EXPERIENCE FROM KEK

Norihito Ohuchi

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Thermal calculation for ILC
Pressure distribution along helium gas return pipe
(Effect of pressure distribution on temperature profile along the accelerator)

Condition of the calculation

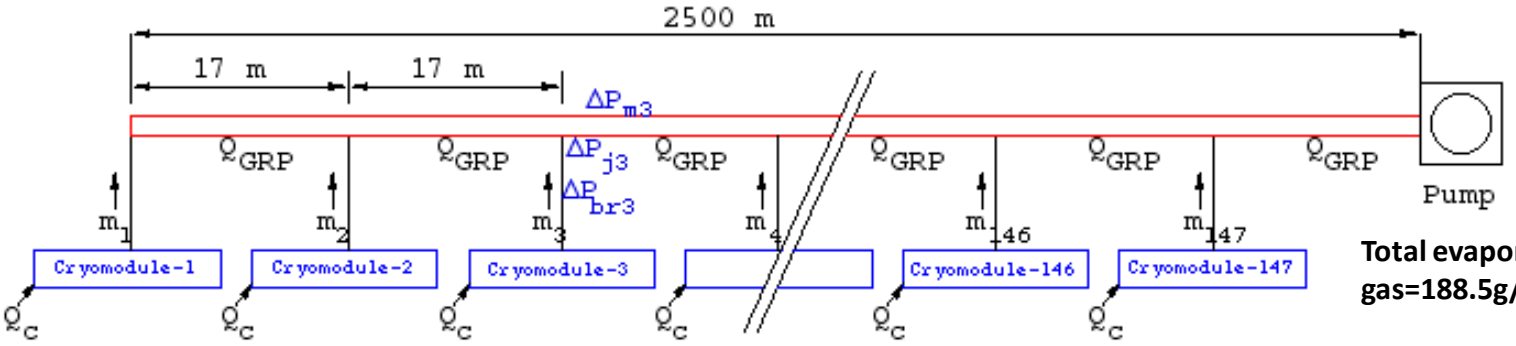
- Inner diameter of helium gas return pipe = 300 mm.
- Cryomodules locate every 17m along the accelerator of 2.5 km. Total number of cryomodules is 147.
- Heat load of one cryomodule is assumed to be 10W or 30W.

Equation of pressure drop

$$\Delta P = 4 f \times (G^2/2\rho) \times (L/D)$$

f : friction factor, G:mass flow rate(kg/m^2/s),
ρ : density (kg/m^3), L:pipe length (m),
D : inner diameter (m), ΔP: pressure drop(Pa)

P=3.129kPa



Total evaporated gas=188.5g/s

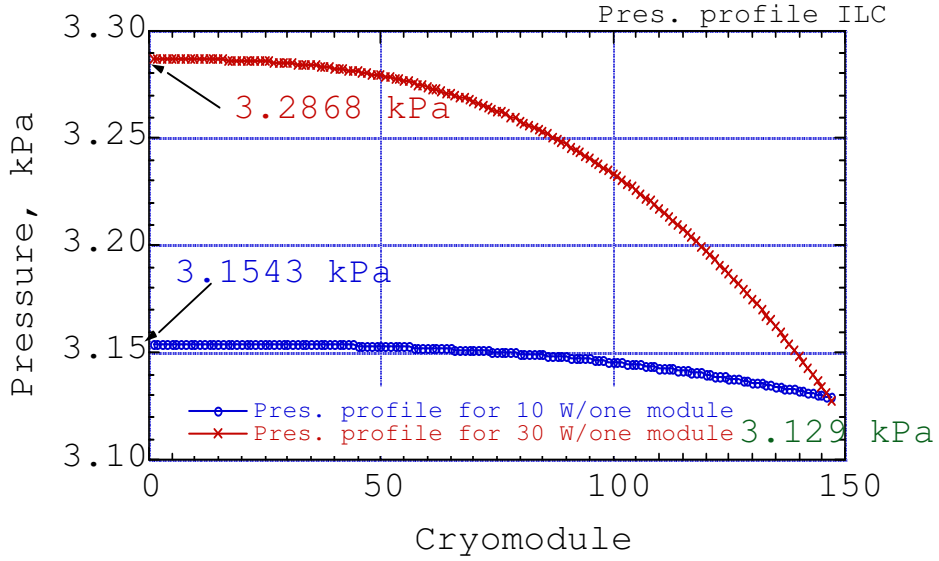
Calculation model of pressure profile by evaporated gas

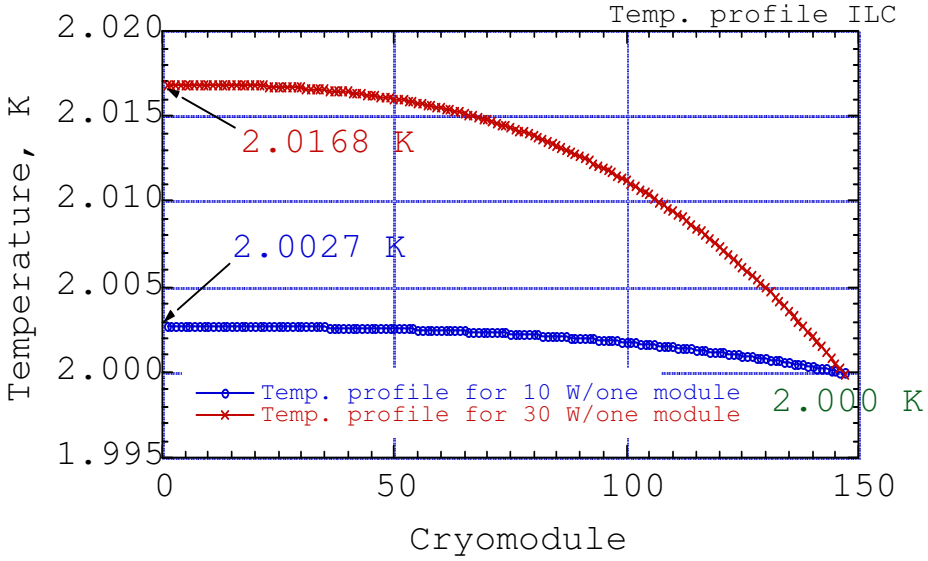
Heat load of one module : Q_c=10W or 30W

Evaporated gas : m= 0.43 g/s for 10W or 1.28g/s for 30W

Pressure distribution along helium gas return pipe

(Effect of pressure distribution on temperature profile along the accelerator)





- Pressure drop along the 2.5 km GRP = 25 Pa for 10 W, 158 Pa for 30W
- Temperature difference along the 2.5 km GRP = 3 mK for 10 W, 17 mK for 30W

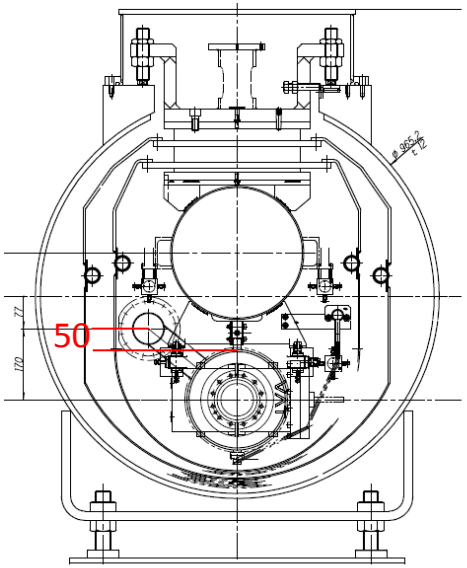
(The present design heat load = 11.4 W)

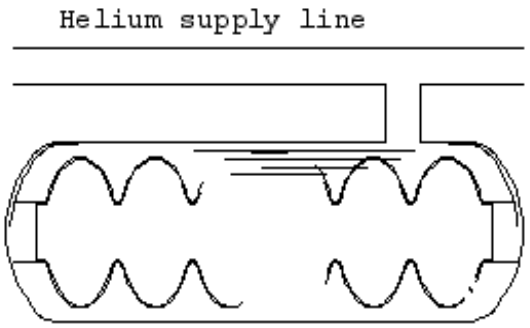
Temperature profile in the cavity helium vessel

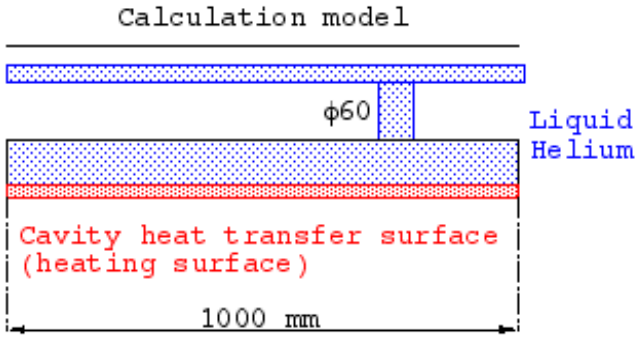
Calculation of the temperature profile in the liquid helium with heat load.

- Heat load: 30W for four cavities (ILC design = ~12W for 9 cavities)
- Heating surface is the cavity surface, and the shape of 9 cells is assumed to be cylinder for simplification.
  - Pipe diameter between LHe supply line and cavity jacket = 60 mm
  - Cavity jacket length = 1000 mm
  - Distance between cavity heating surface and jacket inner surface = 6 mm
- Thermal calculation is performed with the two fluid model of super-fluid component and normal-fluid component (with viscosity and entropy).

Calculation model





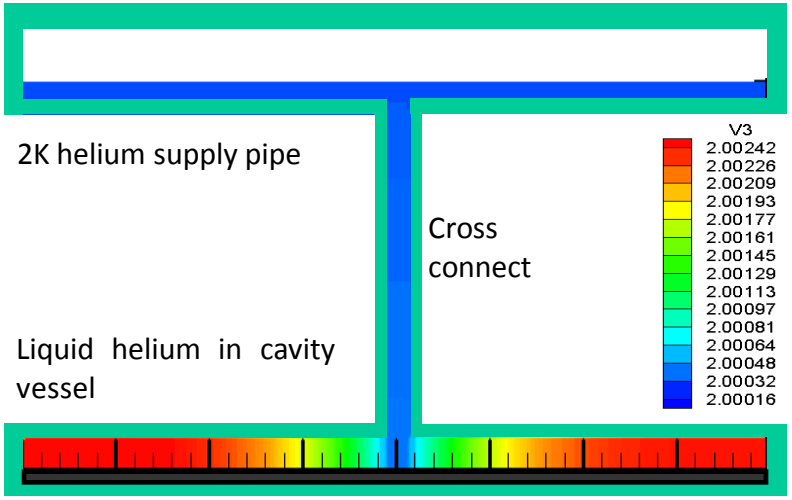


Cavity vessel and 2K helium supply pipe

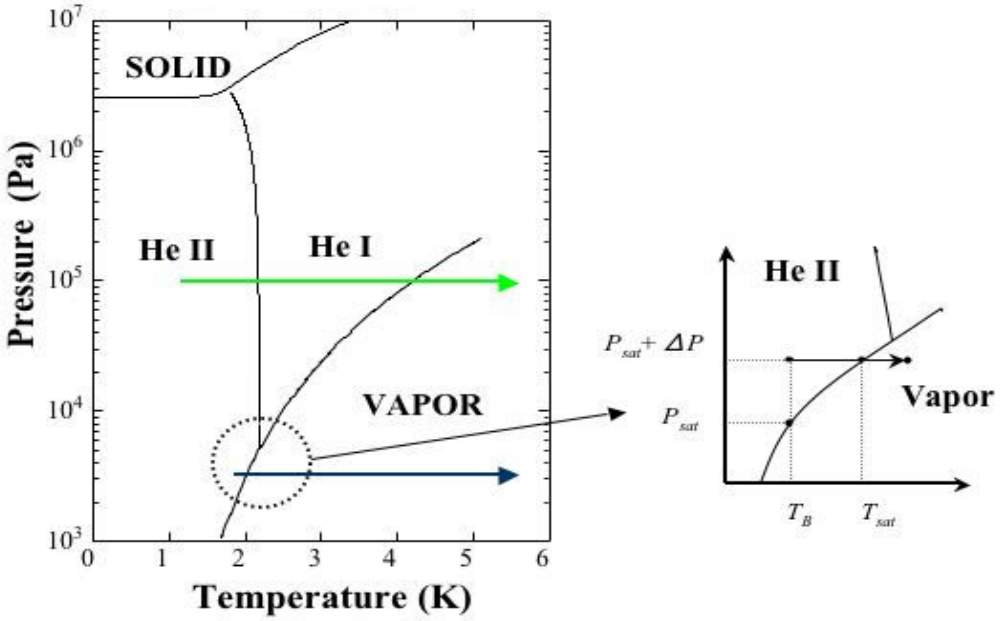
Temperature profile in the cavity helium vessel

Calculation results

- There exists temperature profile which shows the turbulent condition in the superfluid helium.
  - At the both ends, T= 2.0024 K, and at the liquid surface, T= 2.000 K.
- The temperature gradient is induced in the sub-cooled condition by the hydraulic head pressure from the liquid surface to the heating area.
- Smaller the evaporation area leads to higher temperature of the balk helium, and to smaller sub-cooled condition.
  - Easy to happen a vapor film on the heating surface and decrease of cooling efficiency.



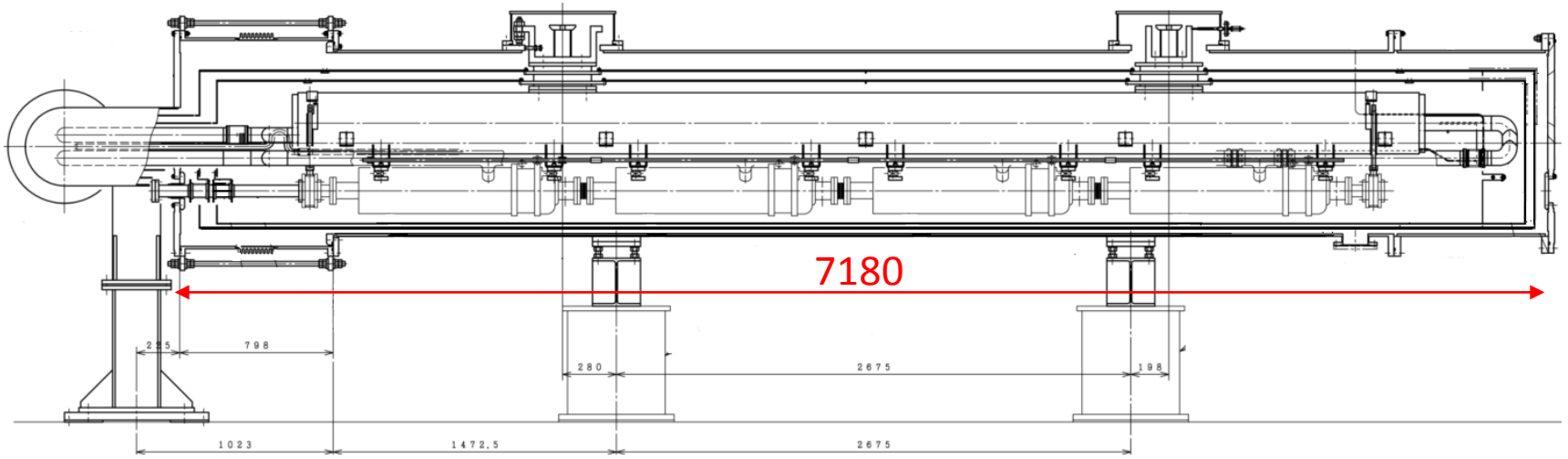
P-T diagram of He



$\sigma g \Delta h = 145.6 \times 9.8 \times 0.05 = 65.5 Pa$

$\Delta T = 0.0074 K$

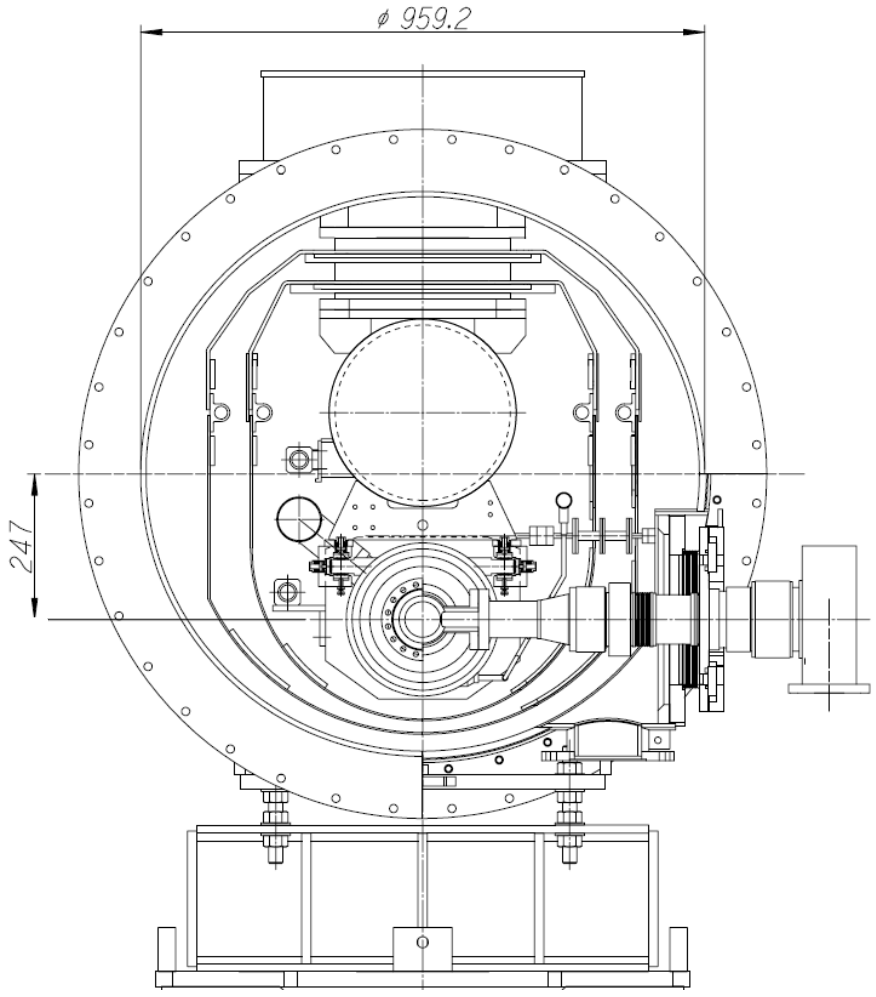
KEK-STF Cryomodule



The cold test of STF cryomodule was p reformed from May to December 2008.

The cold test of STF cryostat with dummy cavity jackets was preformed in April and May 2009 in order to measure the GRP deformation by thermal cycle.

KEK-STF Cryomodule



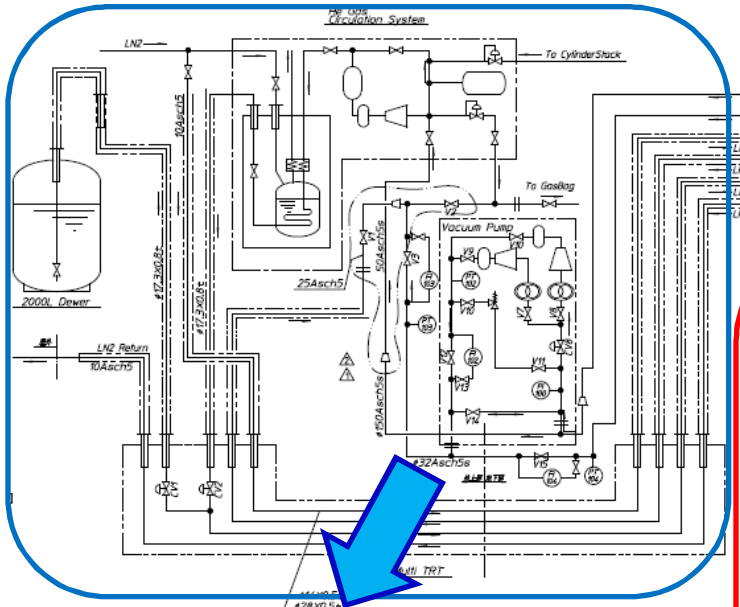
Cross section of KEK-STF cryomodule

Design: based on DESY TTF-III

Cavity type : TESLA-like cavity
Number of cavities in module = 4
Length of vac. vessel = 7180 mm
Outer Dia. of vac. vessel = 965.2mm
Length of He gas return pipe = 5830 mm
Inner Dia. of gas return pipe = 298 mm
Cold Mass
- 4 cavities = 410 kg
- 4 dummy cavity vessels = 94 kg
- He gas return pipe = 515 kg
- 2K helium supply pipe = 50 kg
- 5K thermal radiation shield = 190 kg
- 80K thermal radiation shield = 220 kg

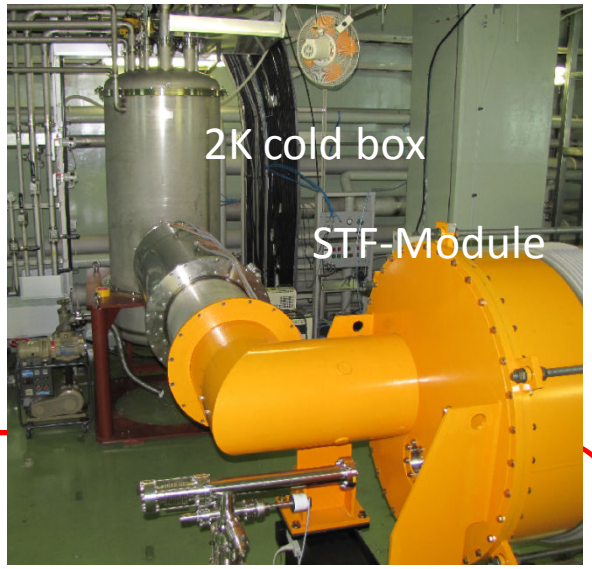
STF cryomodule cooling diagram

1. Refrigerator system: 600 W @4.4K
2. 2000 L liquid helium Dewar
3. Helium gas at 80 K cycling system for cool-down
   - Mass flow rate of helium gas at 80 K = 1 g/s



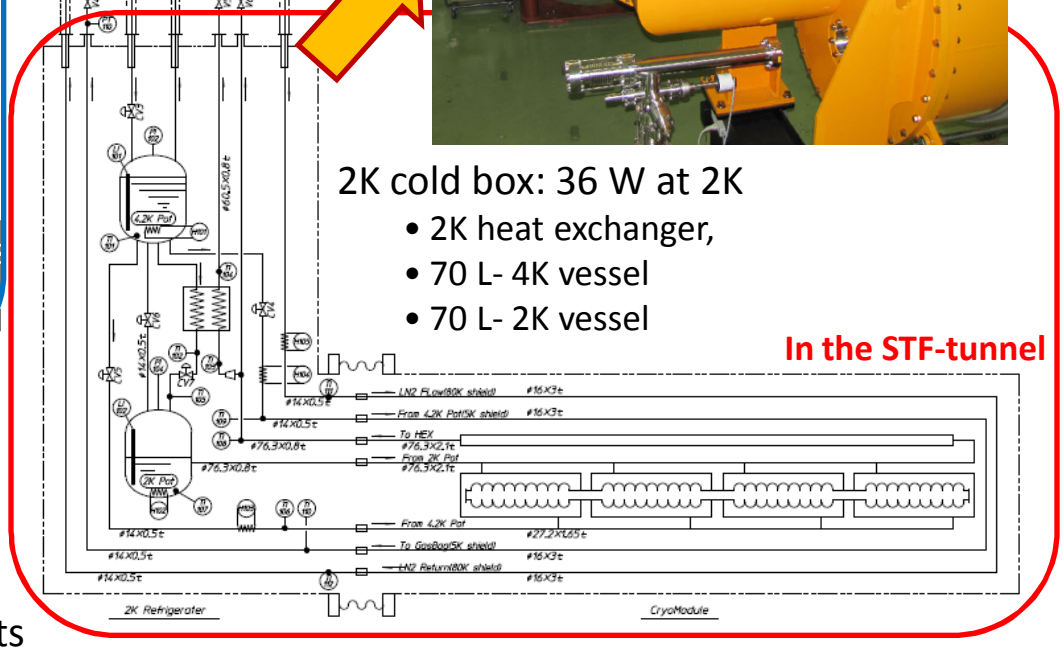
Tag No.

801	TI102
802	TI105
803	TI106
804	TI108
805	TI109
806	TI110



2K cold box: 36 W at 2K
- 2K heat exchanger,
- 70 L- 4K vessel
- 70 L- 2K vessel

In the STF-tunnel

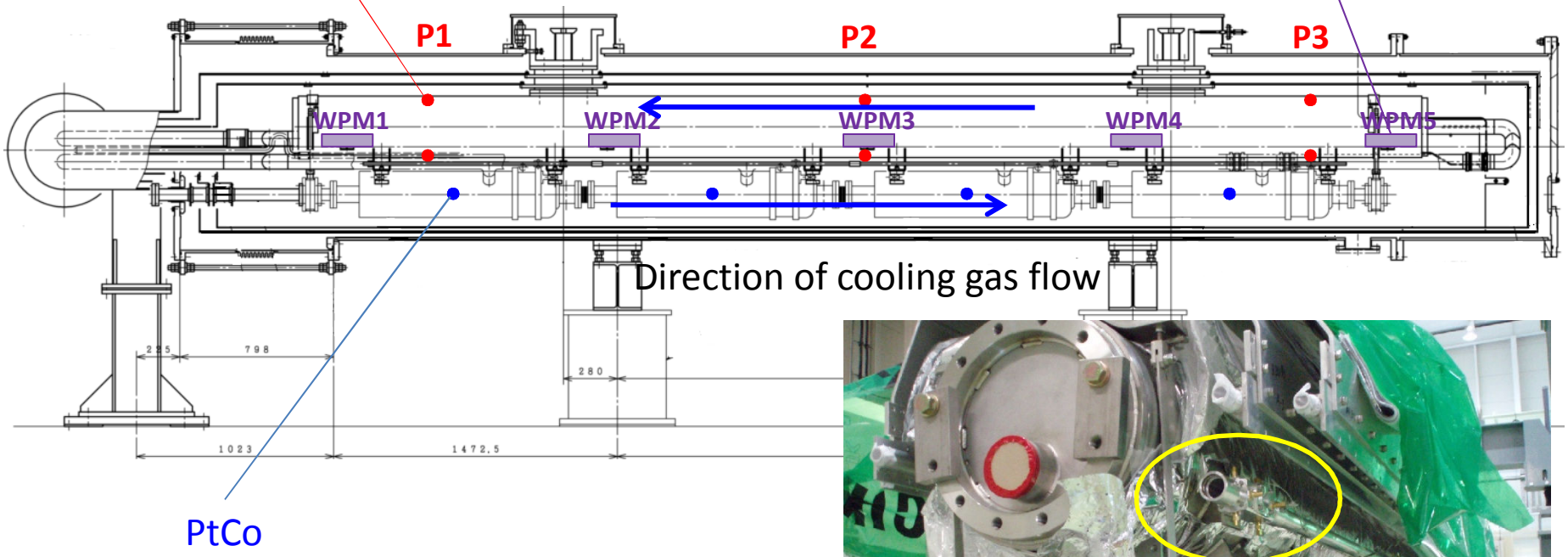


4 Pumping units
- 4 (rotary pump + mechanical booster pump)
- Pumping capacity = 1300m^3/h@3kPa

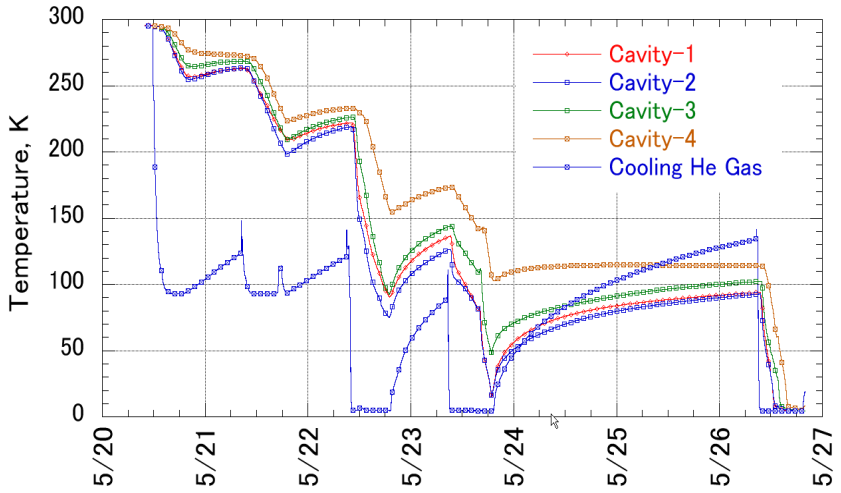
Temperature sensors and WPMs on GRP

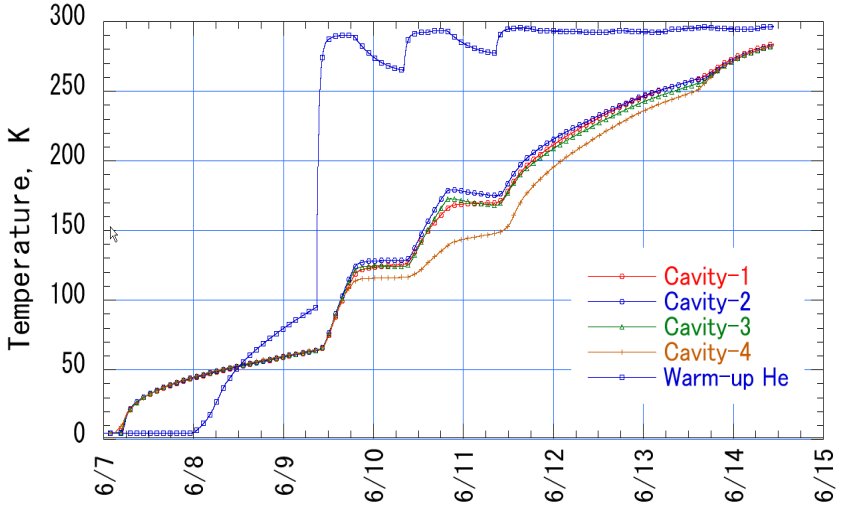
Cernox and Cu-Constantan TC
(top and bottom of pipe)

5 Wire Position Monitors



Cooldown of STF cryomodule 4 cavities





Thermal cycle of STF Cryomodule with four cavities

1. Cool-down of 4 cavities (R.T. → 200K)

   Cooling method : Circulation of 90 K He gas

   Mass flow rate= 1.0 g/s

   Cooldown speed = 7.3 K/h

2. Cool-down of 4 cavities (200 K → 4 K)

   Cooling method : 4.2K LHe

   Total amount of LHe for cooling = 1630 L

   Cooldown speed = 12.5 K/h

   From room temp. to 4K, total cooling time=49 H

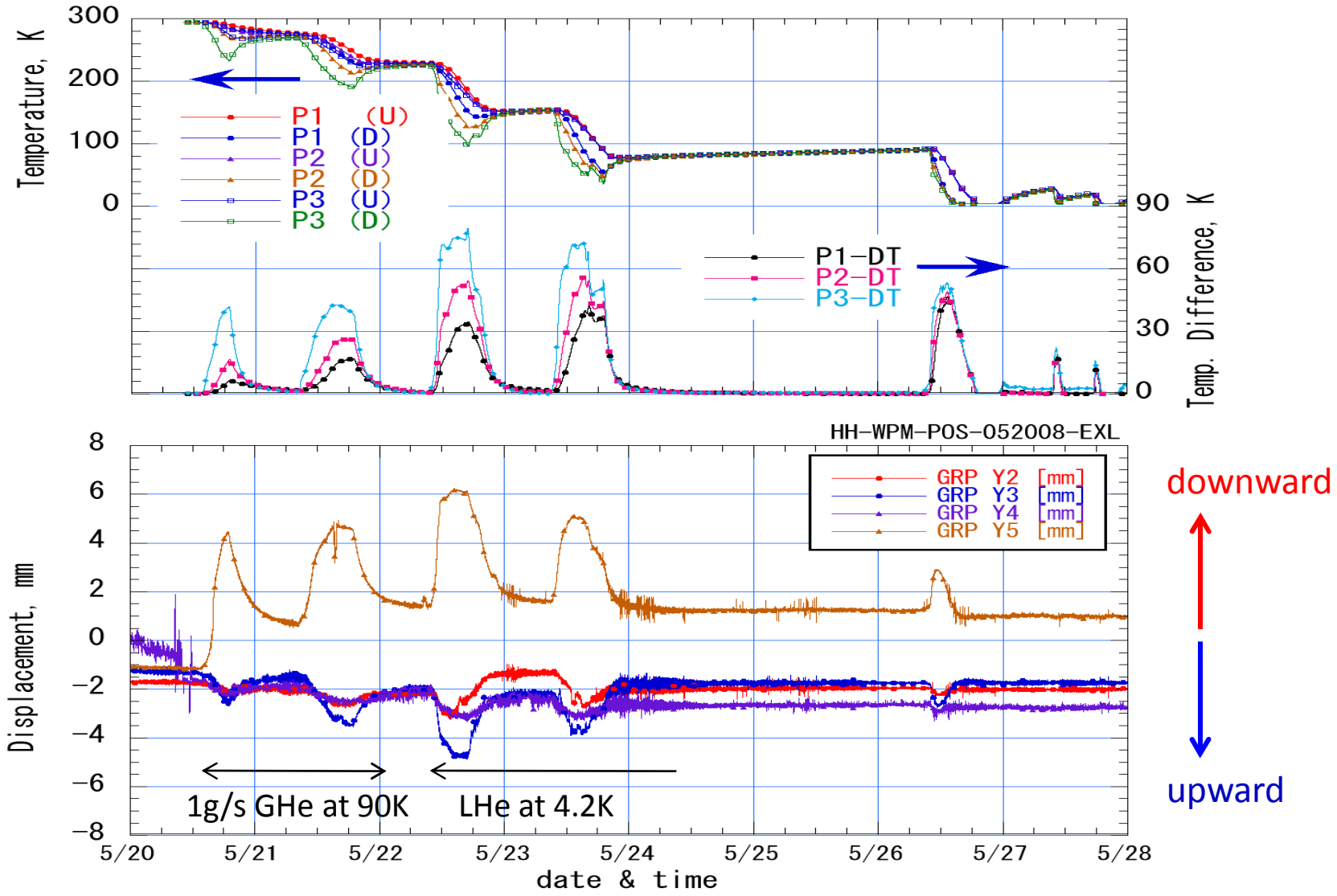
3. Warmup

   2 K → 60 K : heat load from room temperature.

   60 K → 180 K : Circulation of helium gas at 300 K and 1.0 g/s.

   180K → 300 K : Nitrogen gas at 300 K and 9 g/s.

GRP deformation during cool-down

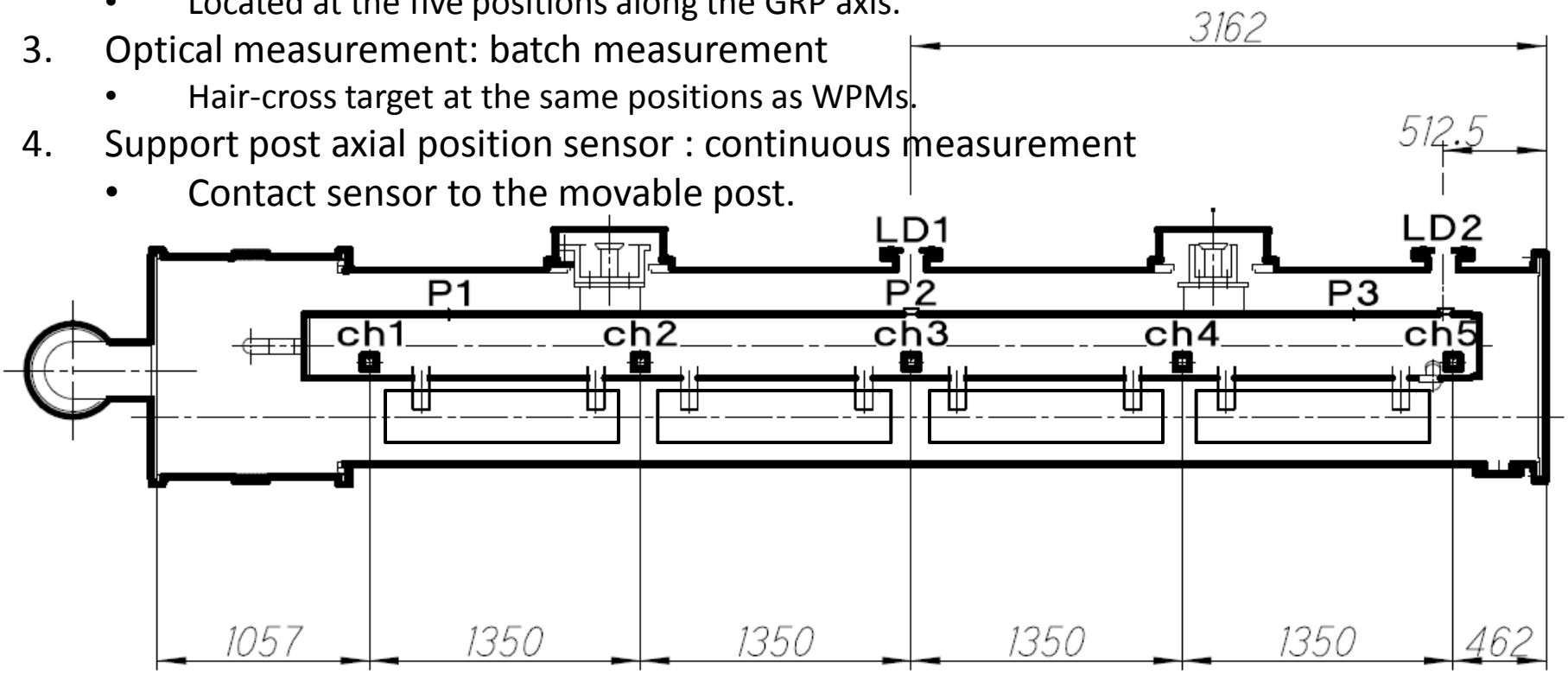


Measurement of GRP deformation

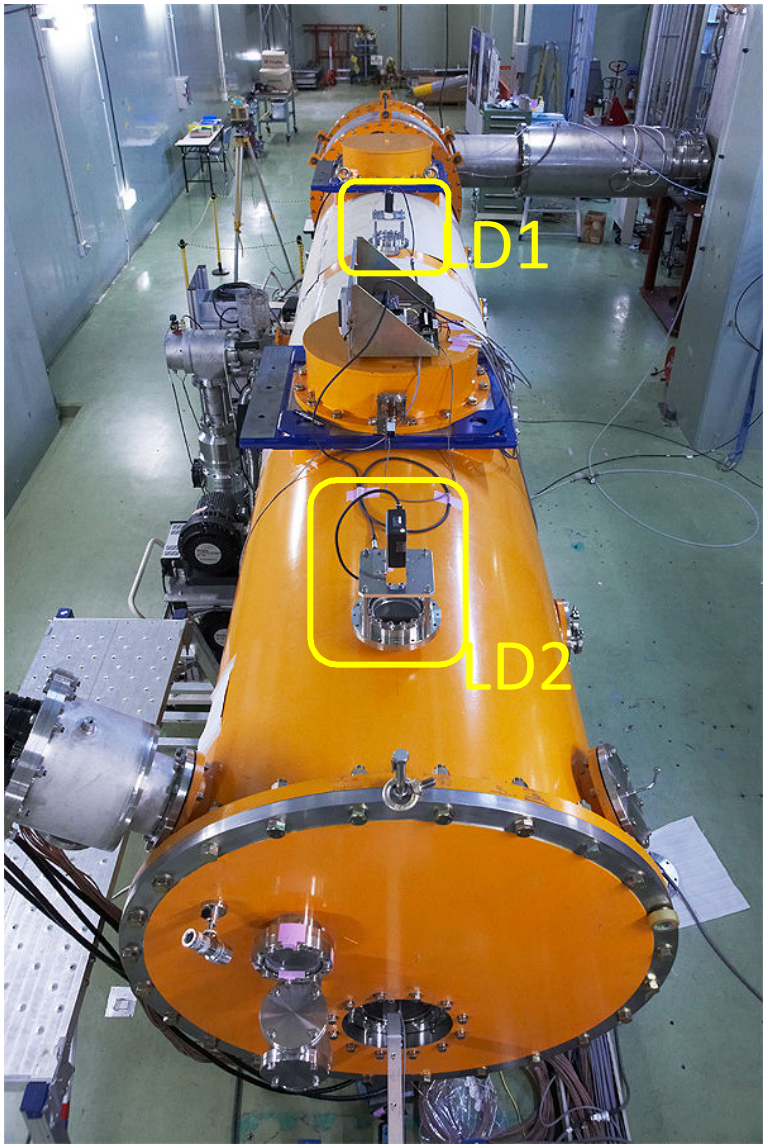
by cryostat with dummy cavity vessels

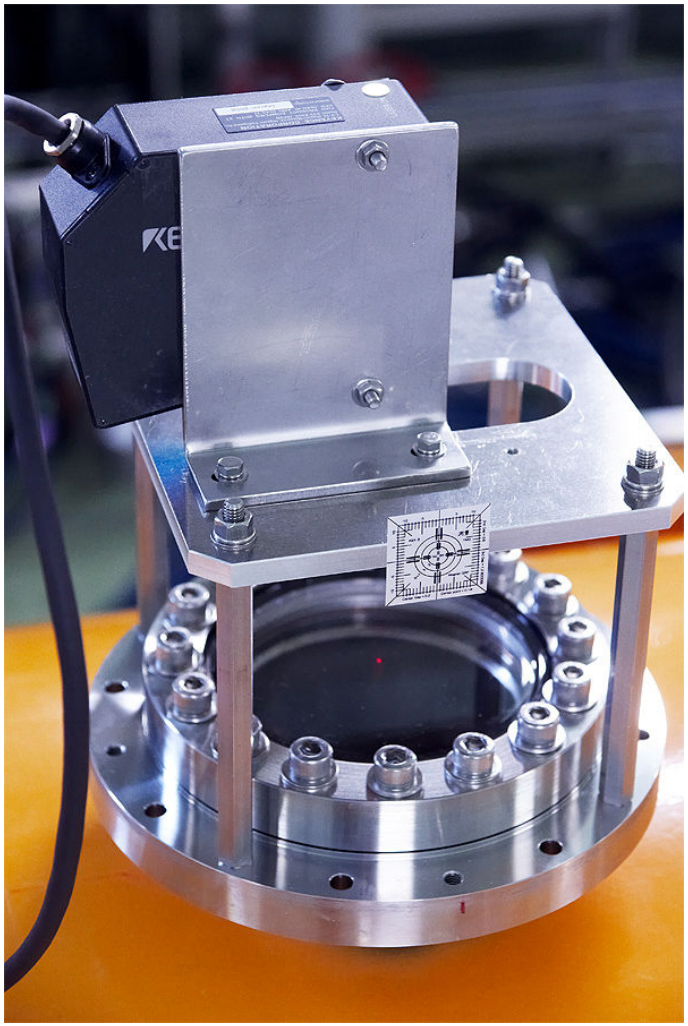
Sensors and measurement set-up

1. Laser distance meter (LD): continuous measurement
   - Located at the center and the end of cryostat to measure the distance between the GRP and vacuum vessel.
2. WPM: continuous measurement
   - Located at the five positions along the GRP axis.
3. Optical measurement: batch measurement
   - Hair-cross target at the same positions as WPMs.
4. Support post axial position sensor : continuous measurement
   - Contact sensor to the movable post.



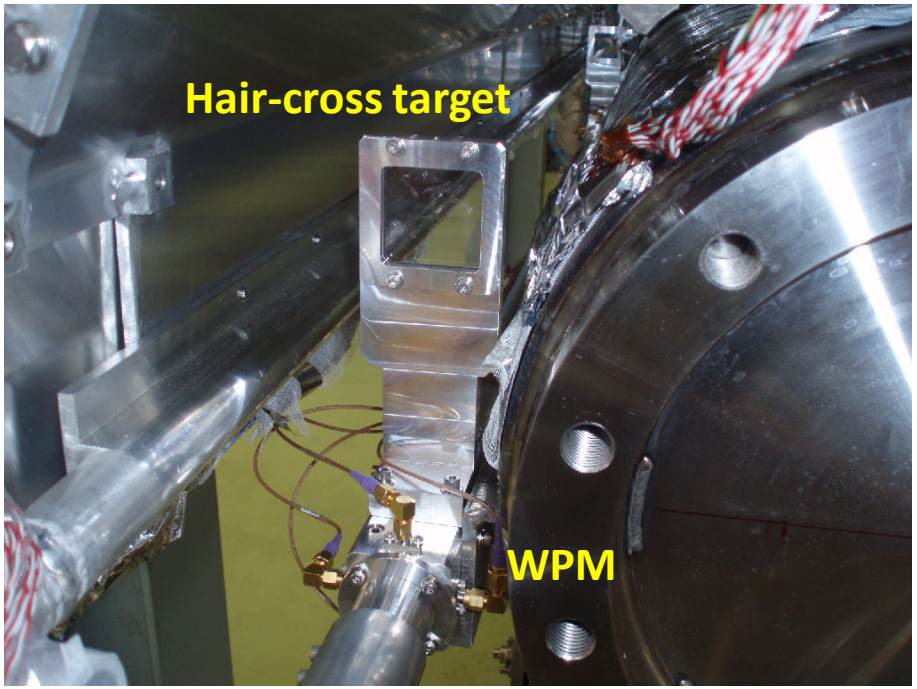
Laser distance meter



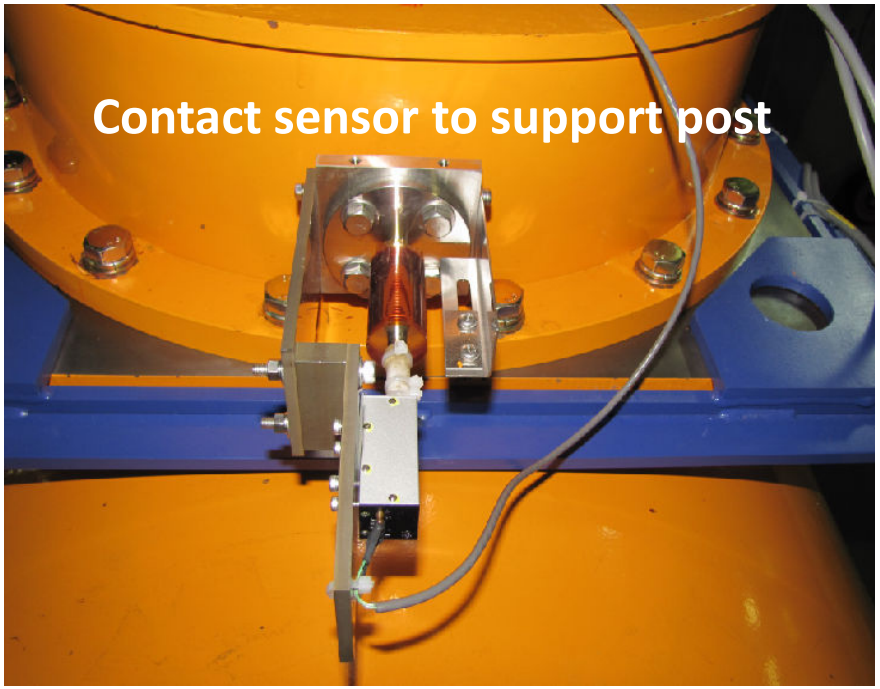


Optical window for laser on the cryostat

Hair-cross target and contact sensor



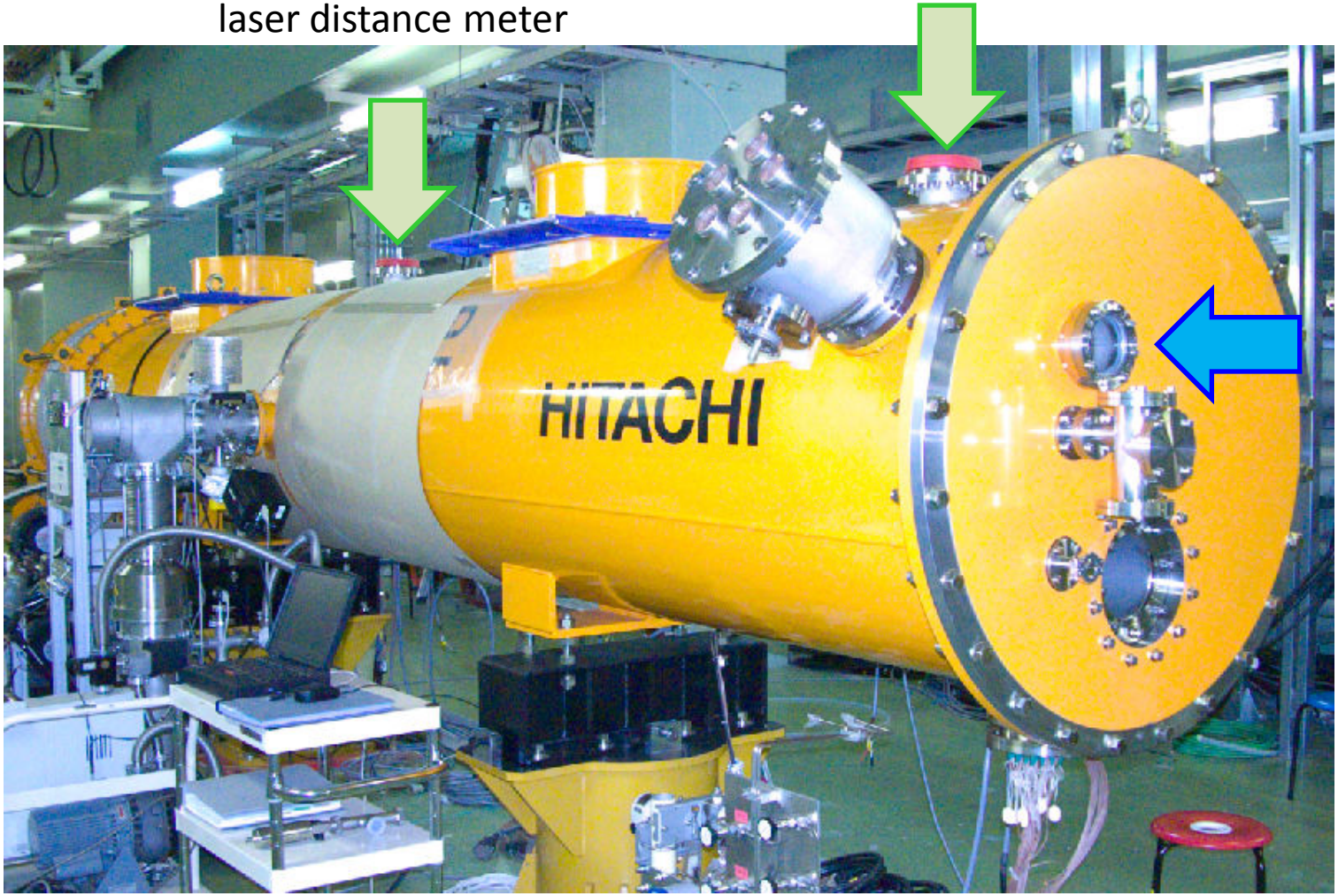
Hair cross targets were mounted on the wire position monitors to measure the transverse movement of GRP optically.



A Contact sensor was attached to the support post from the vacuum cap to measure the axial movement of the support post directly.

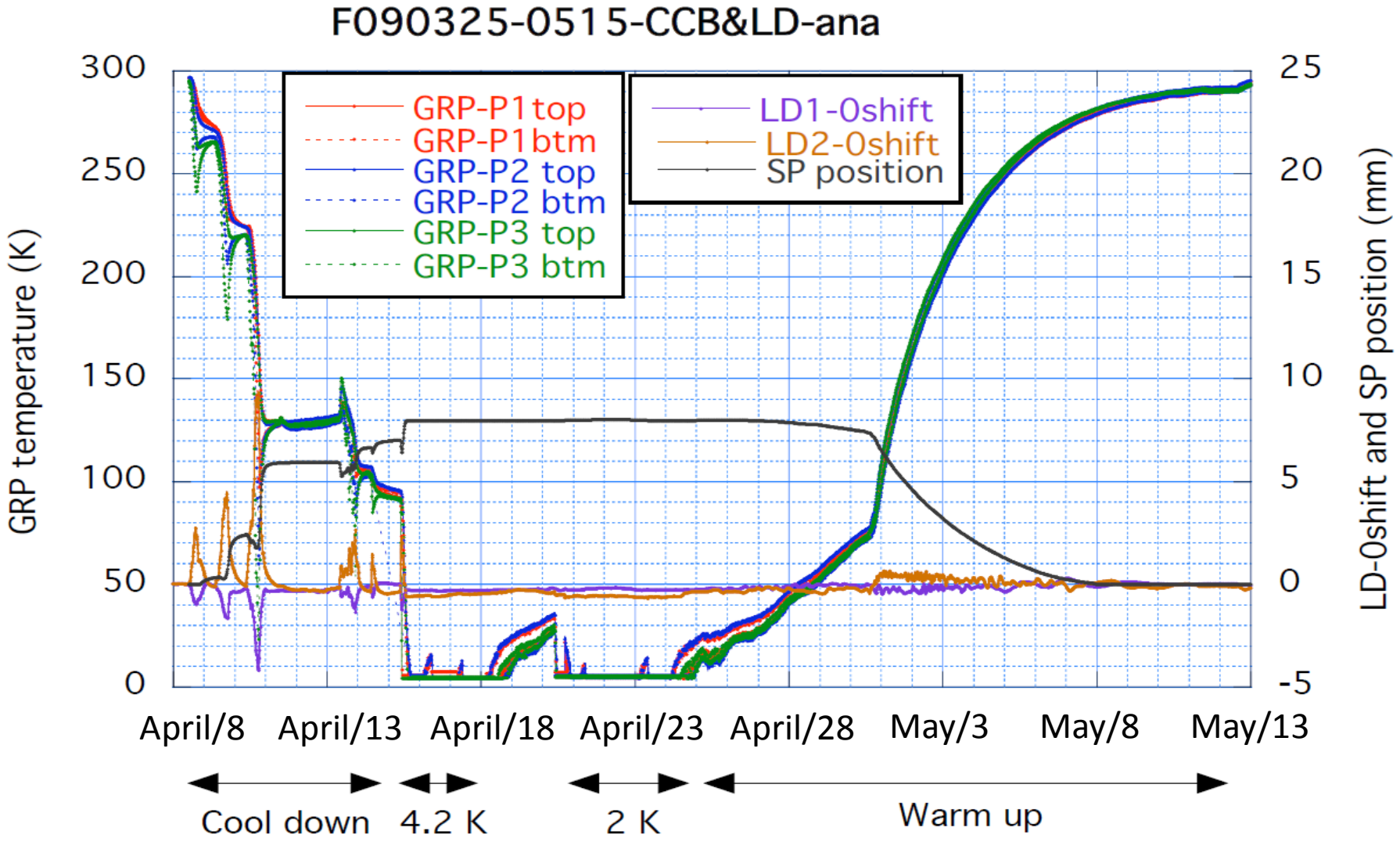
Measured STF cryostat with 4 dummy cavity jackets

Optical window for the laser distance meter

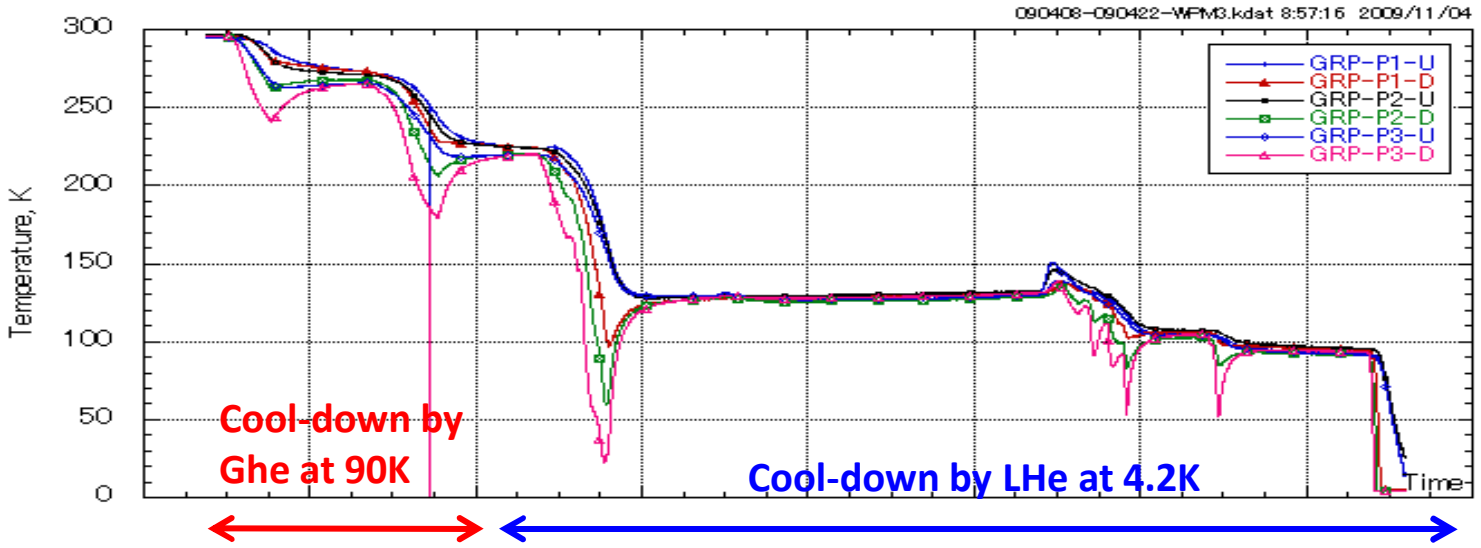


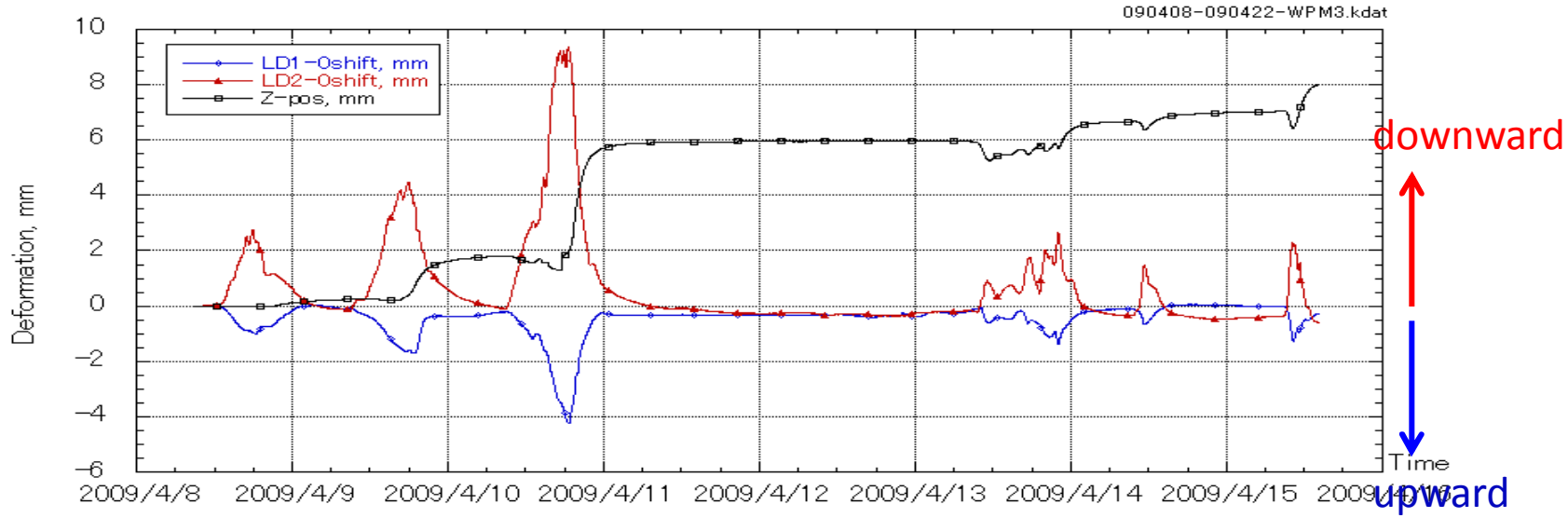
Optical window to see the hair cross targets.

Cool-down/warm-up of GRP

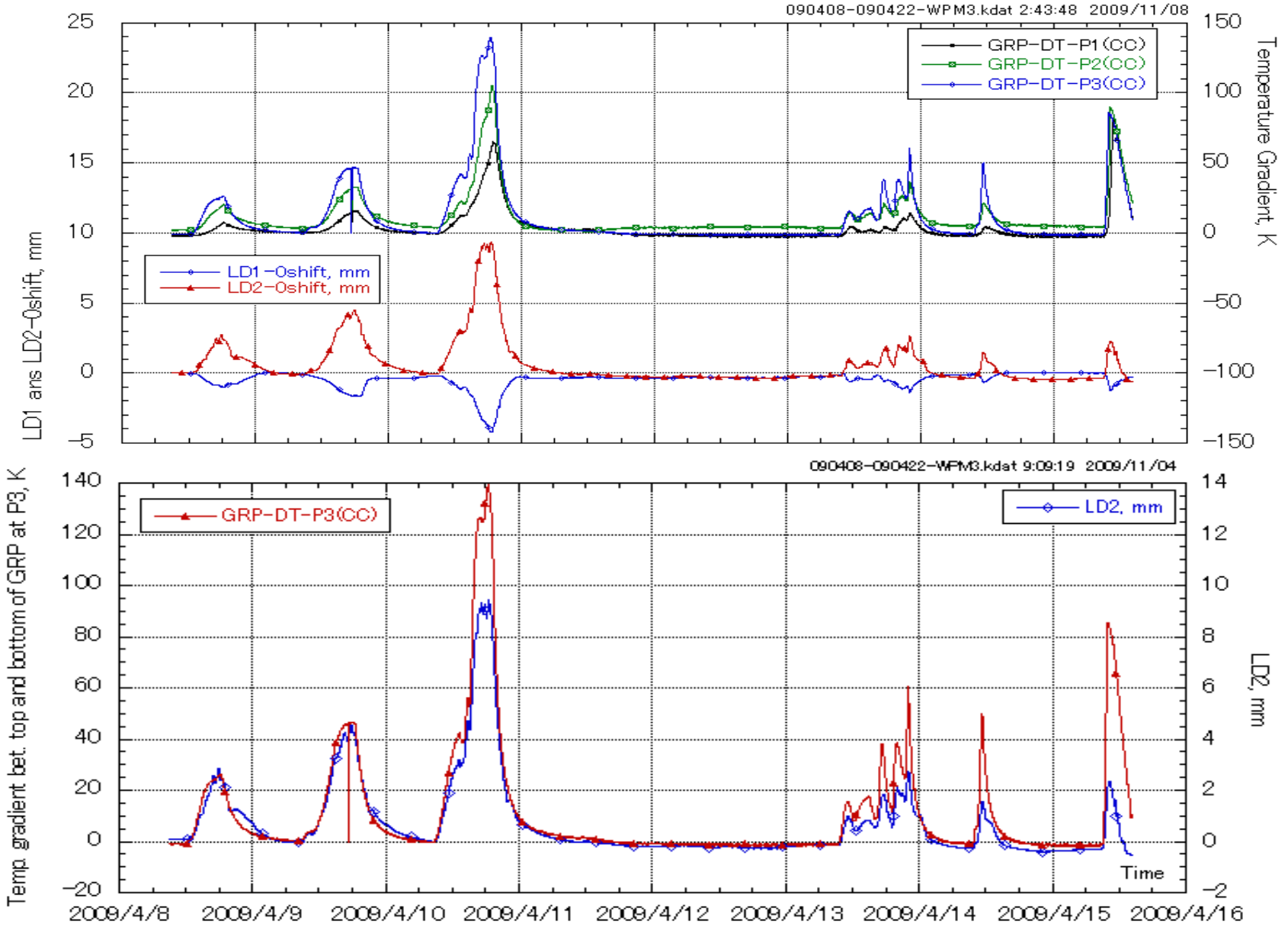


GRP deformation during cool-down

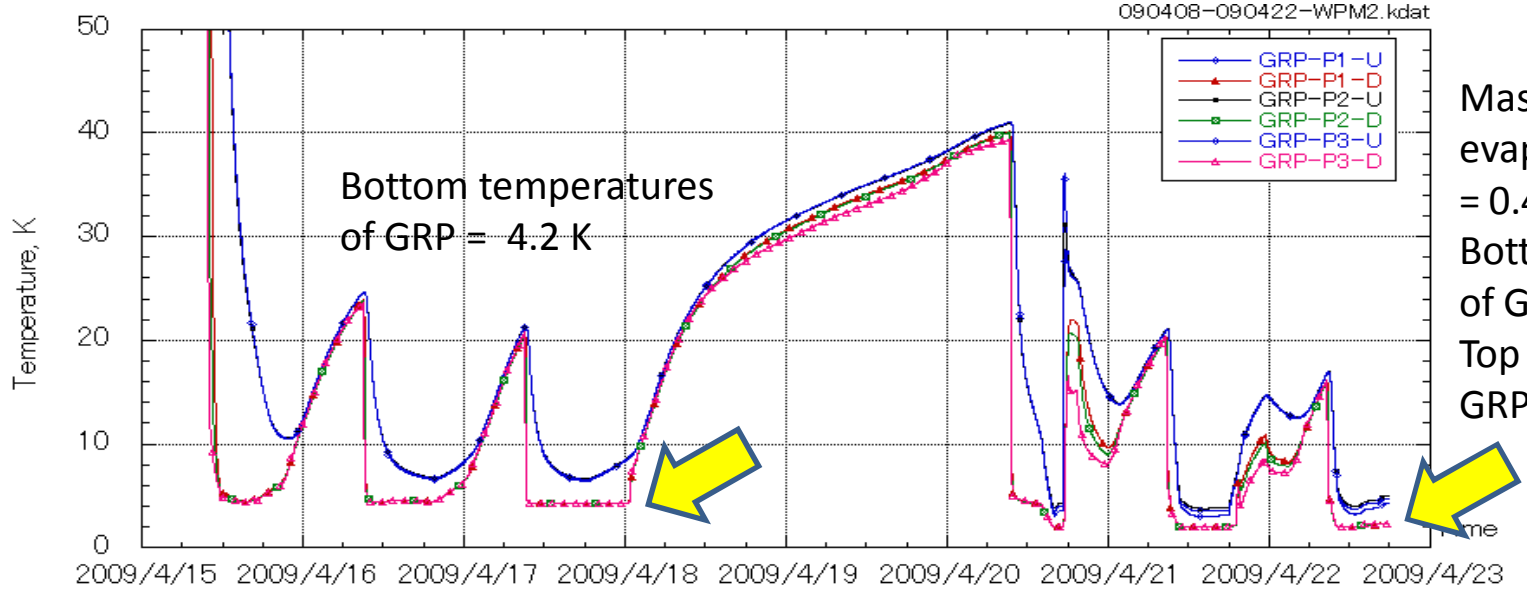




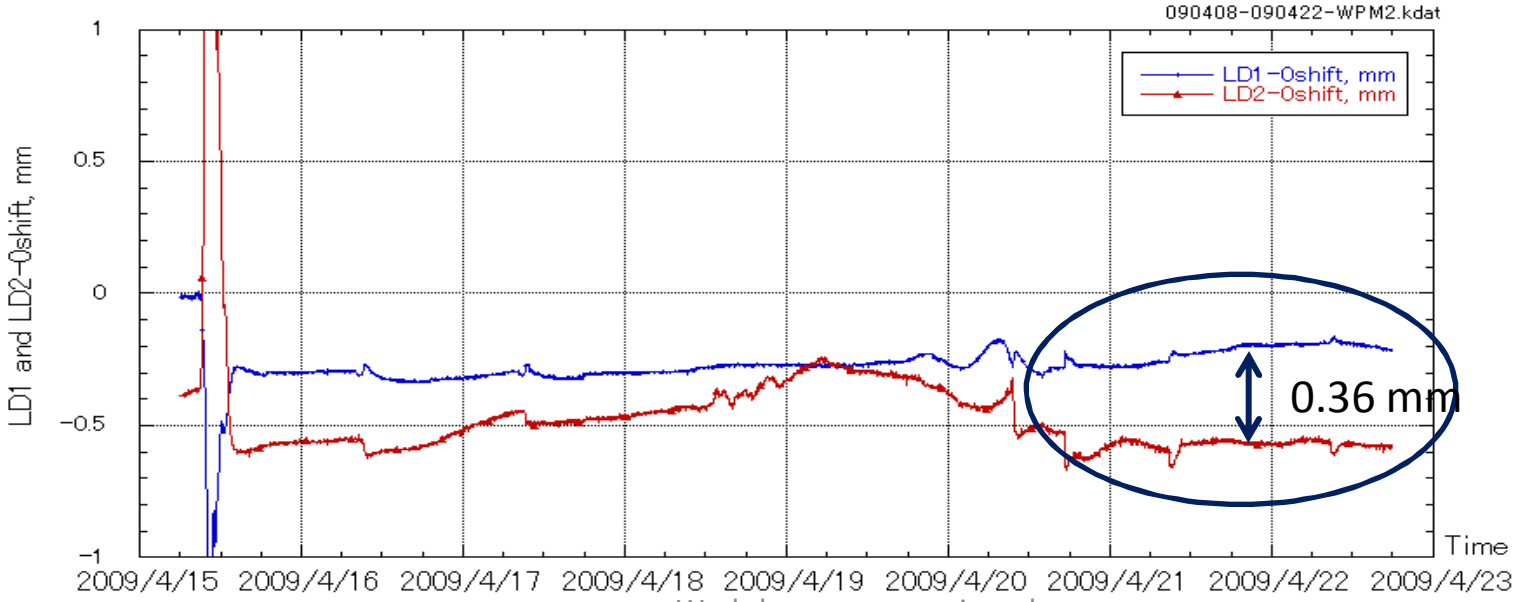
Temperature gradient and position change of GRP



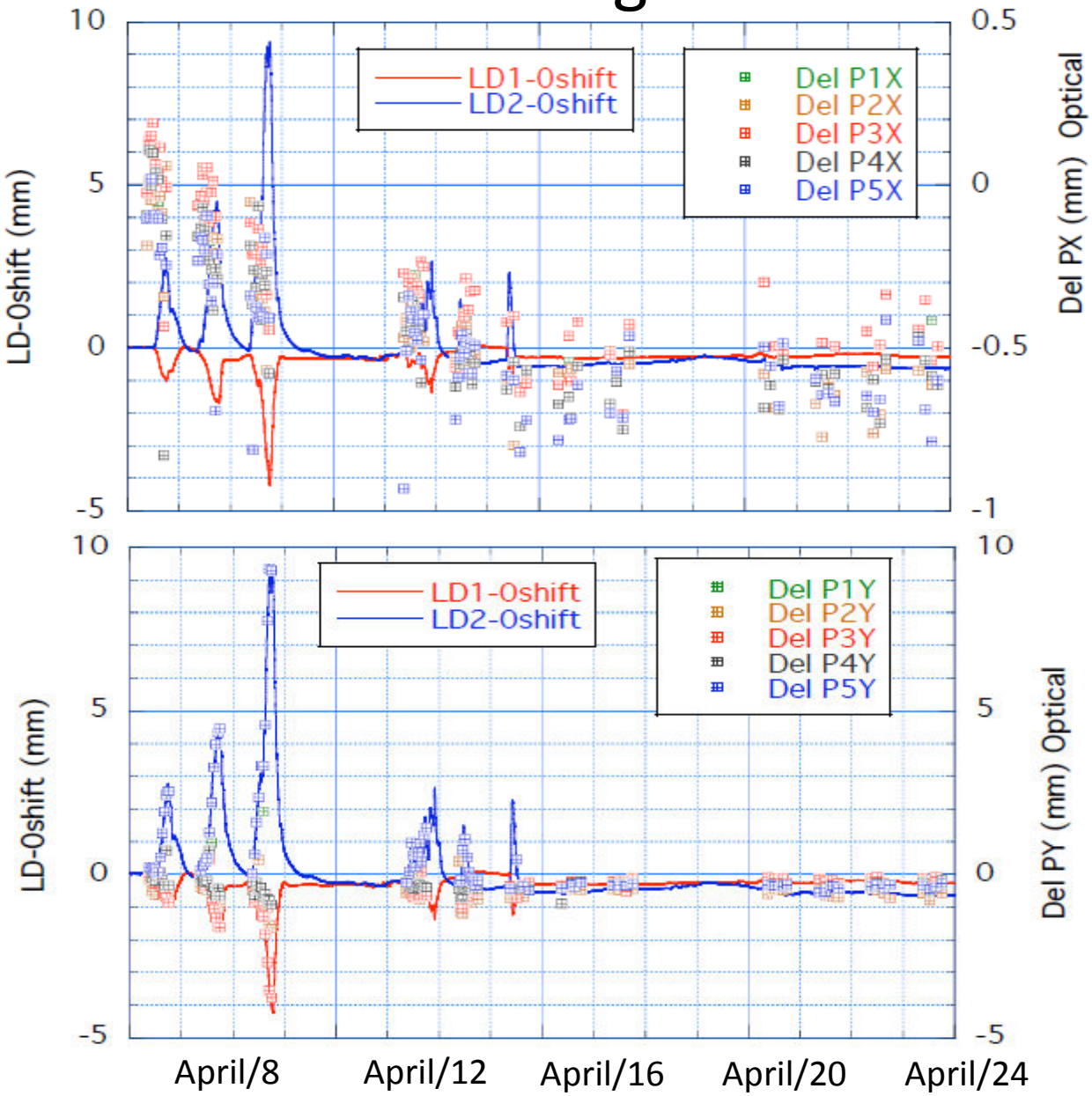
GRP deformation at temperature below 40K



Mass flow rate of evaporated helium gas = 0.4 g/s
Bottom temperatures of GRP = 2.4 K
Top temperatures of GRP = 4.3 ~ 5.0 K



Hair-cross target measurements by scope



Horizontal movements

Measured shift = ~0.5 mm
The observed data shows thermal contraction of the gas return pipe and the WPM base.

Vertical movements

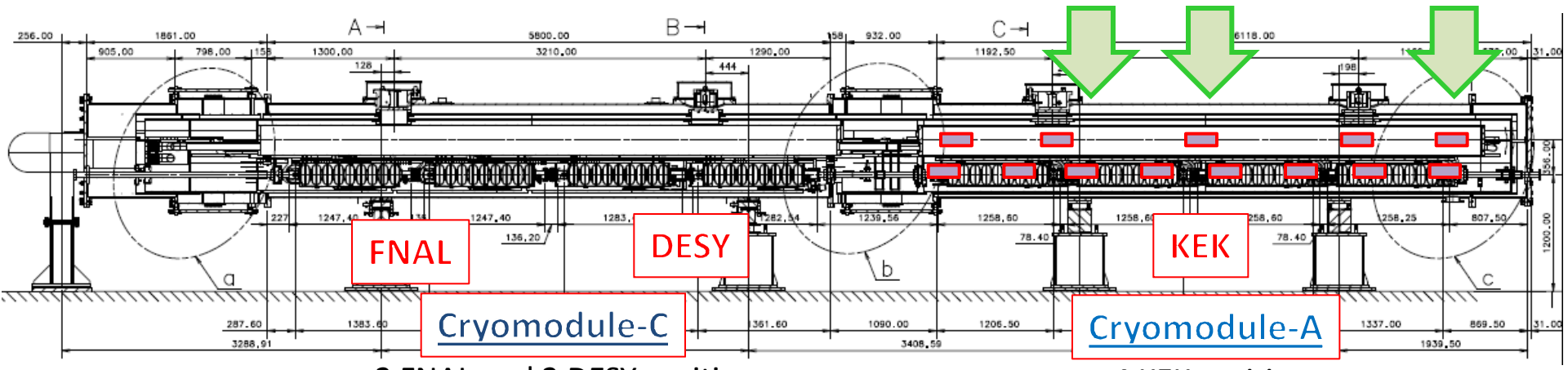
The observed data correctly traced the data measured by the laser distance meter.

Precision of the measurement by scope is ±0.2mm and depends on the personnel.

AS THE NEXT STEP

Measurement of thermal characteristics of cryomodule components in S1-G cryomodule

3 laser distance meters



2 FNAL and 2 DESY cavities

4 KEK cavities

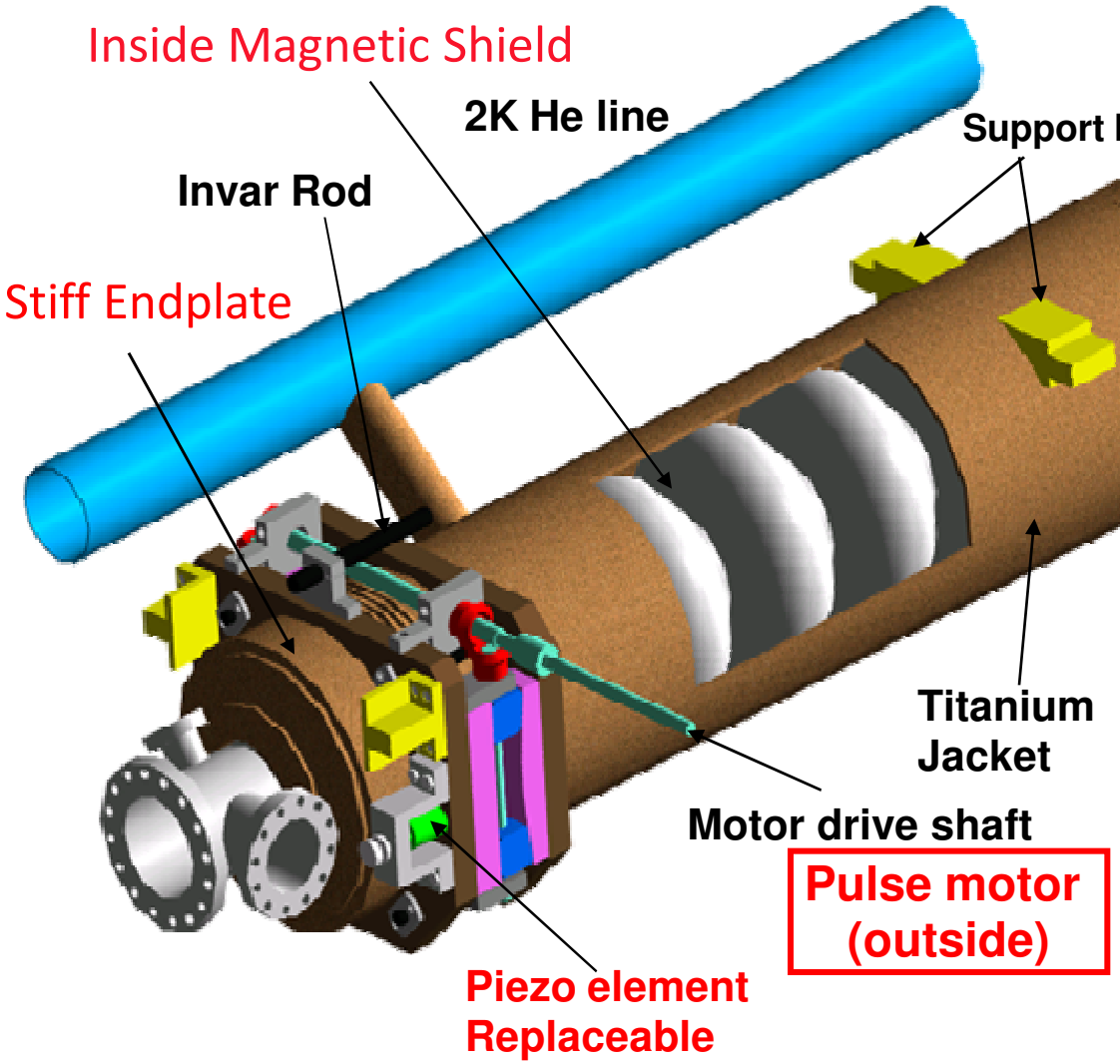
Sensors for S1-G cryomodule
Module-C: 145 sensors
Module-A: 156 sensors

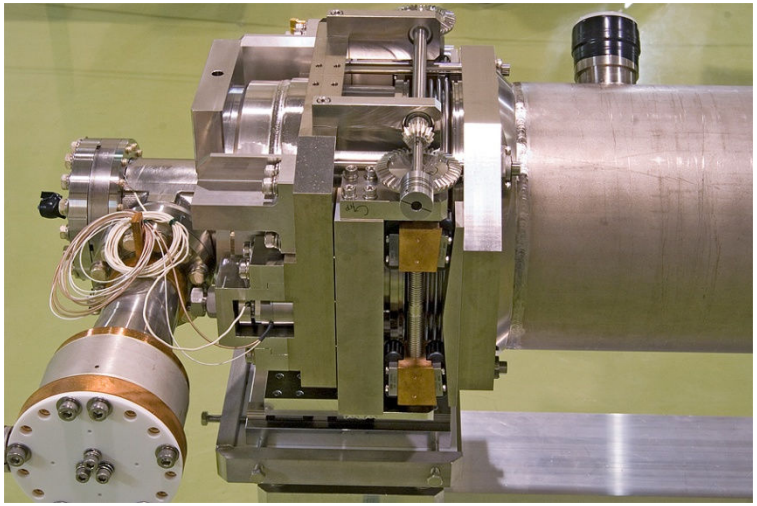
For Cryomodule-A

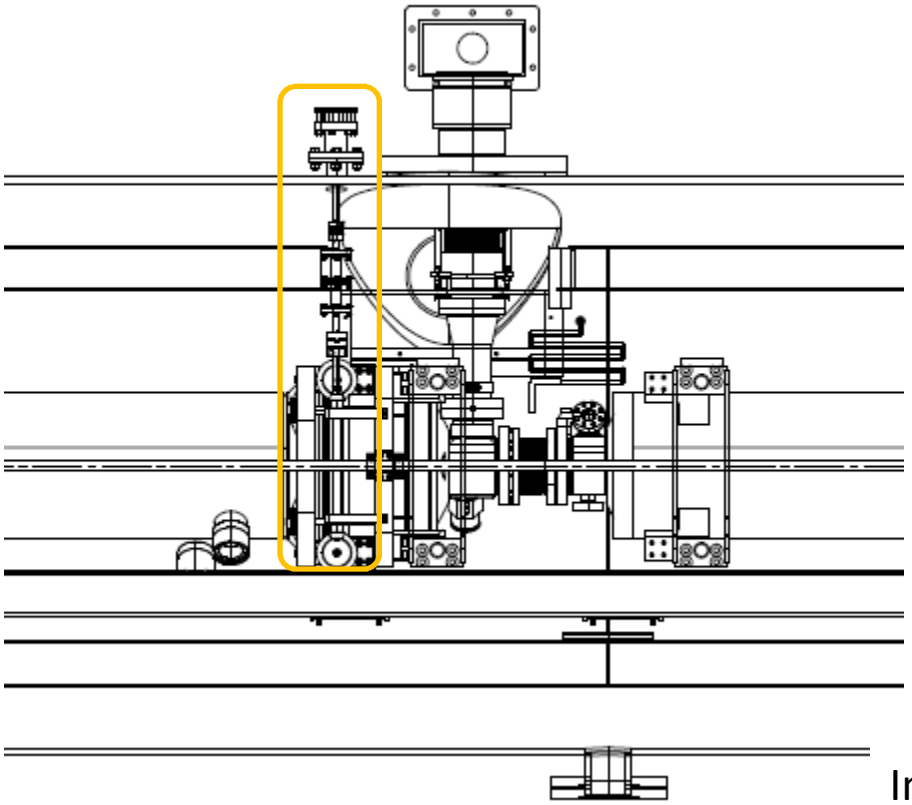
- 5 WPMs on GRP
- 8 WPMs on the four KEK cavities
- 12 strain gauges on GRP
- 6 PtCo and 6 Cernox thermal sensors on GRP

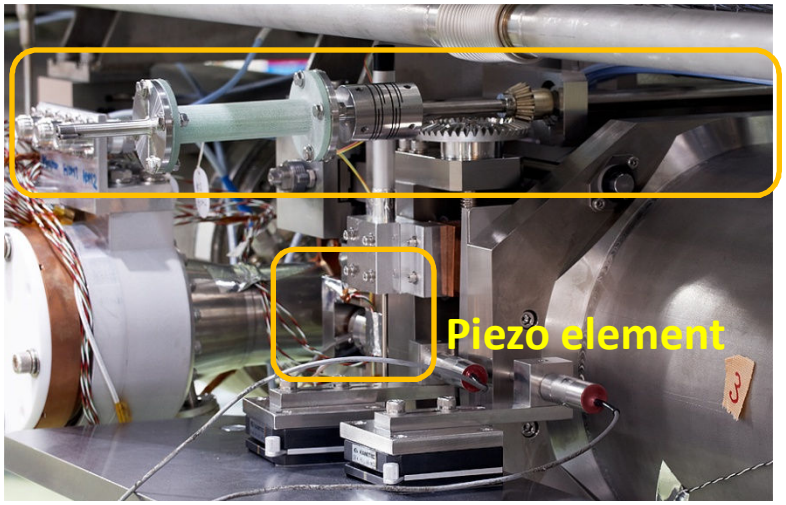
The cold test of S1-G cryomodule will start from June 2010.

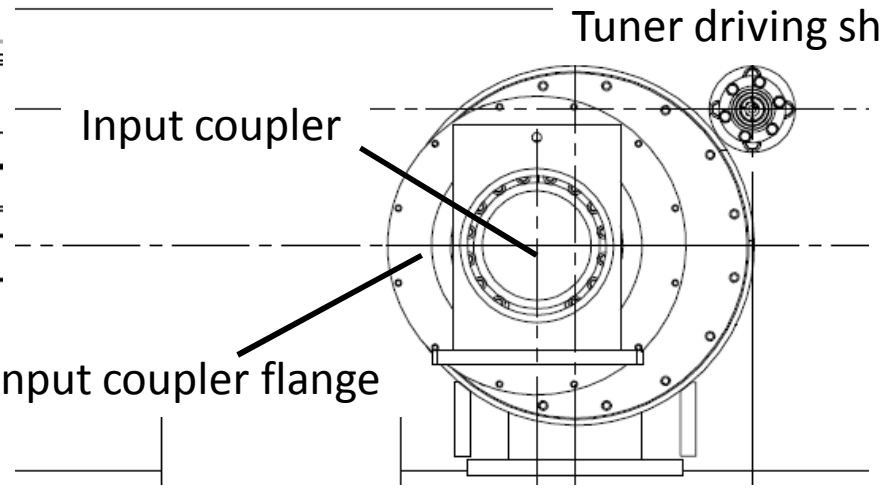
KEK Tuner System : Slide Jack Tuner







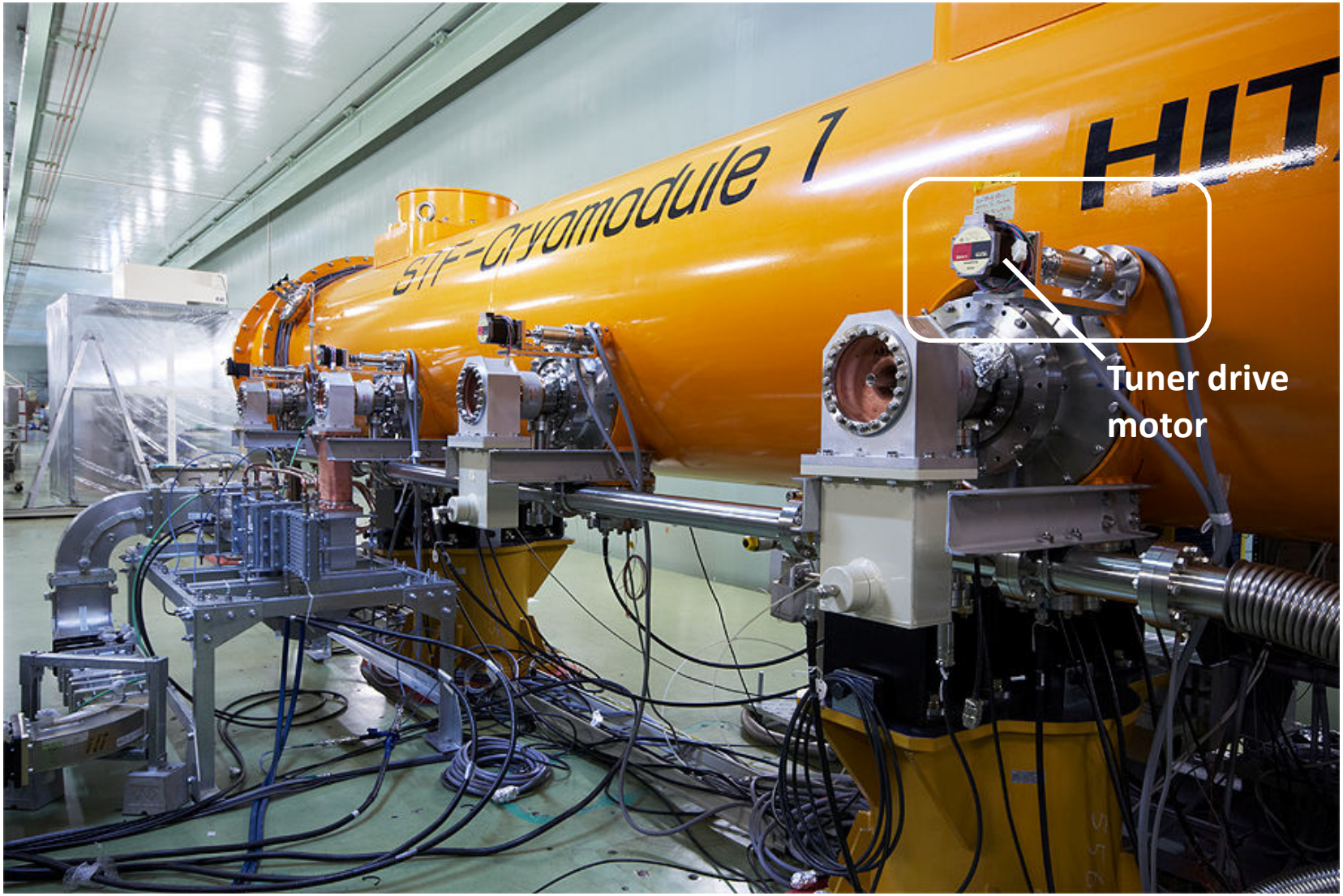




Heat loads through the drive shaft to 2K = 0.1 W

Tuner shaft elements and Piezo can be maintained from the outside of the cryostat by disassembling the input coupler flanges.

Tuner Driver Motor and Cryostat



Summary

- Thermal calculation for ILC cryomodule
  - Pressure drop along the 2.5 km GRP = 25 Pa for 10 W, 158 Pa for 30W
  - Temperature difference along the 2.5 km GRP = 3 mK for 10 W, 17 mK for 30W
  - The heat load of 7.5 W/cavity induces the temperature gradient of 2.4 mK, and the helium is still in the subcooled condition.
- STF cryomodule cold test
  - During the cooldown, the gas return pipe showed a large deformation (banana shape).
  - The movement of gas return pipe:

	Bef. cooldown	4K	2K	After warmup
Center (LD1)	0.0 mm	-0.3 mm	-0.2 mm	0.0 mm
End (LD2)	0.0 mm	-0.5 mm	-0.56 mm	-0.08 mm

- KEK tuner system
  - The tuner driving motor locates outside of cryostat.
  - The cryostat is designed so that the Piezo can be maintained at trouble.
  - There exists no trouble during the operation.