Strain Gage measurements

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Strain Gage: Intro

Strain gage measure the strain

- $\varepsilon_{i} = \Delta L_{i} \,/\, L_{i}$
- $\Delta R_{i} \,/\, R_{i} = K\, \varepsilon_{i}$
- K ~ 2 is the gage factor
- L_{i} ~ 7mm is the strain-gage length

$$\left(\frac{\Delta R}{R_0}\right)_{T/O} = \left[\beta_G + F_G\left(\frac{1+K_t}{1-\nu_0 K_t}\right)(\alpha_S - \alpha_G)\right]\Delta T \qquad (1)$$

where, in consistent units:

$\left(\frac{\Delta R}{R_0}\right)_{T/O}$ = unit change in resistance from the initial reference resistance, R_0, caused by change in temperature resulting in thermal output.

β_G = temperature coefficient of resistance of the grid conductor.

F_G = gage factor of the strain gage.†

K_t = transverse sensitivity of the strain gage.

ν_0 = Poisson's ratio (0.285) of the standard test material used in calibrating the gage for its gage factor.

TABLE 1—NOMINAL THERMAL EXPANSION COEFFICIENTS OF ENGINEERING MATERIALS

MATERIAL DESCRIPTION	EXPANSION COEFFICIENTS** Per °F	EXPANSION COEFFICIENTS** [Per °C]	RECOMMENDED S-T-C NUMBER
ALUMINA, fired	3.0	[5.4]	03
ALUMINUM Alloy, 2024-T4*, 7075-T6	12.9	[23.2]	13*
BERYLLIUM, pure	6.4	[11.5]	06
BERYLLIUM COPPER, Cu 75, Be 25	9.3	[16.7]	09
BRASS, Cartridge, Cu 70, Zn 30	11.1	[20.0]	13
BRONZE, Phosphor, Cu 90, Sn 10	10.2	[18.4]	09
CAST IRON, gray	6.0	[10.8]	06
COPPER, pure	9.2	[16.5]	09
GLASS, Soda, Lime, Silica	5.1	[9.2]	05
INCONEL, Ni-Cr-Fe alloy	7.0	[12.6]	06
INCONEL X, Ni-Cr-Fe alloy	6.7	[12.1]	06
INVAR, Fe-Ni alloy	0.8	[1.4]	00
MAGNESIUM Alloy*, AZ-31B	14.5	[26.1]	15*
MOLYBDENUM*, pure	2.7	[4.9]	03*
MONEL, Ni-Cu alloy	7.5	[13.5]	06
NICKEL-A, Cu-Zn-Ni alloy	6.6	[11.9]	06
QUARTZ, fused	0.3	[0.5]	00
STEEL Alloy, 4340	6.3	[11.3]	06
STEEL, Carbon, 1008, 1018*	6.7	[12.1]	06*
STEEL, Stainless, Age Hardenable (17-4PH)	6.0	[10.8]	06
STEEL, Stainless, Age Hardenable (17-7PH)	5.7	[10.3]	06
STEEL, Stainless, Age Hardenable (PH15-7Mo)	5.0	[9.0]	05
STEEL, Stainless, Austenitic (304*)	9.6	[17.3]	09*
STEEL, Stainless, Austenitic (310)	8.0	[14.4]	09
STEEL, Stainless, Austenitic (316)	8.9	[16.0]	09
STEEL, Stainless, Ferritic (410)	5.5	[9.9]	05
TIN, pure	13.0	[23.4]	13
TITANIUM, pure	4.8	[8.6]	05
TITANIUM Alloy, 6AL-4V*	4.9	[8.8]	05*
TITANIUM SILICATE*, polycrystalline	0.0	[0.0]	00*
TUNGSTEN, pure	2.4	[4.3]	03
ZIRCONIUM, pure	3.1	[5.6]	03

* Indicates type of material used in determining thermal output

Strain Gage: Methodology

In our samples thermal output vs T given for Steel 1018

$$\epsilon_{T/O} = \left(\frac{\beta_G}{F_G} - \alpha_G \right) \Delta T + \alpha_S \Delta T$$

$\varepsilon = \Delta L \ / \ L$

For Another material X:

$$\epsilon_X = \left(\frac{\beta_G}{F_G} - \alpha_G \right) \Delta T + \alpha_X \Delta T$$

- $\varepsilon_X - \varepsilon_{T/O} = (\alpha_X - \alpha_{steel}) \ \Delta T$
  - The subtraction removes the thermal response of the strain gage and leaves just the part that depends on the substrate

- Measure ε_X as a function of T
- Fit $\varepsilon_X - \varepsilon_{T/O}$ vs T

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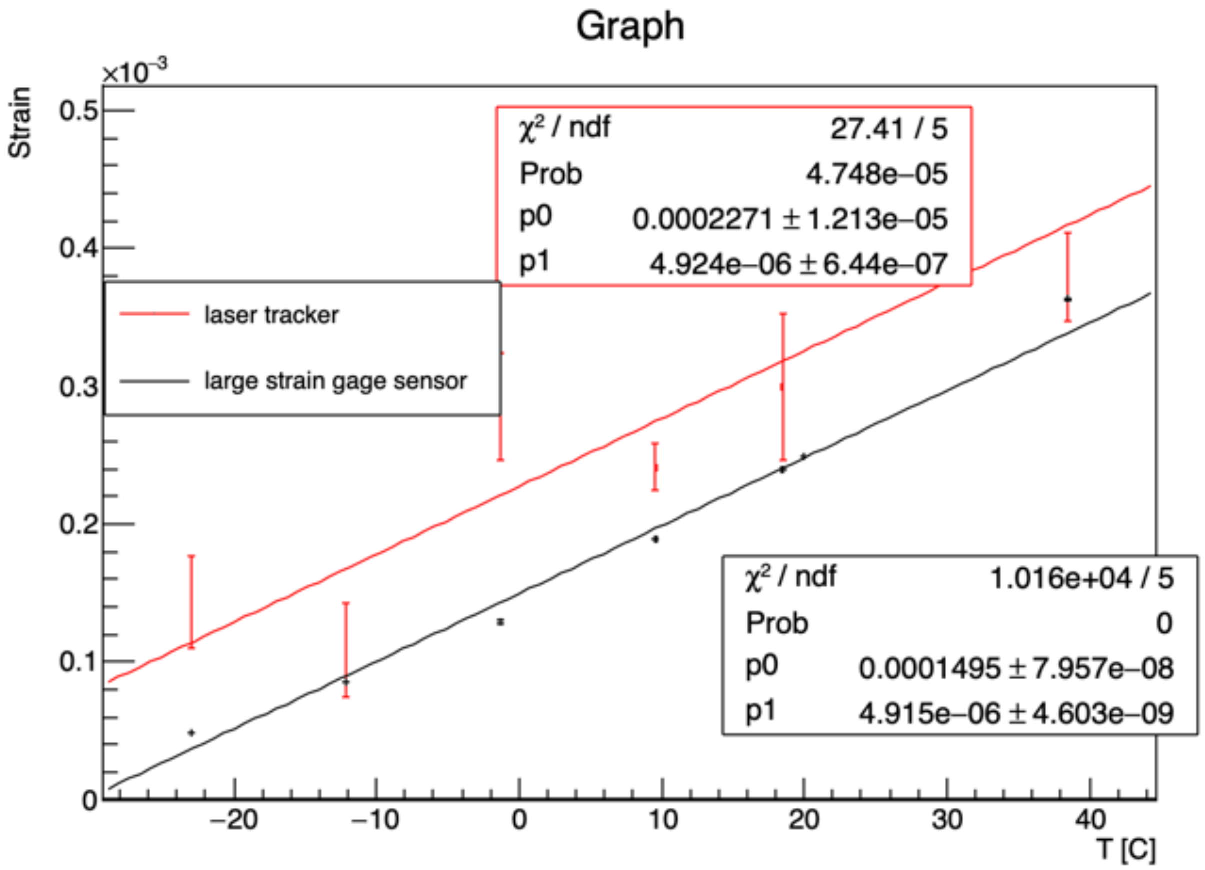
ZIRCONIUM, pure	3.1	[5.6]	03

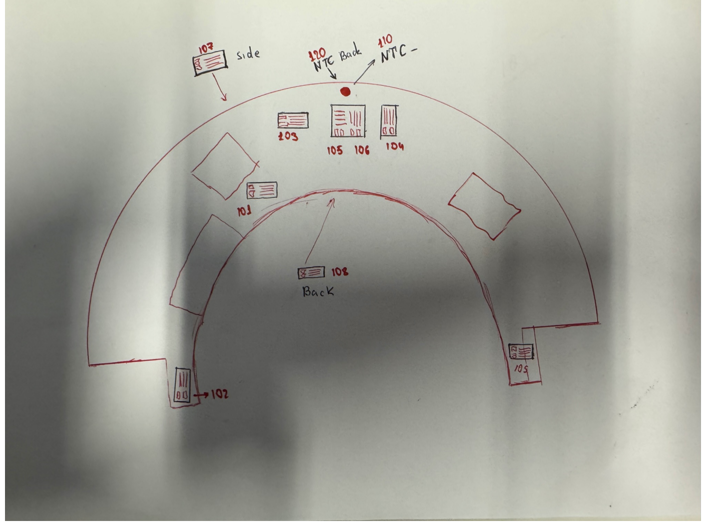
* Indicates type of material used in determining thermal output

Setup

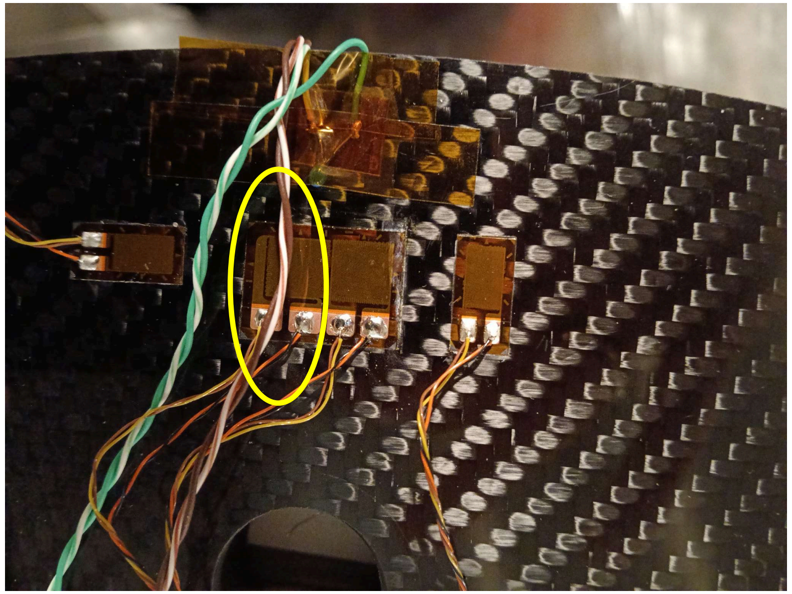
Laser Tracker vs Large Sensor



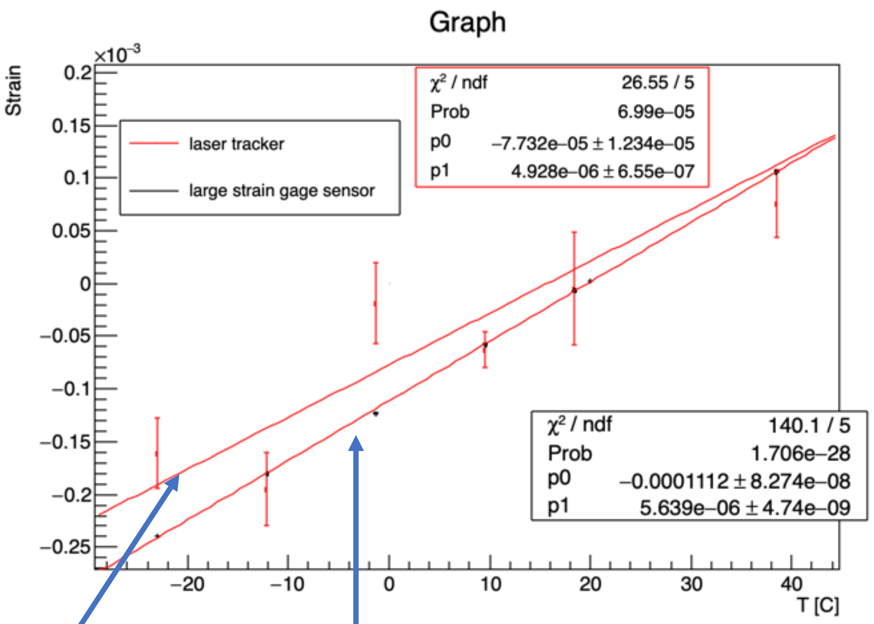
Correction from Steel 2018



Ch105
Same direction as optical targets

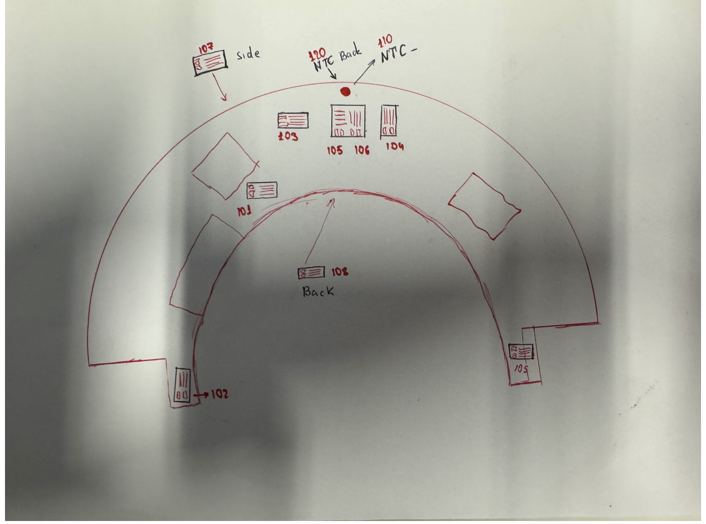


Laser Tracker vs Large Sensor

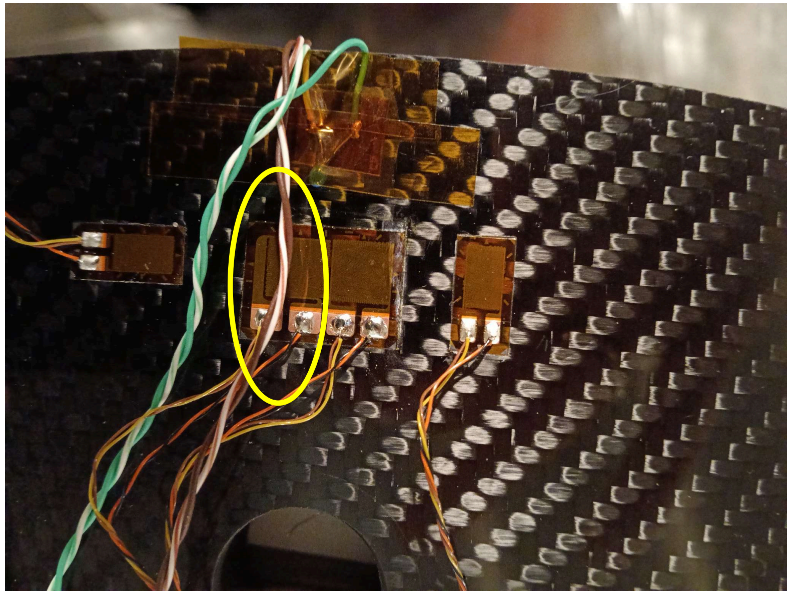


Strain gage with Correction from ZeroDur

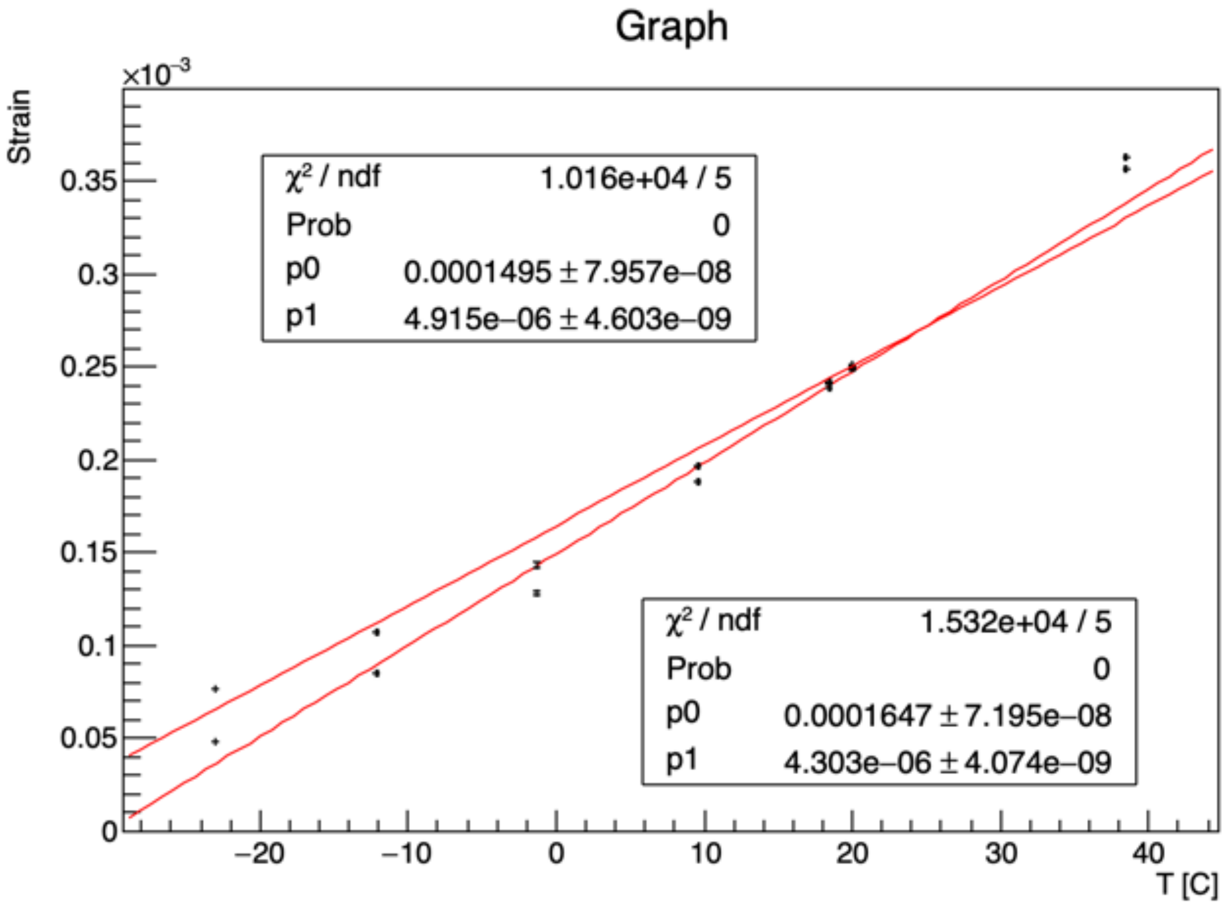
Laser Tracker

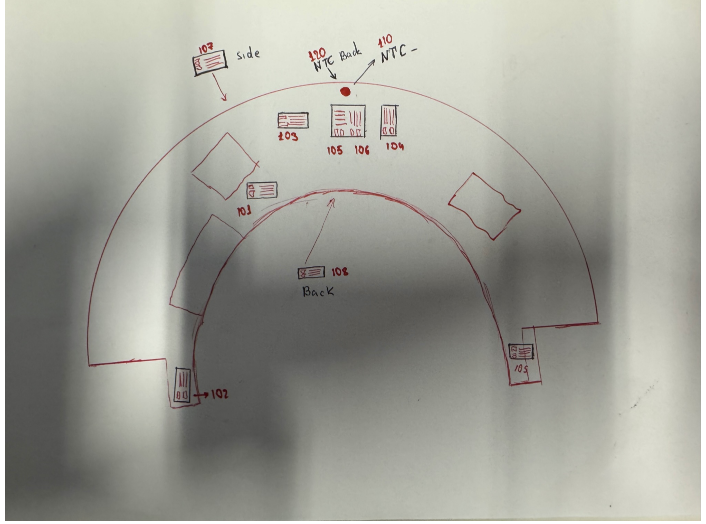


Ch105
Same direction as optical targets



Large Sensors: compare two directions

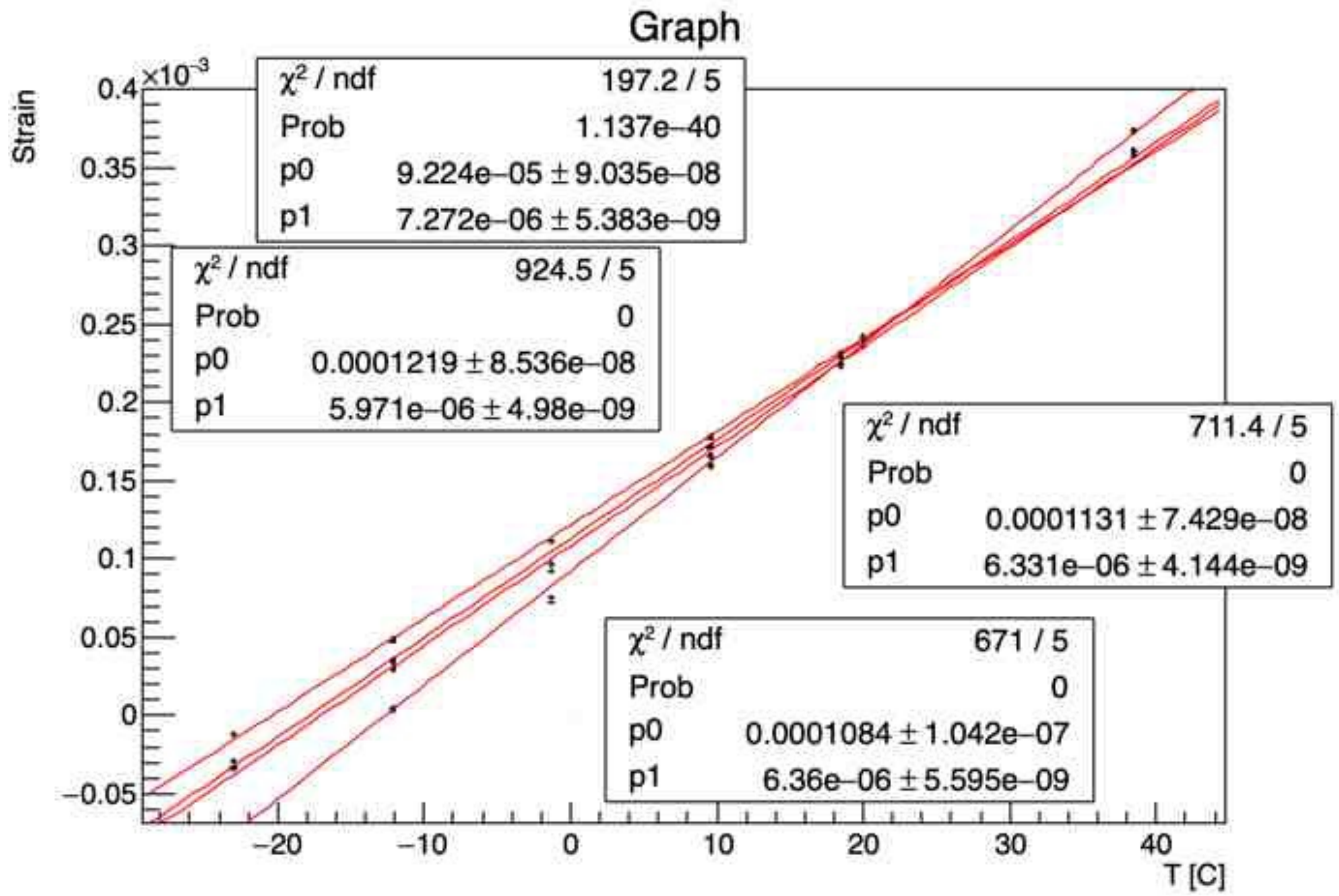


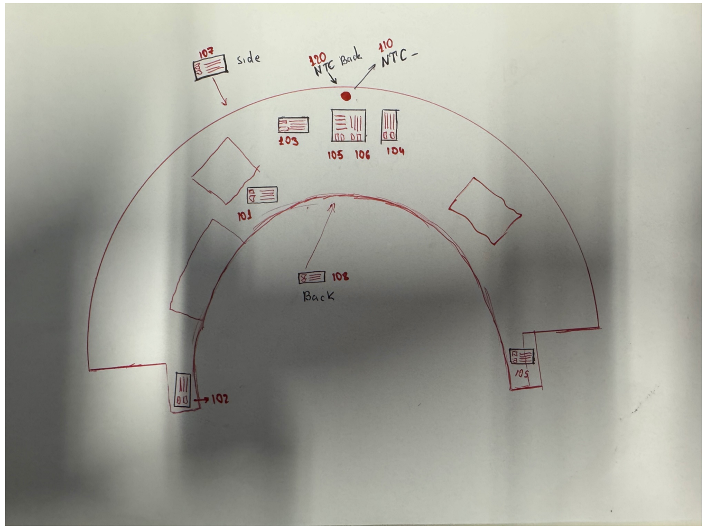


Ch105, Ch106
Parallel and perpendicular directory as optical targets

Correction from Steel 2018

Small Sensors

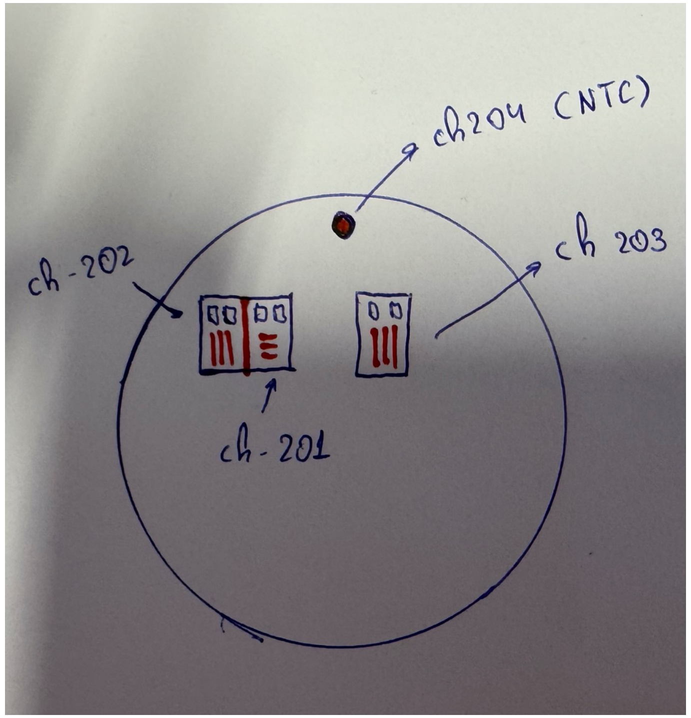


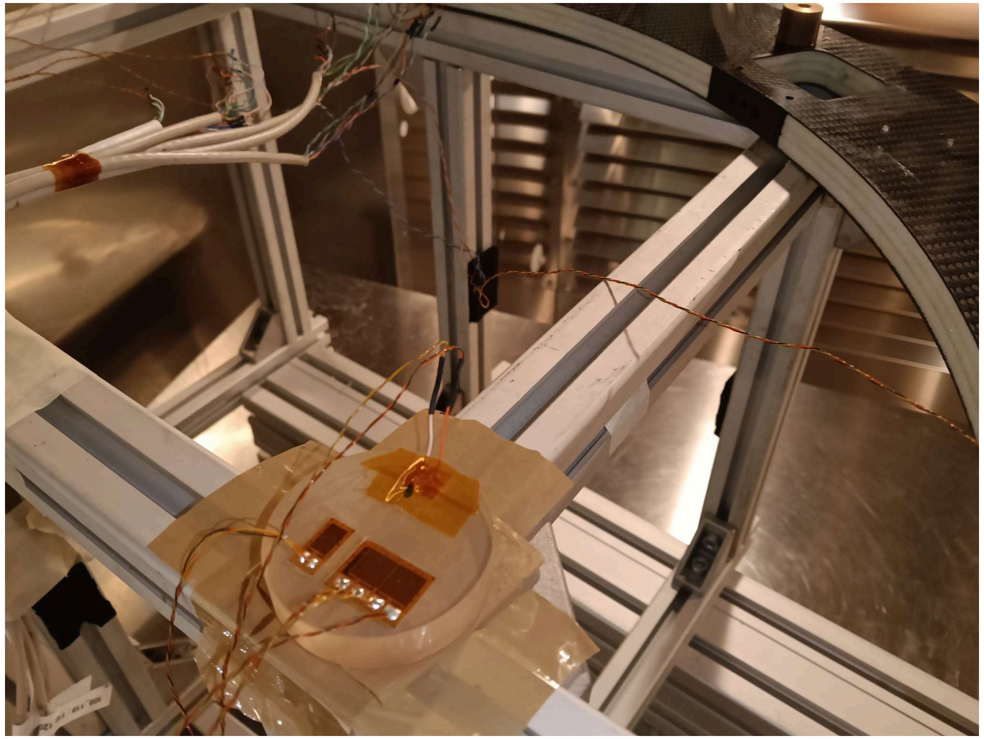


Ch103,104,107,108,102

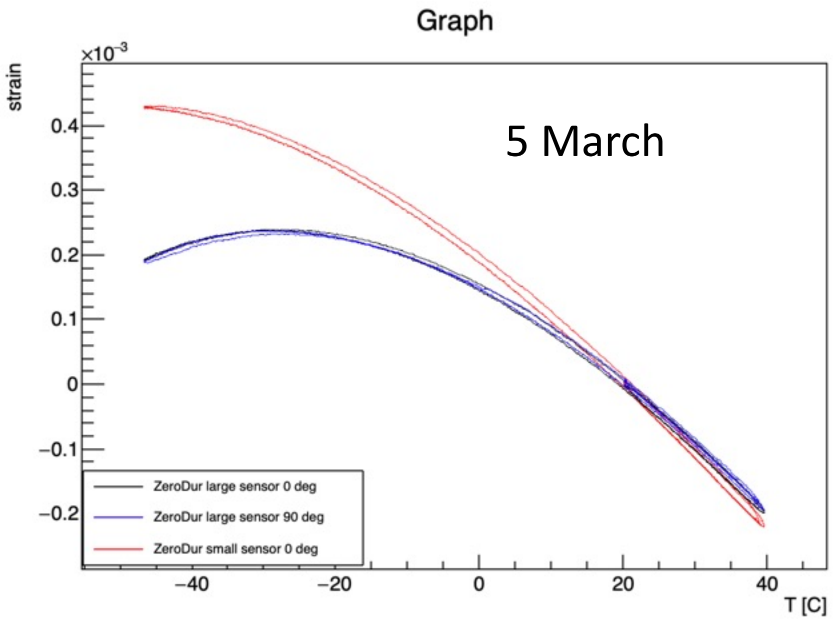
Correction from Steel 2018

ZeroDur

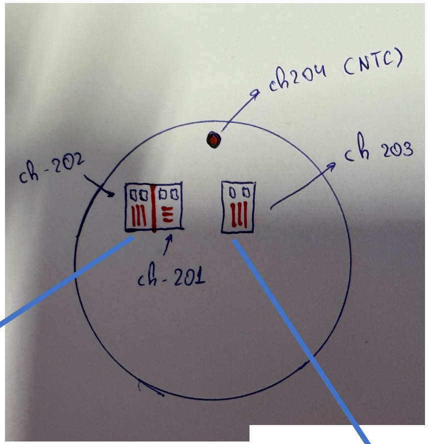




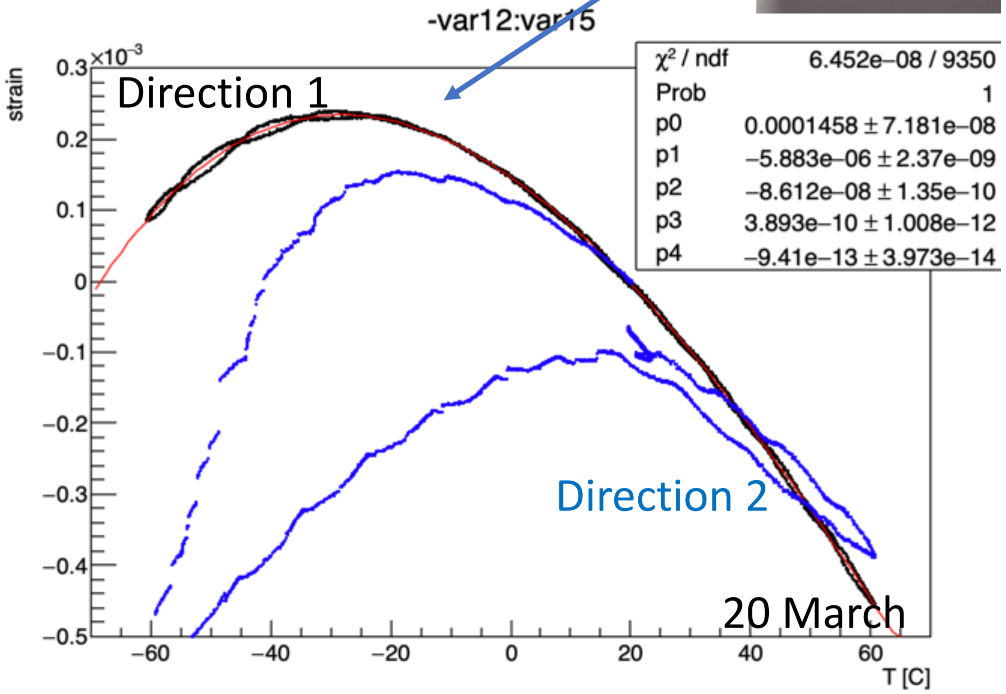
ZeroDur



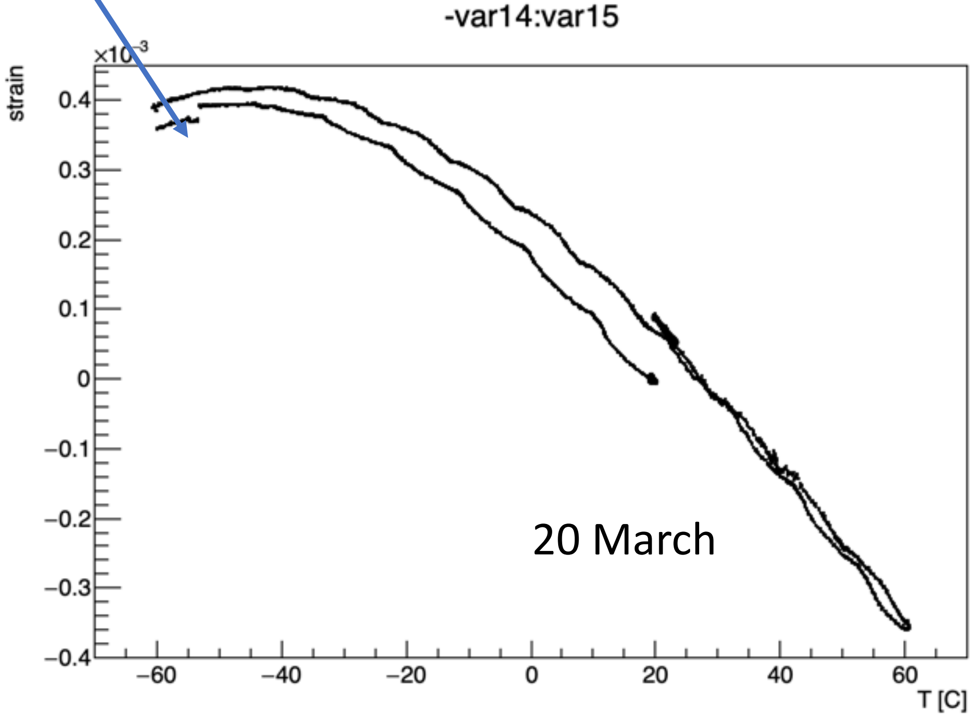
Graph
5 March
strain
×10⁻³
T [C]
ZeroDur large sensor 0 deg
ZeroDur large sensor 90 deg
ZeroDur small sensor 0 deg



ch204 (NTC)
ch-202
ch 203
ch-201



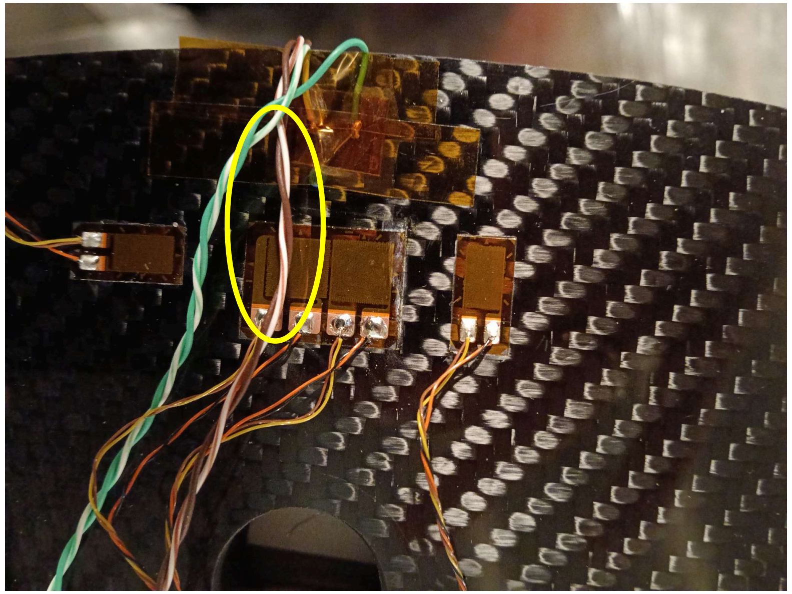
-var12:var15
strain
×10⁻³
Direction 1
Direction 2
20 March
T [C]
χ² / ndf 6.452e−08 / 9350
Prob 1
p0 0.0001458 ± 7.181e−08
p1 −5.883e−06 ± 2.37e−09
p2 −8.612e−08 ± 1.35e−10
p3 3.893e−10 ± 1.008e−12
p4 −9.41e−13 ± 3.973e−14



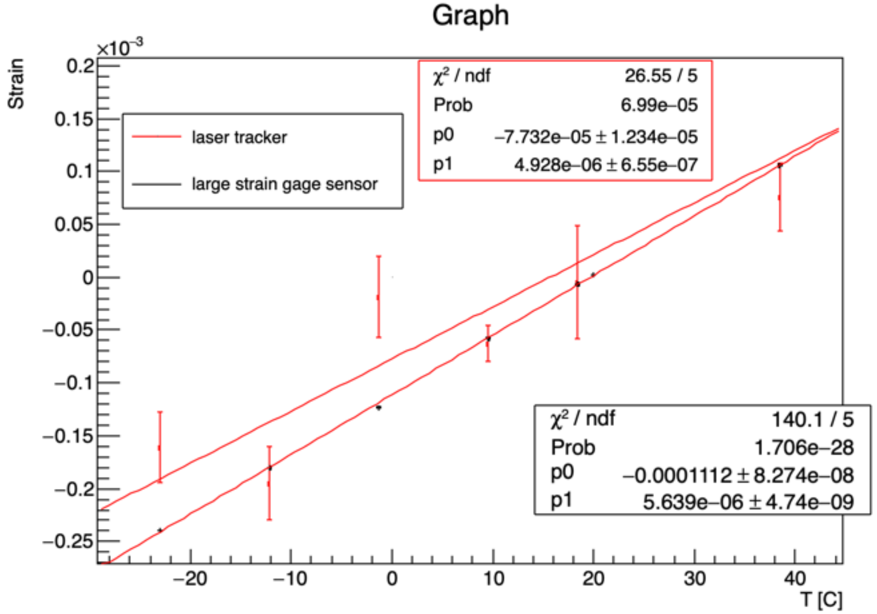
-var14:var15
strain
×10⁻³
20 March
T [C]

Laser Tracker vs Large Sensor: compare corrections

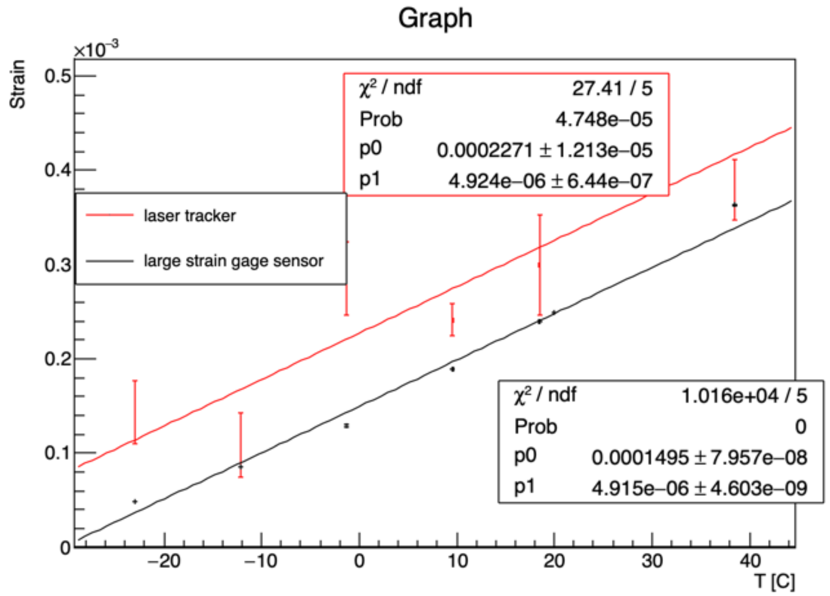
Ch105 Same direction as optical targets



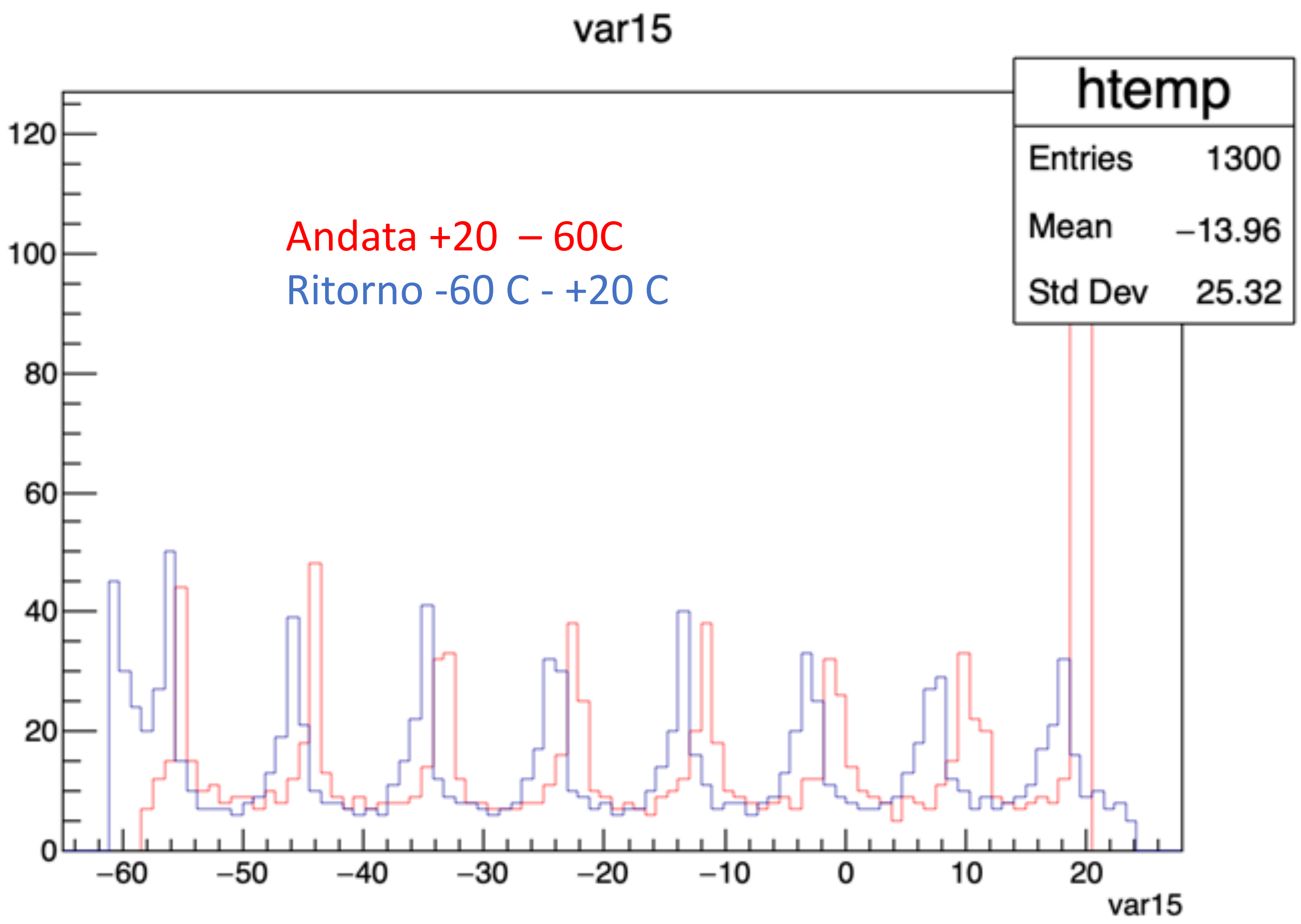
Correction from ZeroDur



Correction from Steel 1018



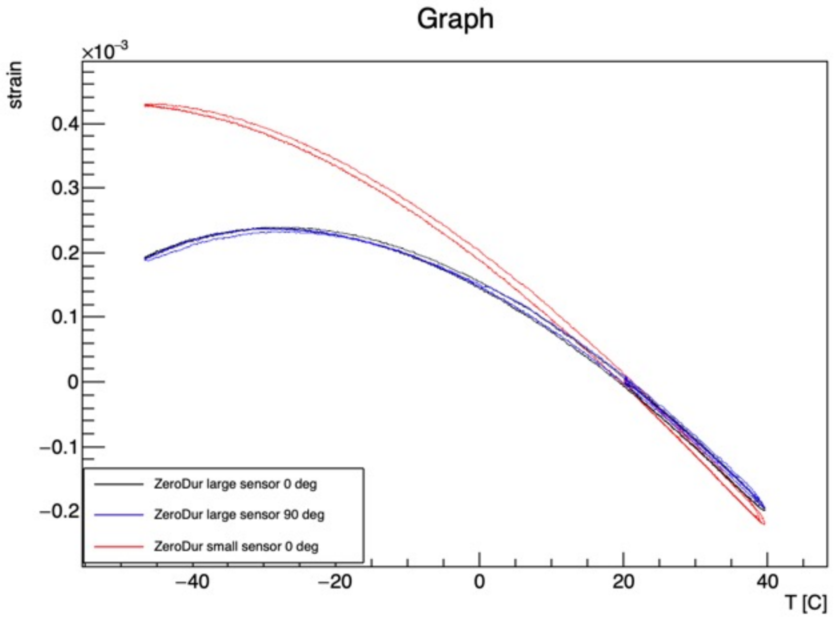
Zero Dur

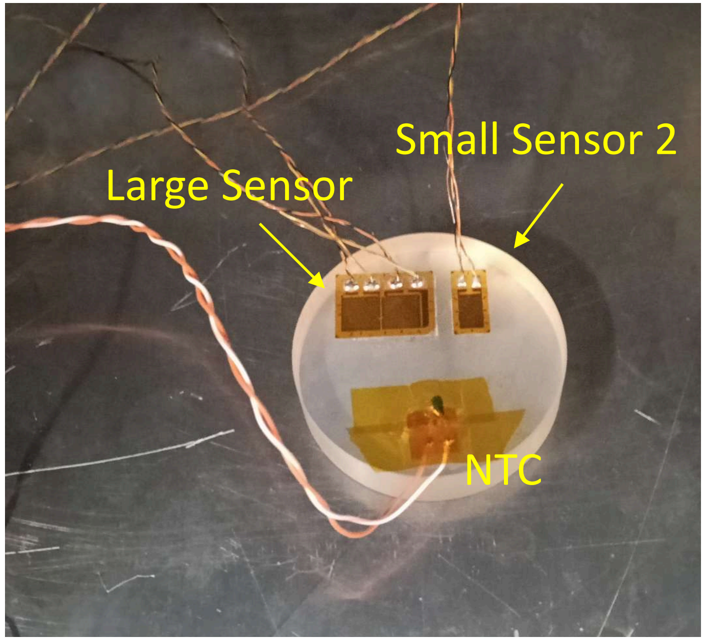


var15
htemp
Entries 1300
Mean −13.96
Std Dev 25.32
Andata +20 – 60C
Ritorno -60 C - +20 C
120
100
80
60
40
20
0
−60
−50
−40
−30
−20
−10
0
10
20
var15

Backup

Zerodur material with CTE =0

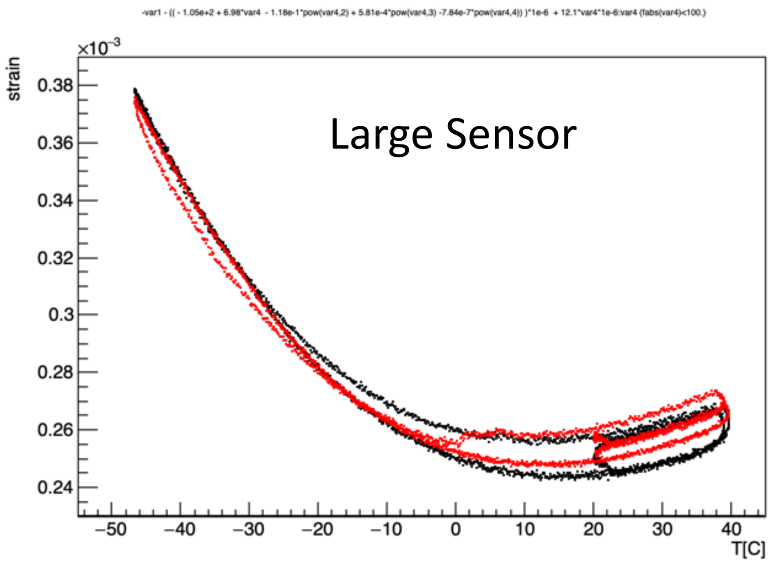


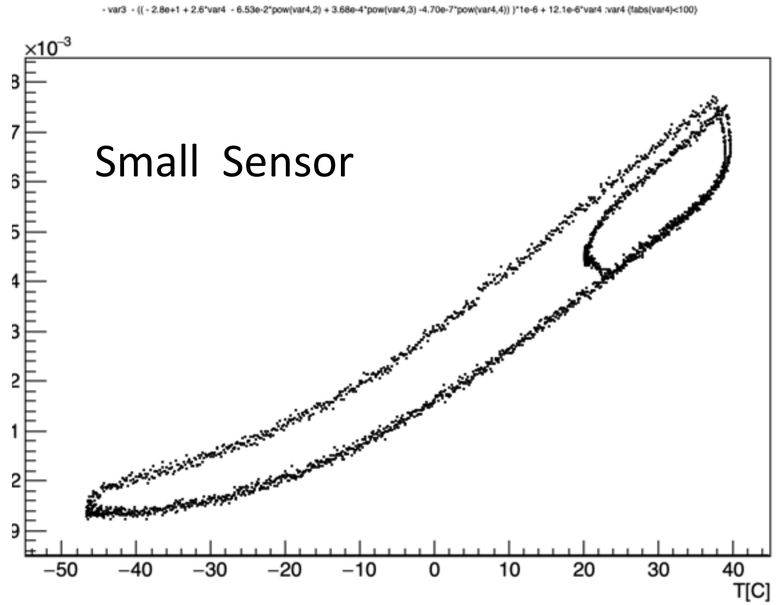


- Apply themal correction
  from company relative to steel 1018

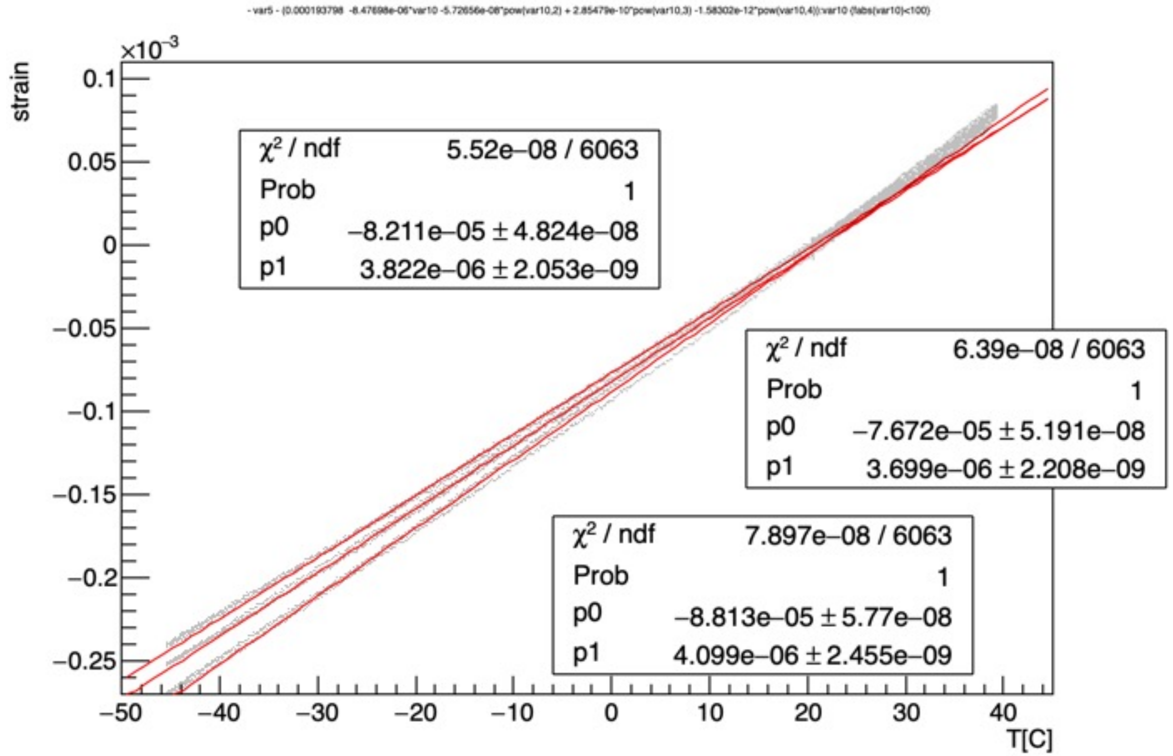
- Expected flat curve vs T
- Residual dependency on T
- Method not reliable
  - Probaby different gluing

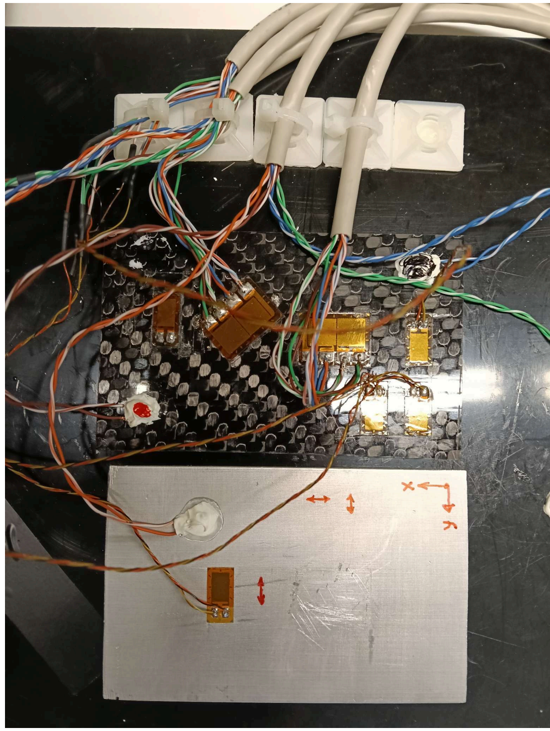
- Change strategy:
  - Move to correction from data on ZeroDur





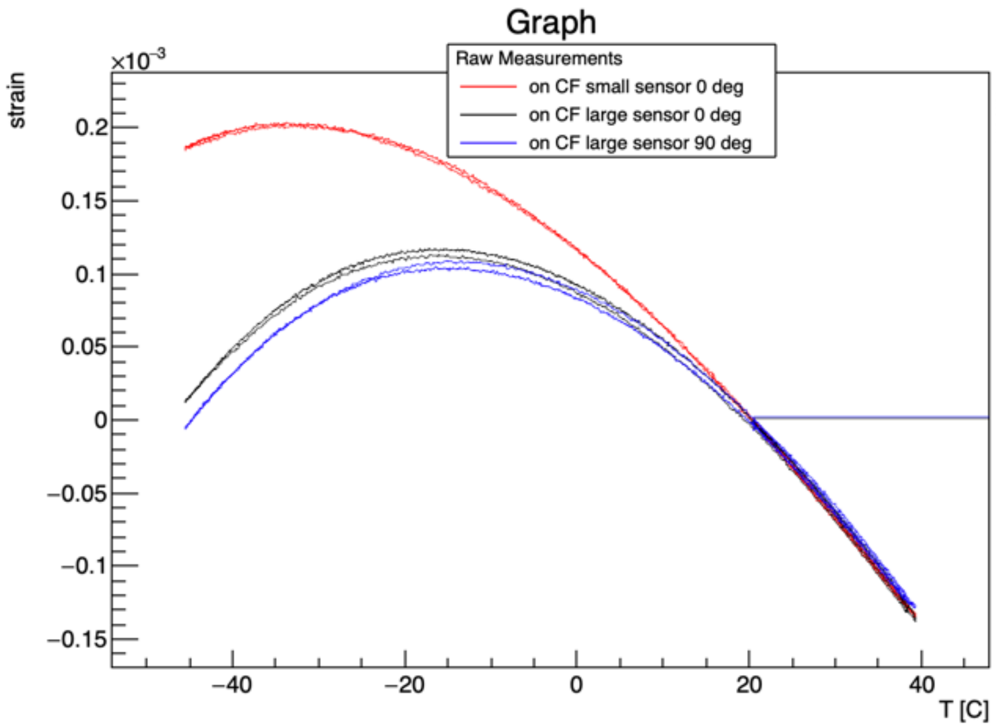
CF corrected with ZeroDur data

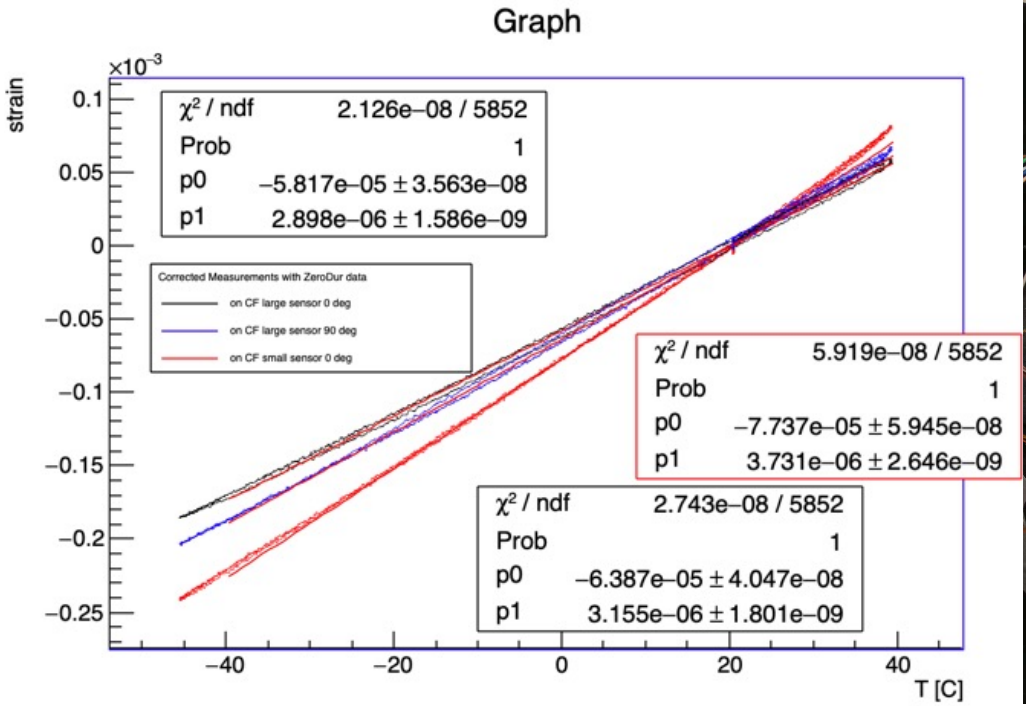


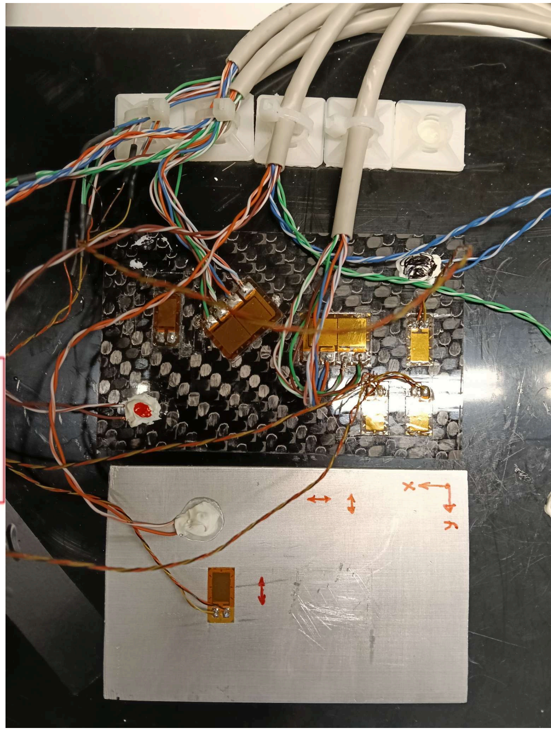


Largest difference on CTE among three small sensors = 0.4 ppm/C

CF corrected with ZeroDur data

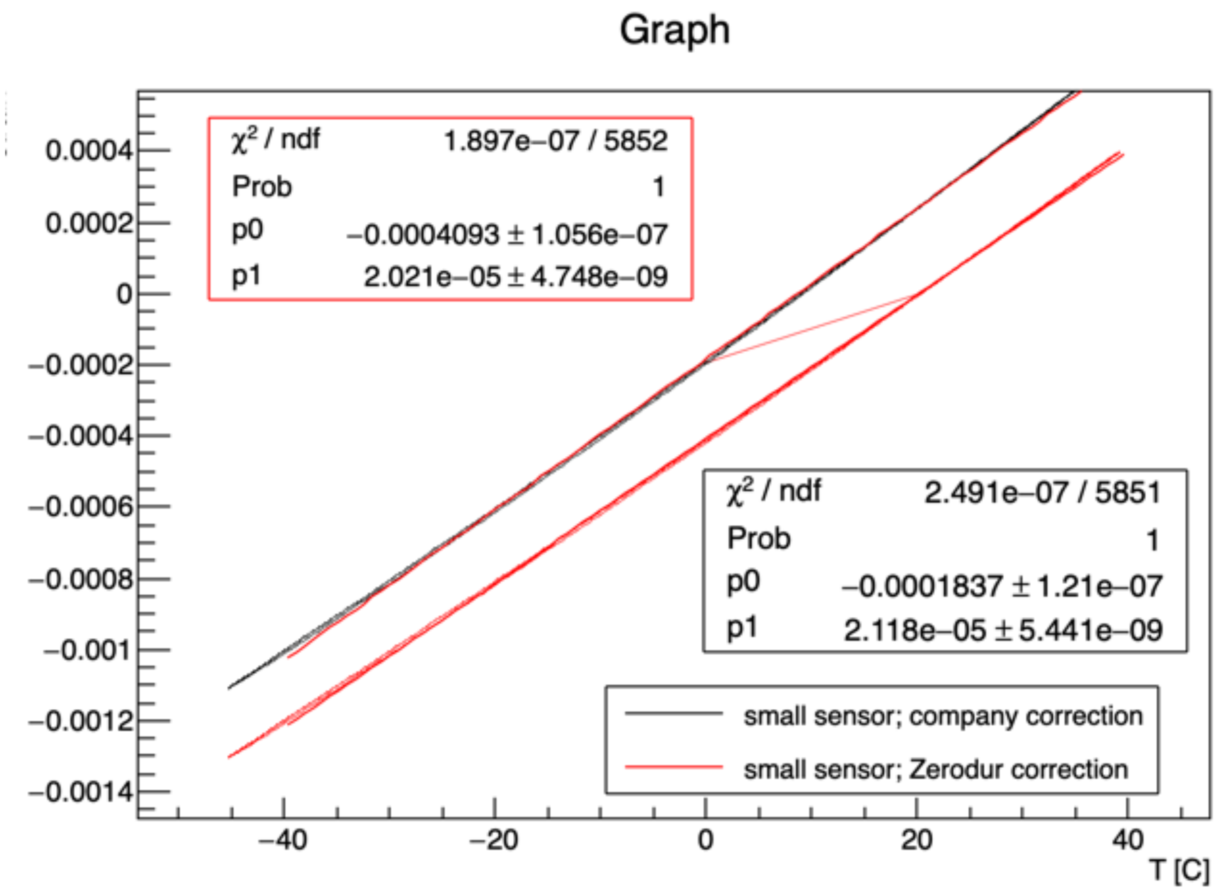




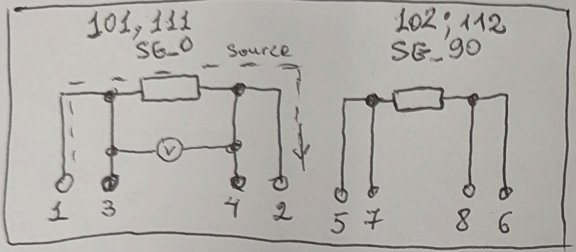


- On Large Sensor better lineary wrt using correction from company
- But larger discrepancy wrt RS (2.1 ppm/C)
- Still discrepancy between large and small sensors

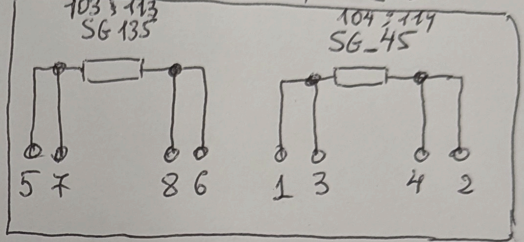
Aluminium, corrected with ZeroDur data



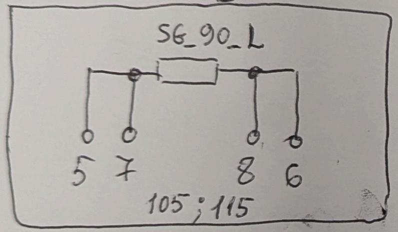
SG_0; SG_90



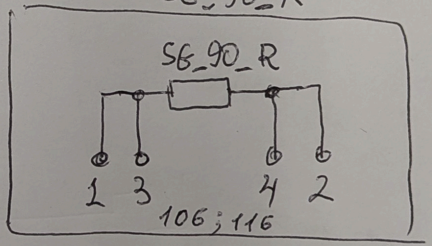
SG_135; SG_45



SG_90_L



SG_90_R



NTCs

107, 108, (10k) calibrated

109, 110, (10k) no calibrated.