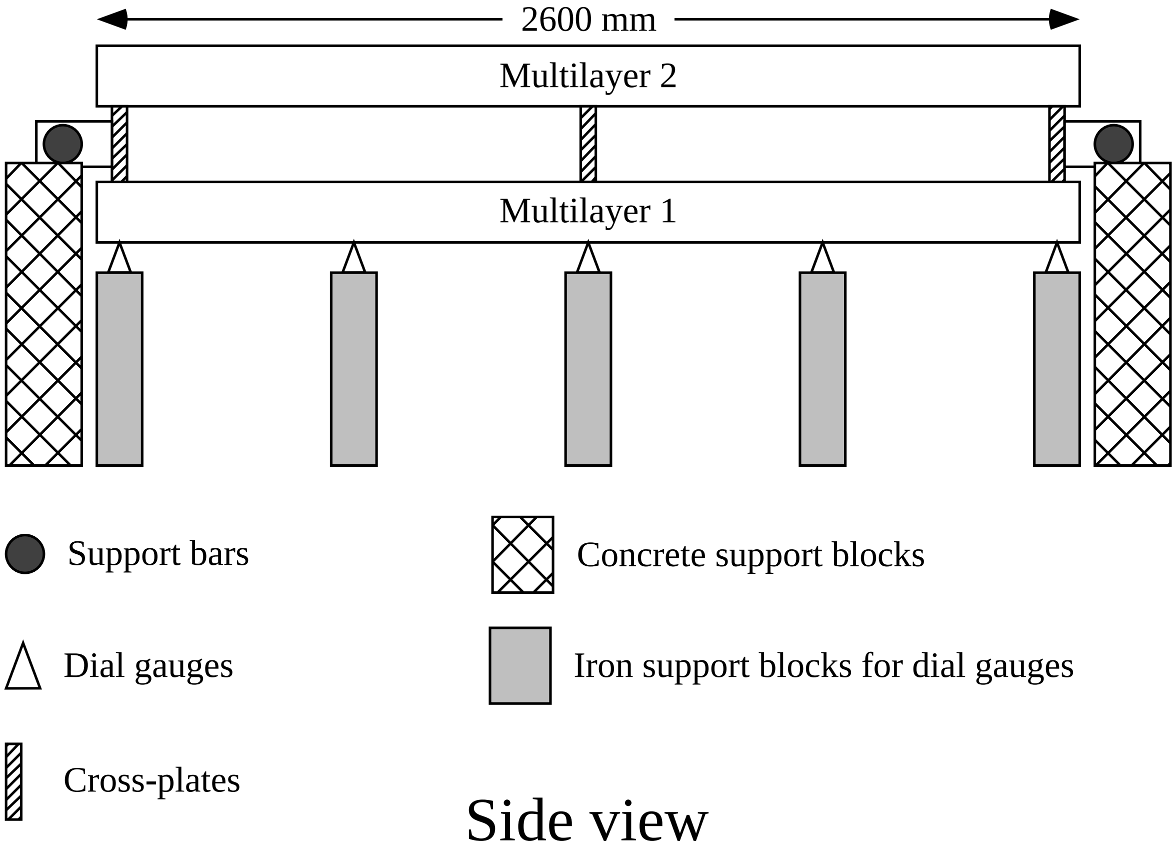


Figure 1: "Calypso" set-up for the mechanical and thermal measurements. The positions of the three cross-plates and of the five dial gauges are shown.

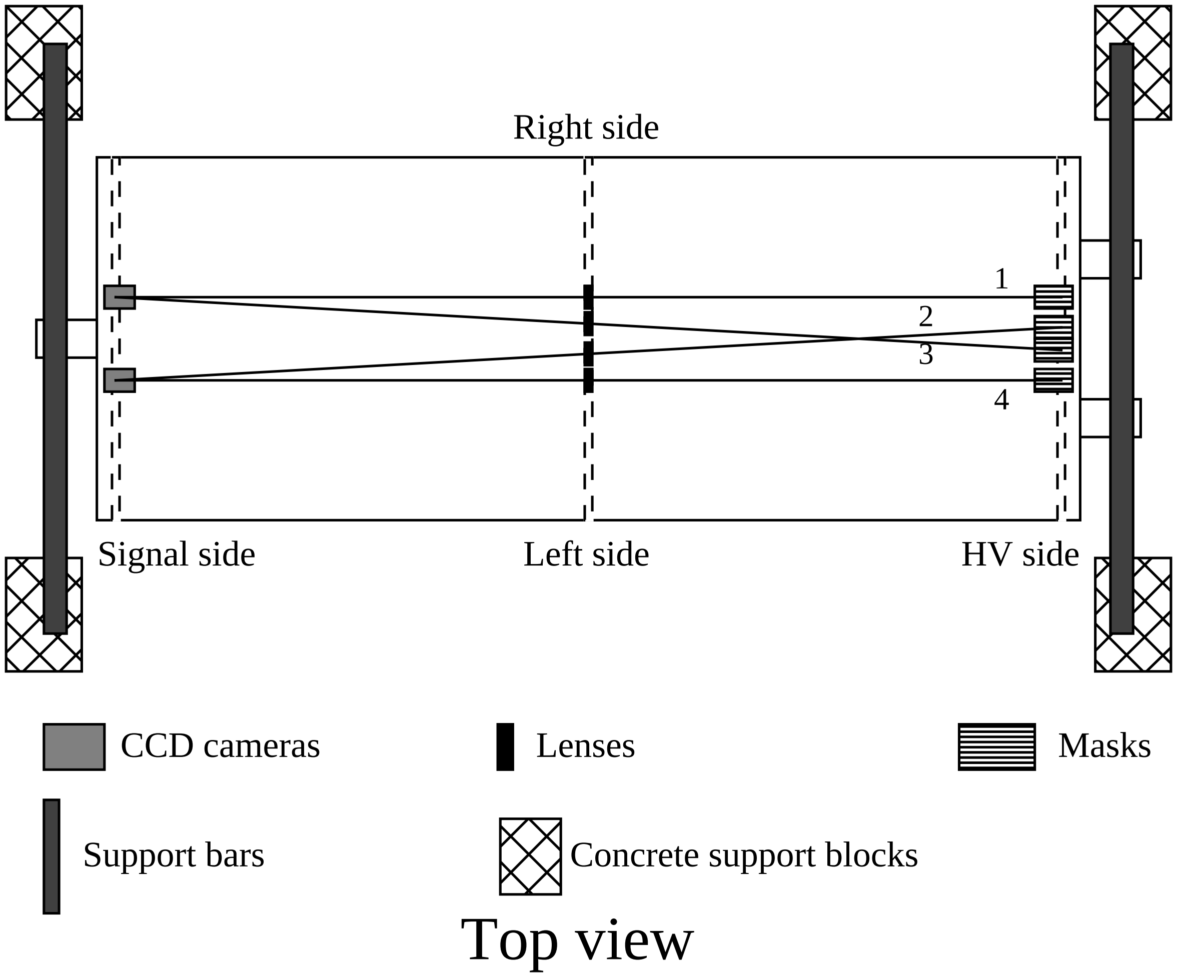


Figure 2: "Calypso" set-up for the mechanical and thermal measurements. The two support rods are shown. A scheme of the RASNIK light rays (1, 2, 3 and 4) is sketched.

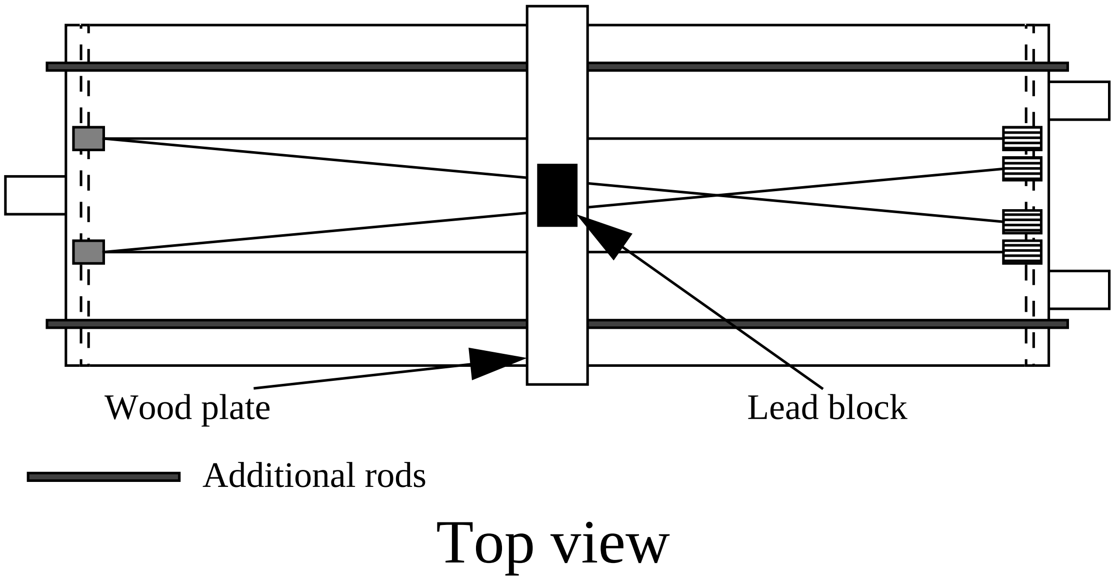


Figure 3: View of "Calypso" with a load in its centre. The stretched rods scheme is shown.

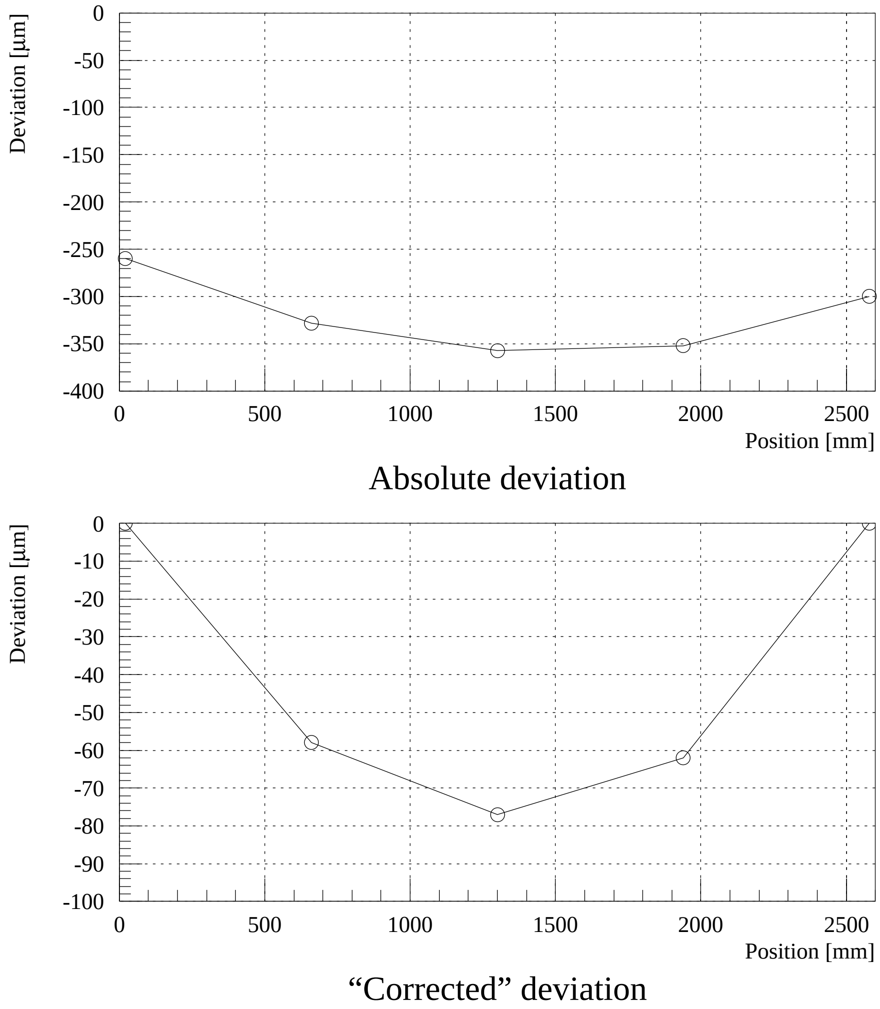


Figure 4: Deflection of “Calypso” measured with the dial gauges for a central 12 kg load. The deflection is given in μm. The dial gauge position is given in mm. The upper plot shows the total deflection measured, while the lower one shows the “corrected” deflection.

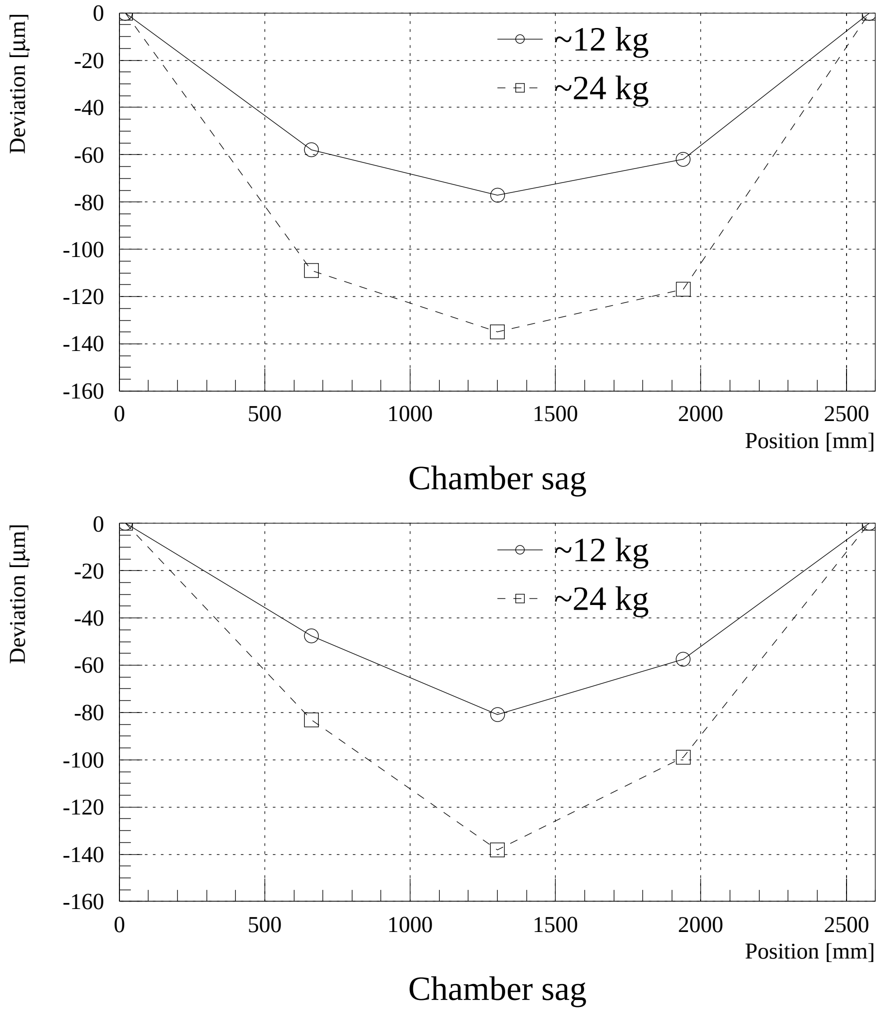
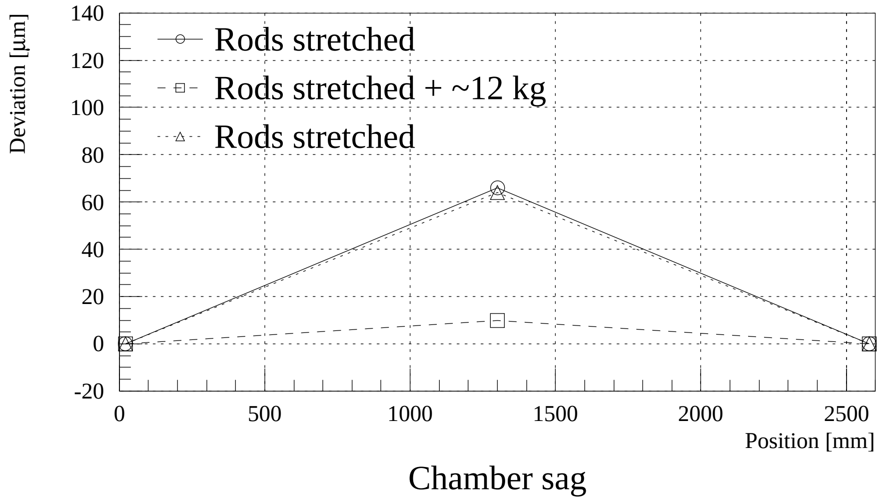


Figure 5: Deflection of "Calypso" for a central 12 and 24 kg load measured with dial gauges when they are placed below the right side (upper plot) or the left side (lower plot) of the chamber.



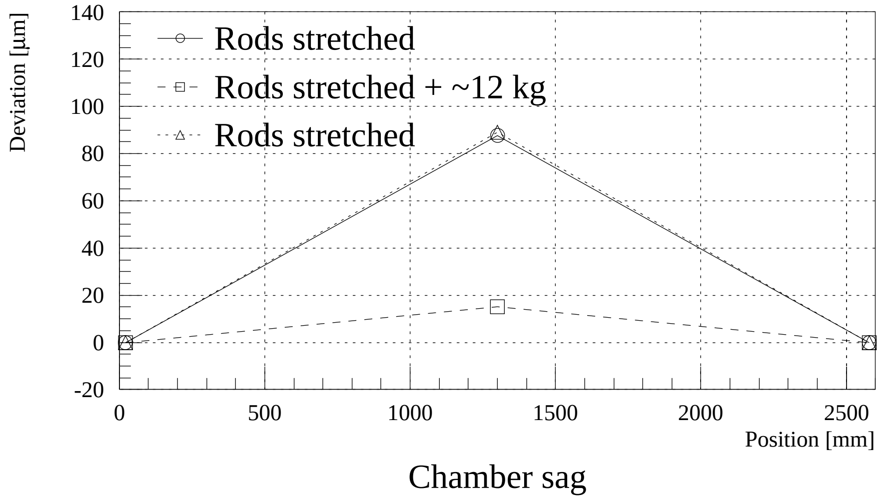


Figure 6: Deflection of "Calypso" with stretched rods and for a central 12 kg load measured with dial gauges when they are placed below the left side (upper plot) or the right side (lower plot) of the chamber.

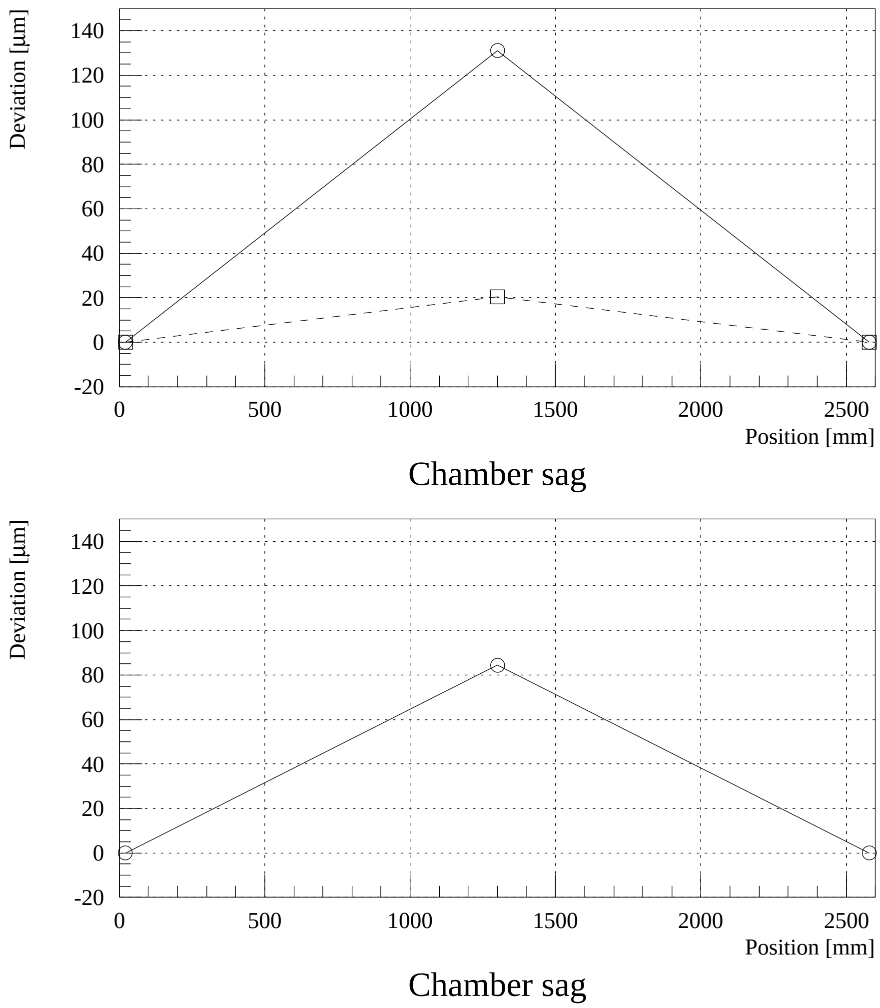


Figure 7: Deflection of "Calypso" due to a temperature gradient of 7 (solid line) and 2 ˚C (dotted line, upper plot) and 7 ˚C (lower plot) between Calypso-2 and Calypso-1. The dial gauges are placed below the right side (upper plot) or the left side (lower plot) of the chamber.

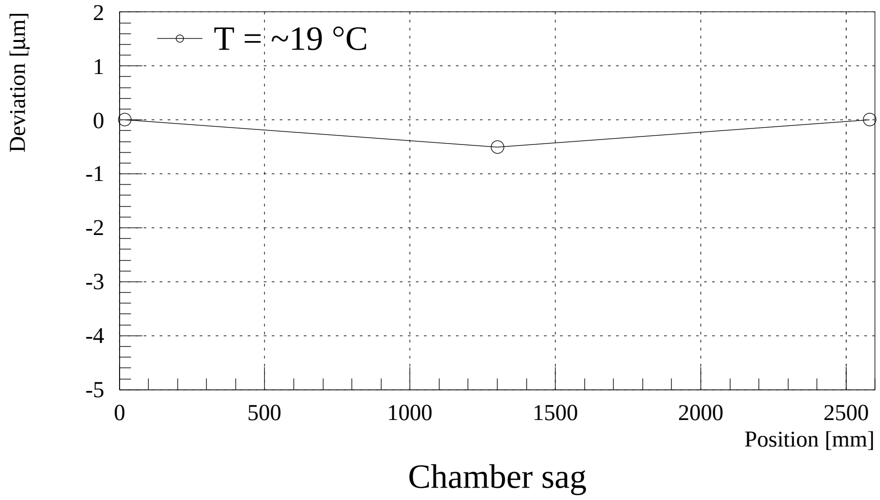


Figure 8: Deflection of "Calypso" due to the heat dissipated by the signal and HV cards. No thermal effect is measured 12 hours after the cards have been turned "on".

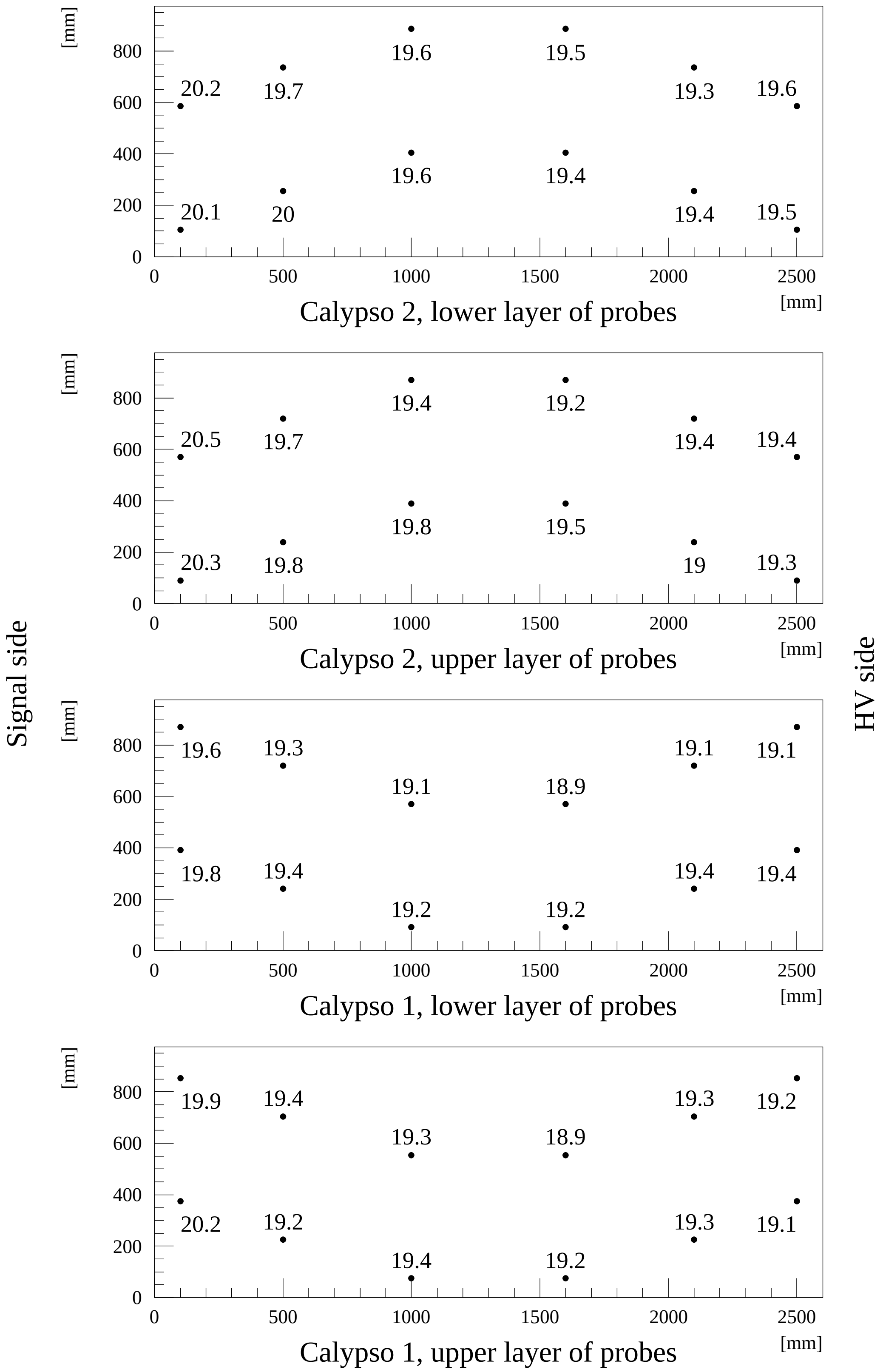


Figure 9: Map of the temperatures for the two layers of probes in Calypso-1 and Calypso-2. The chamber was at room temperature. Temperatures are given in ˚C.

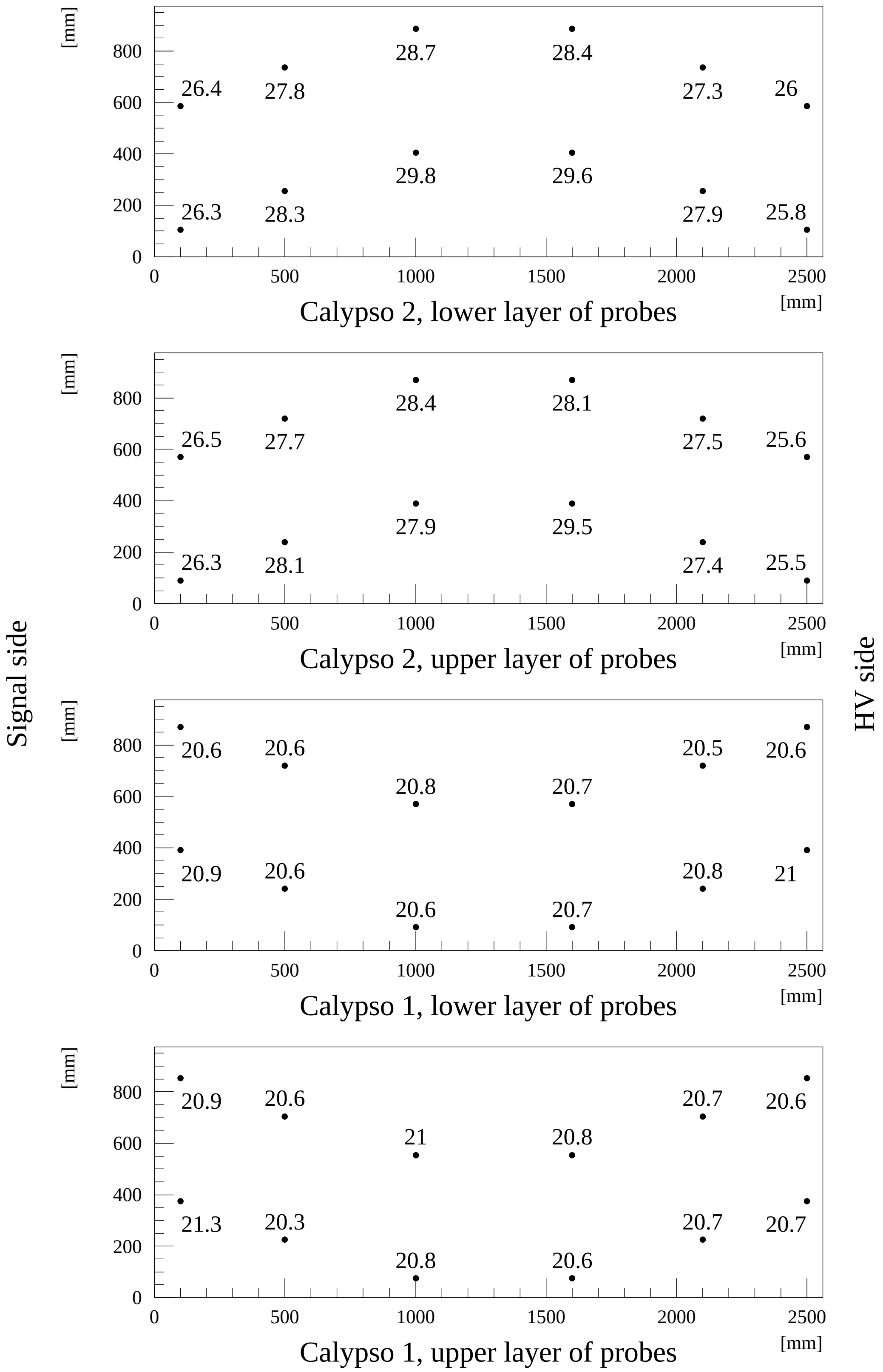


Figure 10: Map of the temperatures for the two layers of probes after two hours of heating of Calypso-2. A non uniform heating along the drift tubes is observed, with a maximum temperature in the centre and minimum values near to the two ends of the chamber. Temperatures are given in ˚C.

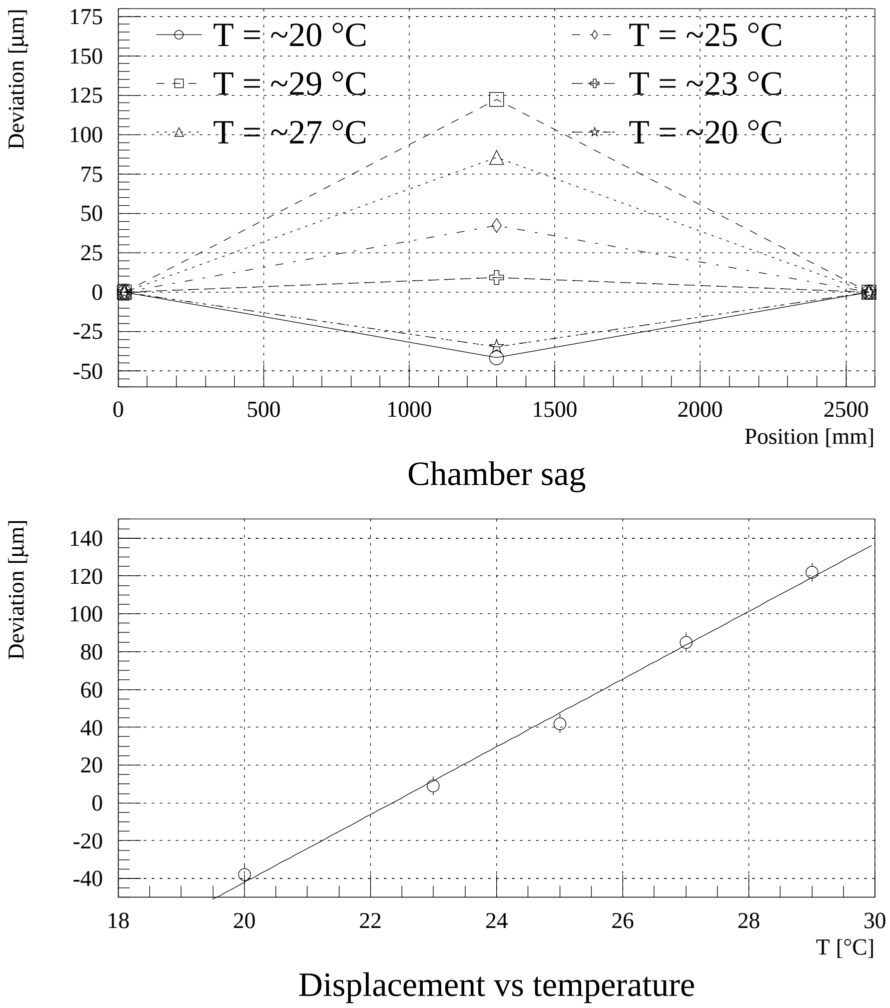


Figure 11: Deflection of “Calypso” measured with dial gauges for six temperature differences between Calypso-2 (which is heated) and Calypso-1 (at room temperature). The lower plot shows the linear relation between deformation and temperature.

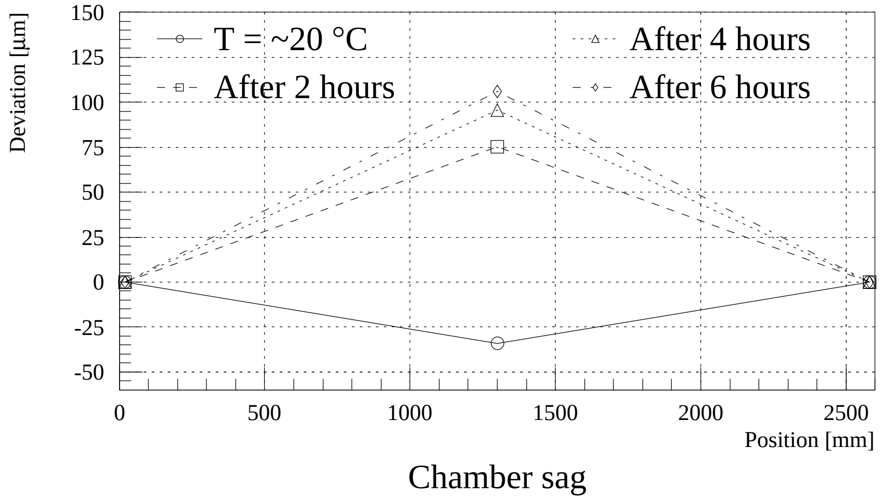


Figure 12: Deflection of “Calypso” measured with dial gauges after the “signal side” half of Calypso-2 has been heated at 32 ˚C. The measurement has been repeated after 2, 4 and 6 h in order to account for heat diffusion along the tubes.

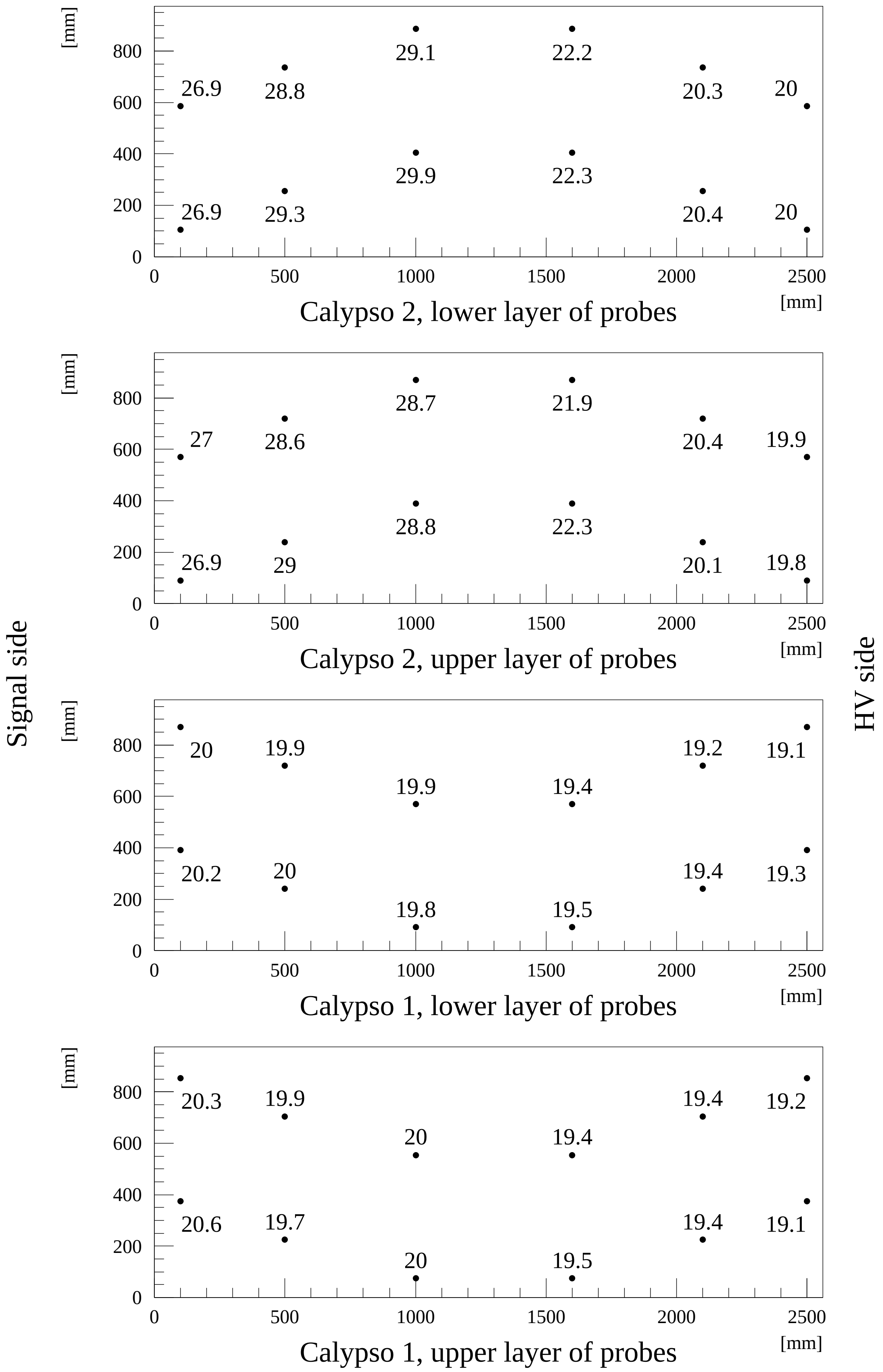


Figure 13: Temperature map of "Calypso" after 2 hours of heating of one half of Calypso-2, namely the signal side.

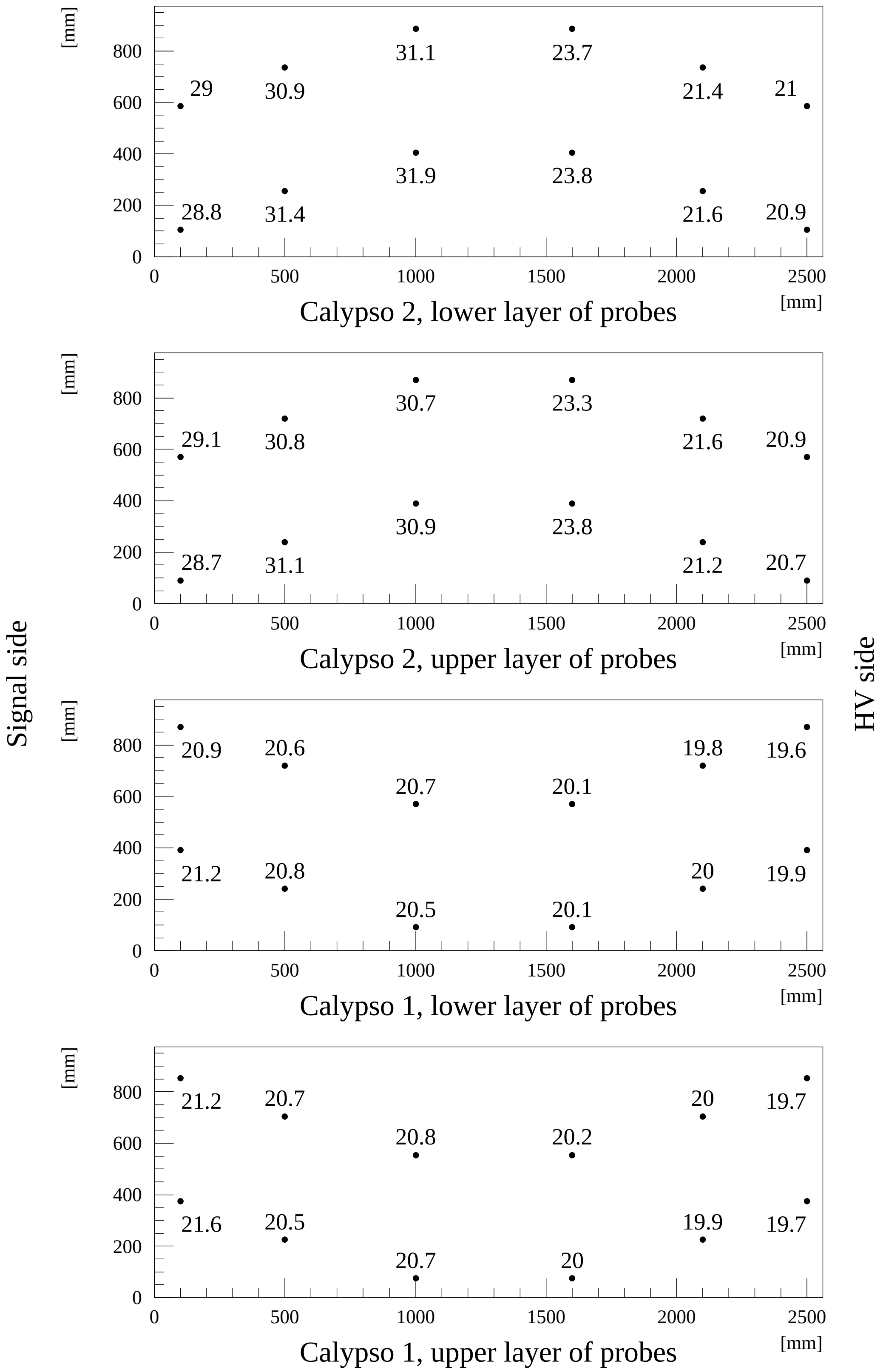


Figure 14: Temperature map of "Calypso" after 4 hours of heating of one half of Calypso-2, namely the signal side.

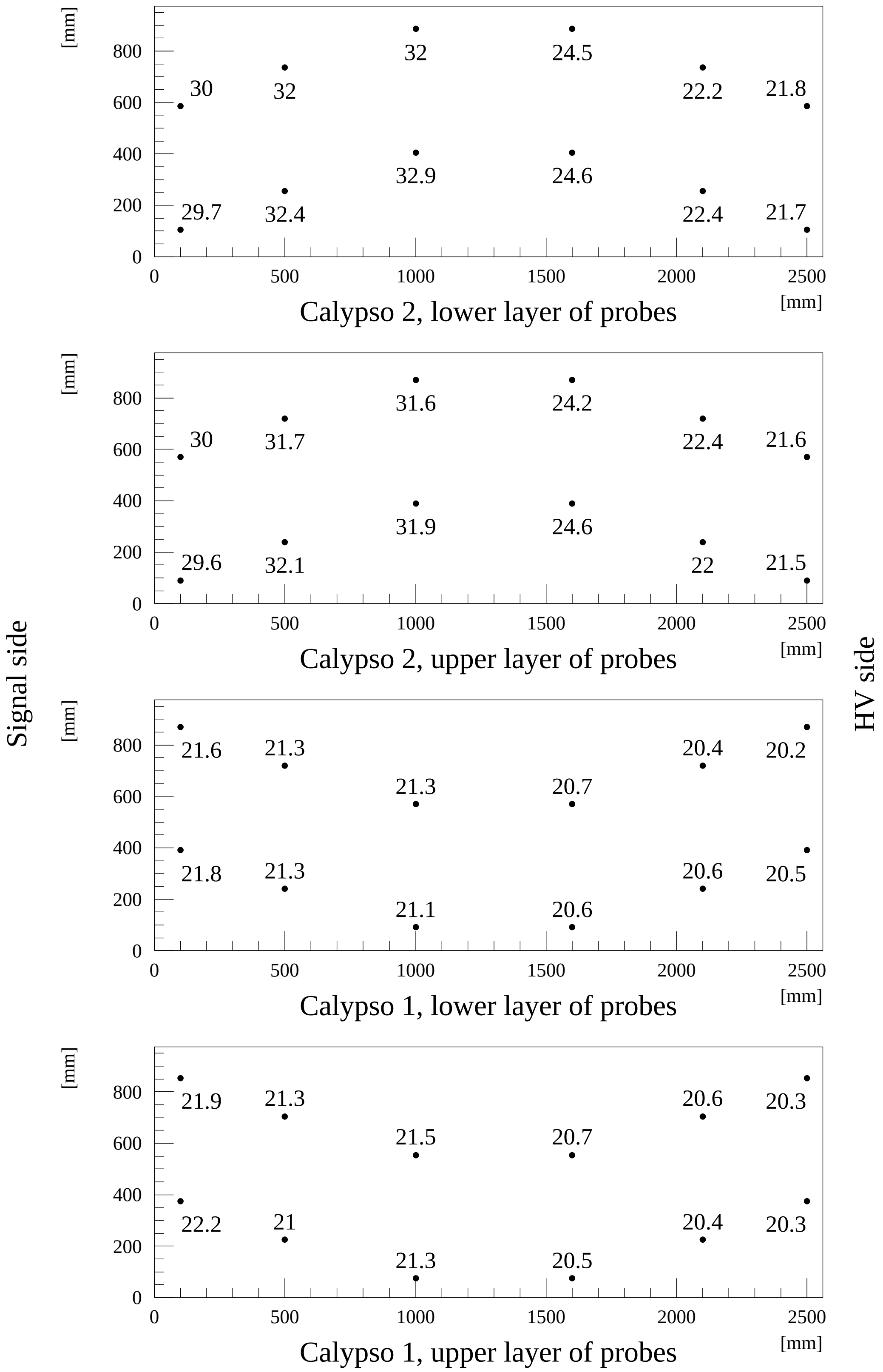


Figure 15: Temperature map of "Calypso" after 6 hours of heating of one half of Calypso-2, namely the signal side.

Summary of the mechanical tests performed on “Calypso”			
Condition	Dial gauges [μm]		RASNIK [μm]
Load ~12 kg	Right	–77	–76
Load ~24 kg	Right	–135	–148
Load ~12 kg	Left	–81	–79
Load ~24 kg	Left	–138	–153
Rods stretched	Left	66	59
Rods stretched + load ~12 kg	Left	10	21
Rods stretched	Left	64	59
Rods stretched	Right	88	79
Rods stretched + load ~12 kg	Right	15	2
Rods stretched	Right	89	78

Table 1: Summary of the results obtained with both dial gauges and RASNIK for all the mechanical tests performed on “Calypso”. The dial gauges position is indicated (Right or Left side of the chamber).

Summary of the thermal tests performed on “Calypso”			
Condition (temperature T in ˚C)	Dial gauges [μm]		RASNIK [μm]
Temperature gradient (T = 7)	Right	131	141
Temperature gradient (T = 2)	Right	21	17
Temperature gradient (T = 7)	Left	85	119
Effect of the signal and HV cards	Left	–0.5	–2
T = 20	Left	–41	–36
T = 29	Left	122	139
T = 27	Left	85	90
T = 25	Left	42	43
T = 23	Left	9	6
T = 20	Left	–35	–36
T = 20	Left	–34	–36
T = 32 on half of Calypso-2 for 2 h	Left	75	91
T = 32 on half of Calypso-2 for 4 h	Left	96	113
T = 32 on half of Calypso-2 for 6 h	Left	106	120

Table 2: Summary of the results obtained with both dial gauges and RASNIK for all the thermal tests performed on “Calypso”. The dial gauges position is indicated (Right or Left side of the chamber).