Development of the position monitor by white light interferometer (WLI) method in cERL cryomodule

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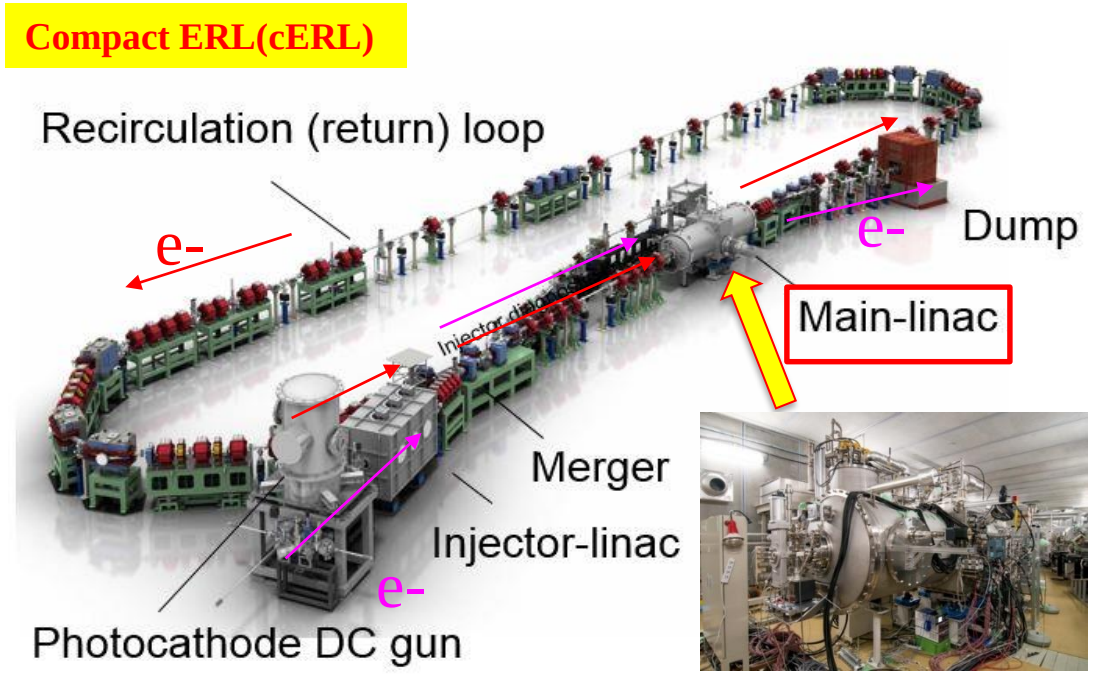
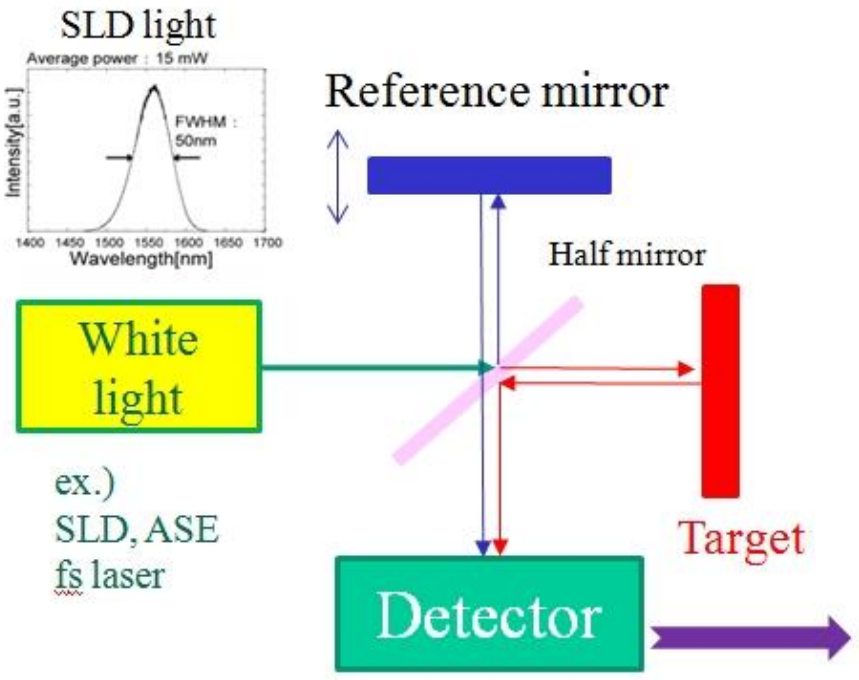
1) Principle and merit of WLI monitor
2) Setup of WLI monitor in cERL cryomodule
3) Measurement results in cERL cryomodule
4) Upgraded WLI monitor
5) Summary

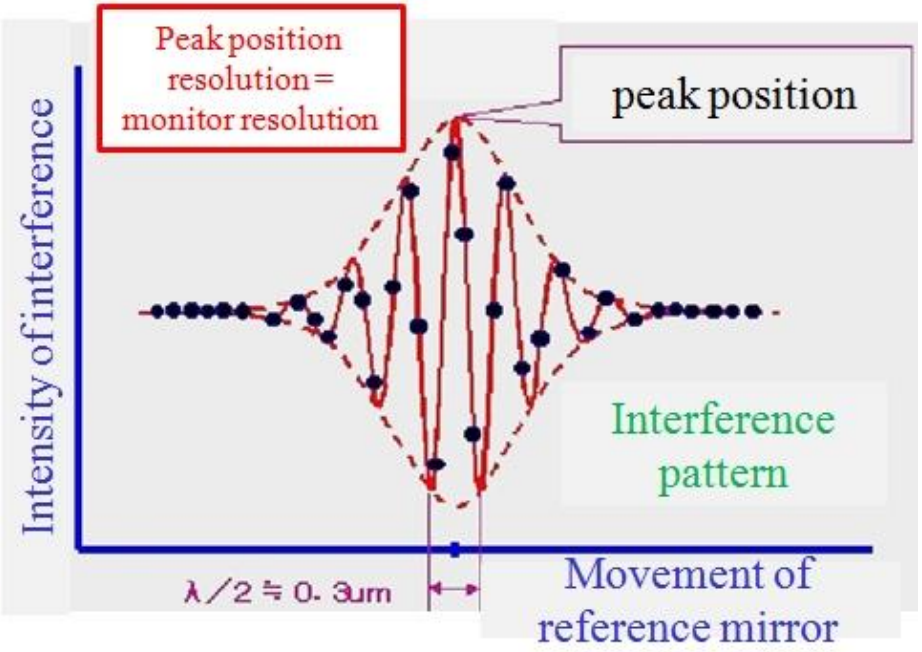


13 pages

1) Principle of the WLI monitor

- WLI monitor was based on the peak detection of the interference pattern when distances of the measured target and the reference mirror are the same.
- While we keep the peak detection under scanning the reference mirror precisely, we know the relative displacement of the target at every second.
- High resolution of less than 1μm with large dynamic of more than 10mm can be available with non-destructive (non-contact) manner.



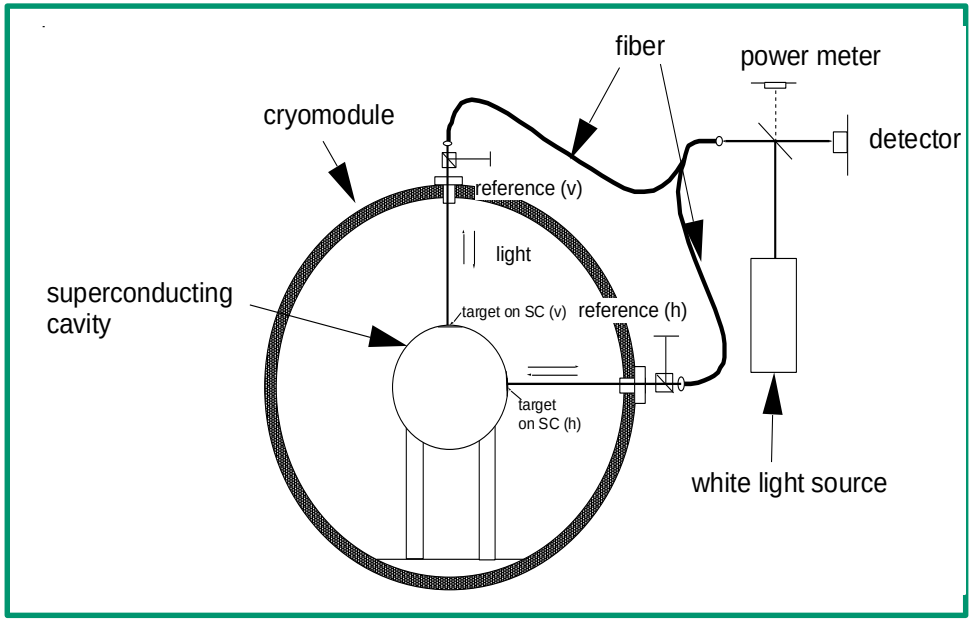


Feature of WLI monitor (compared with other position monitor like wire position monitor)

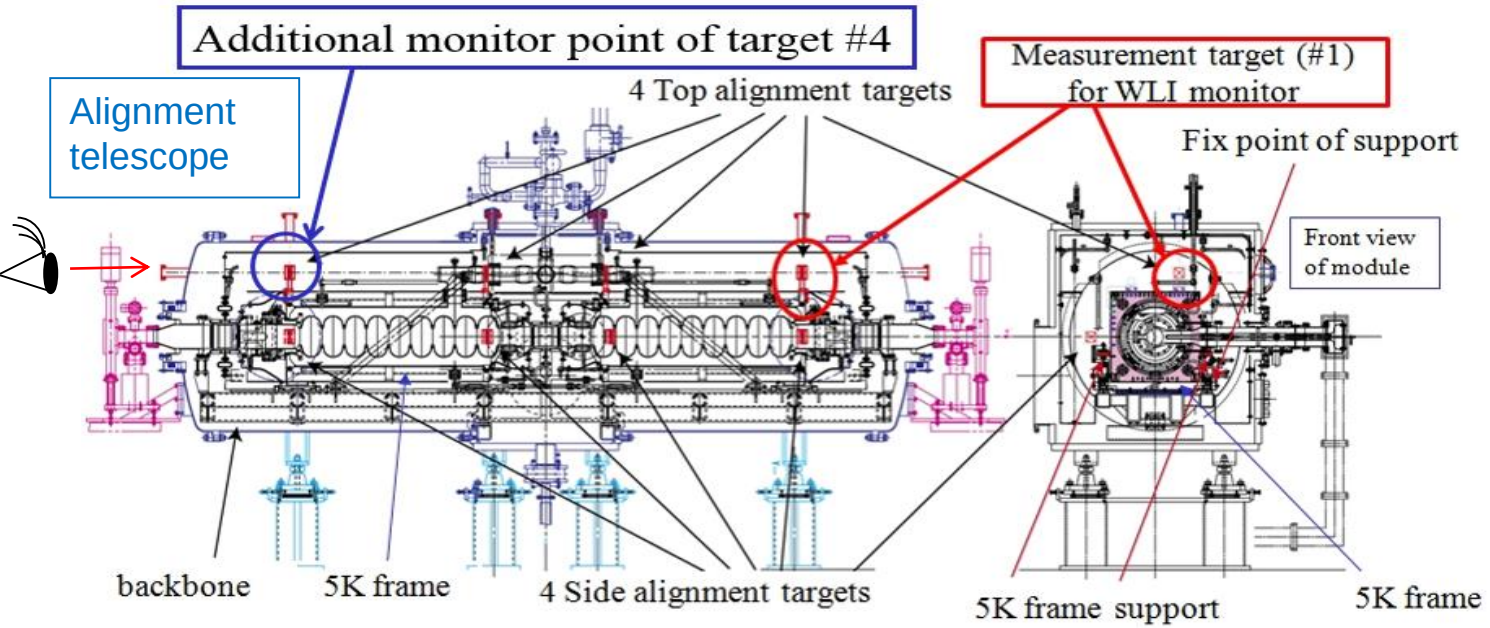
1. Measure the cavity position directly from the outside the cryo-vessel even thanks to the white light interferometry.
2. Less than 1 μm resolution of this monitor will be achieved with the large dynamic range of more than 100mm.
3. When the monitor was broken, we easily repaired the sensor without opening the cryomodule.
4. Small aperture of view ports can be placed for monitoring and thus reduce the thermal radiation.

Schematic drawing and requirement of WLI monitor to cERL cryomodule

Parameters	Requirements of new WLI monitor
Stability	< +-10μm
Dynamic range	> +-30mm
Measurement points	2 positions of x-y values

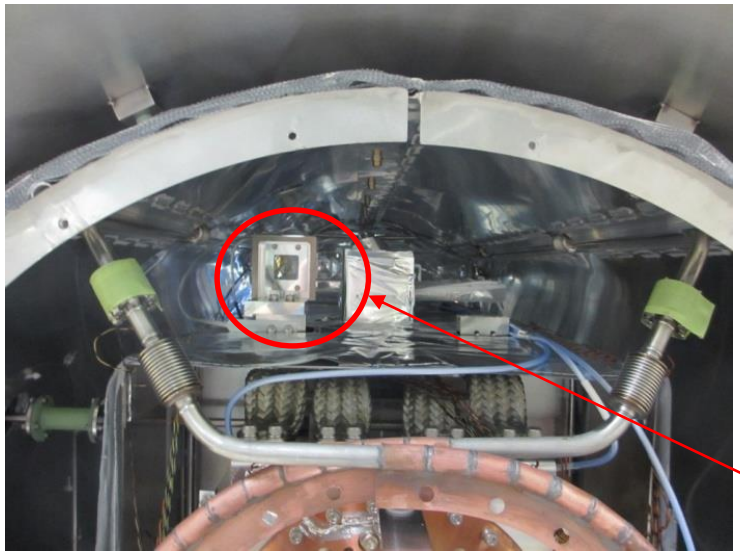


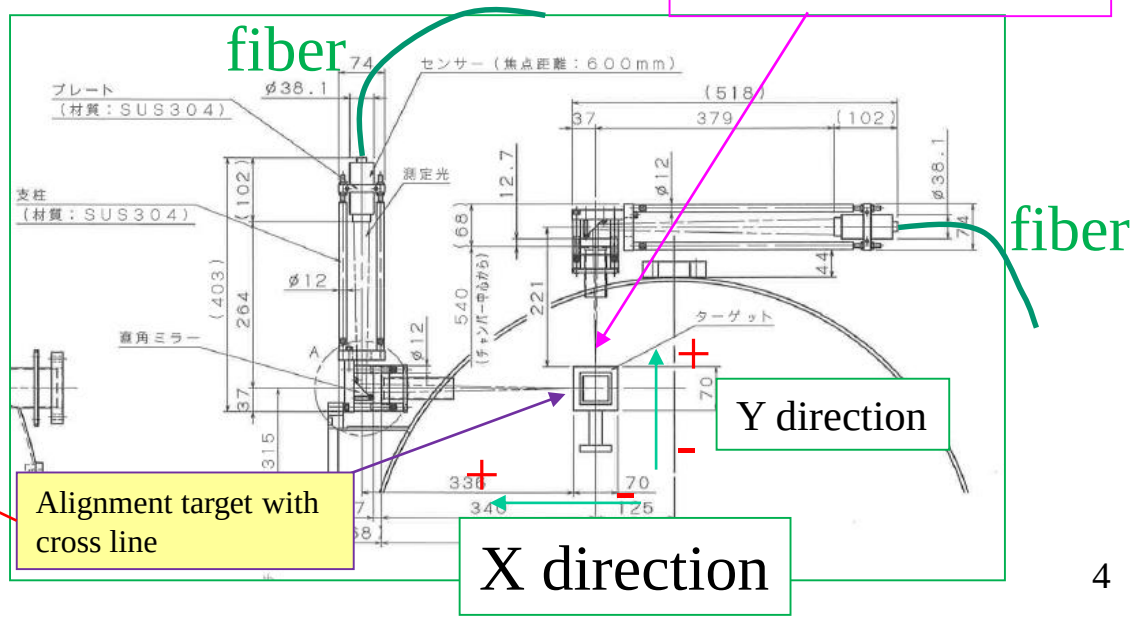
2) Setup of first WLI monitor for cERL main linac cryomodule



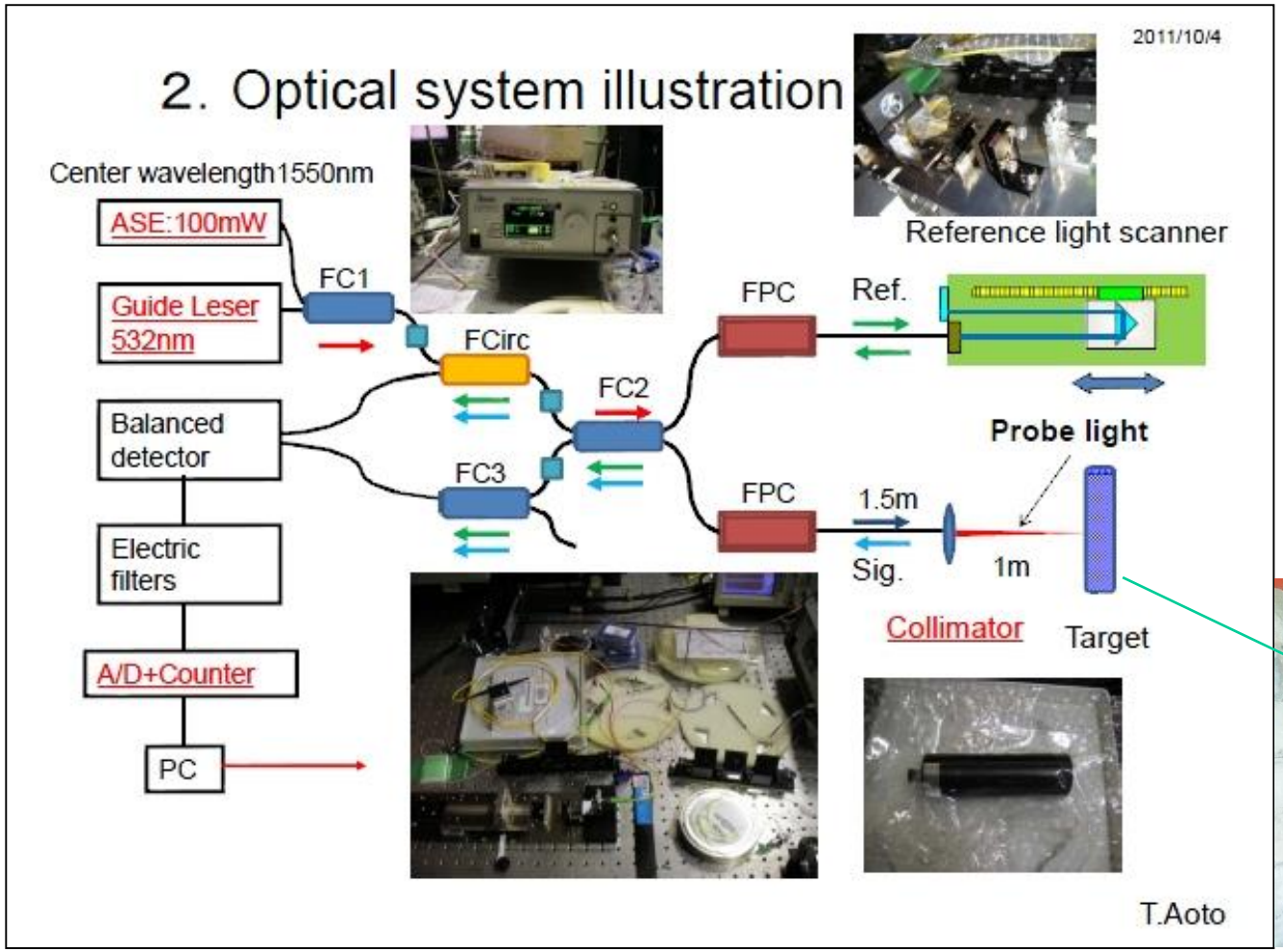
The eight optical alignment targets were set the known position on the 5K frame as below. Viewing the cross lines of these optical targets through the view port by the alignment telescope under cooling, we could catch up the movements of cavities.

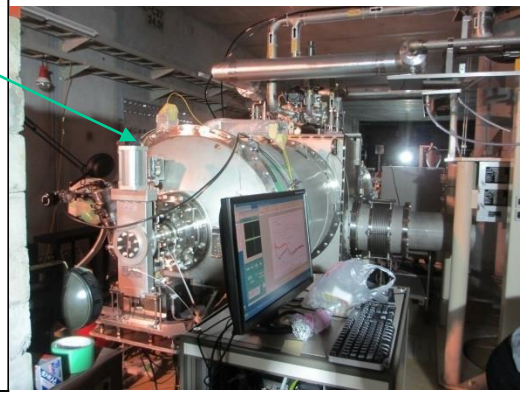
The target of #1 set on the upstream of the cryomodule was used for monitoring the movement of cavities by the WLI monitor





First WLI monitor system (optical system & picture)

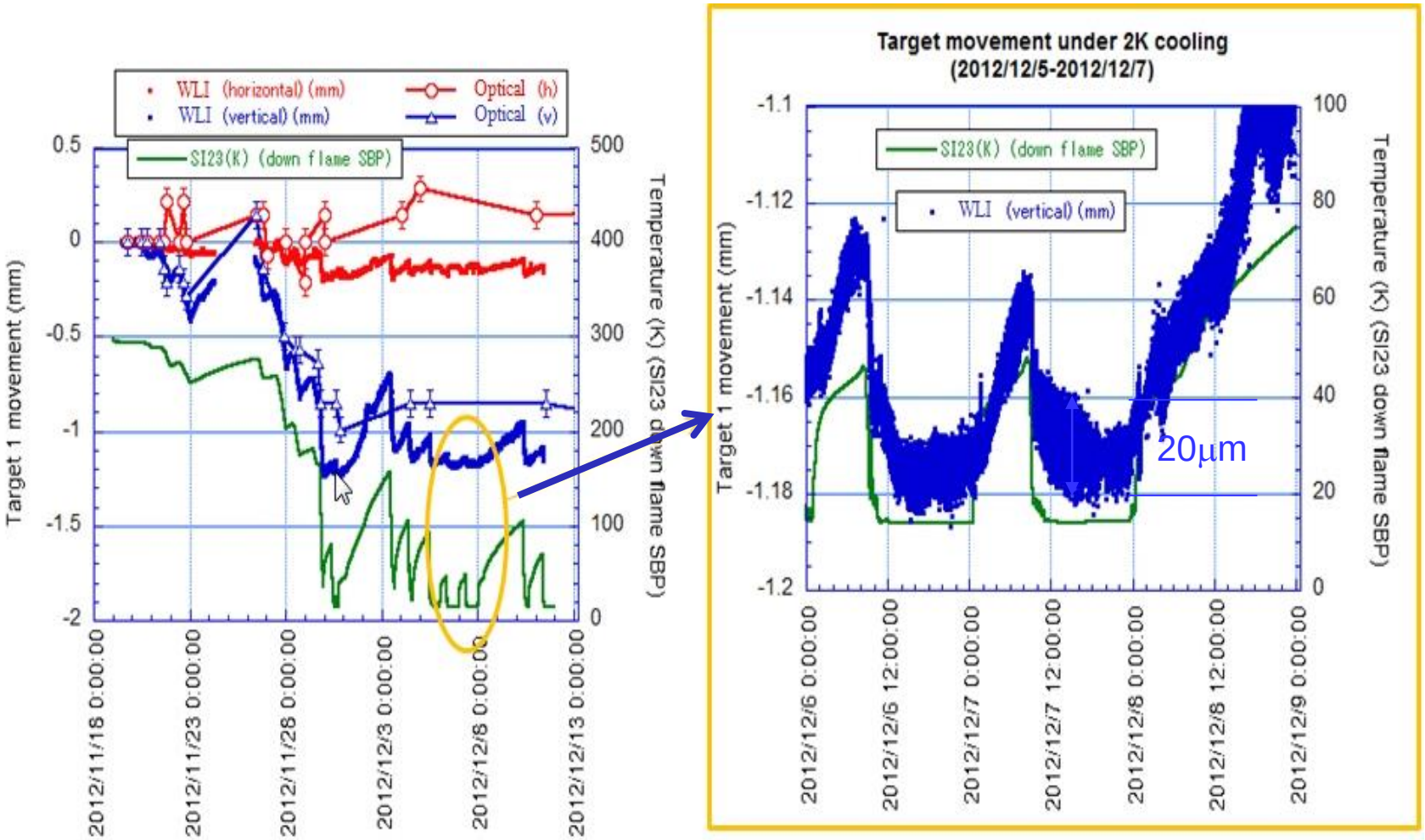




Temperature-stabilized fiber was used for both reference and monitor

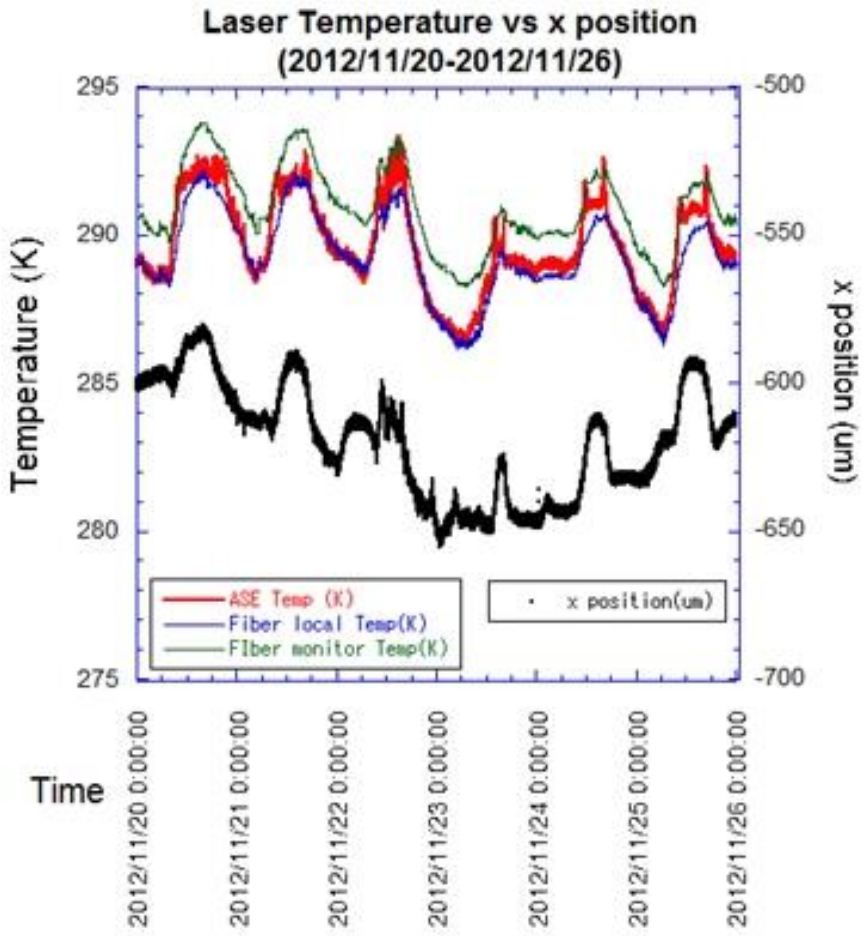
First both fibers of 3 m were first installed to reduce the thermal dependence of each fiber.

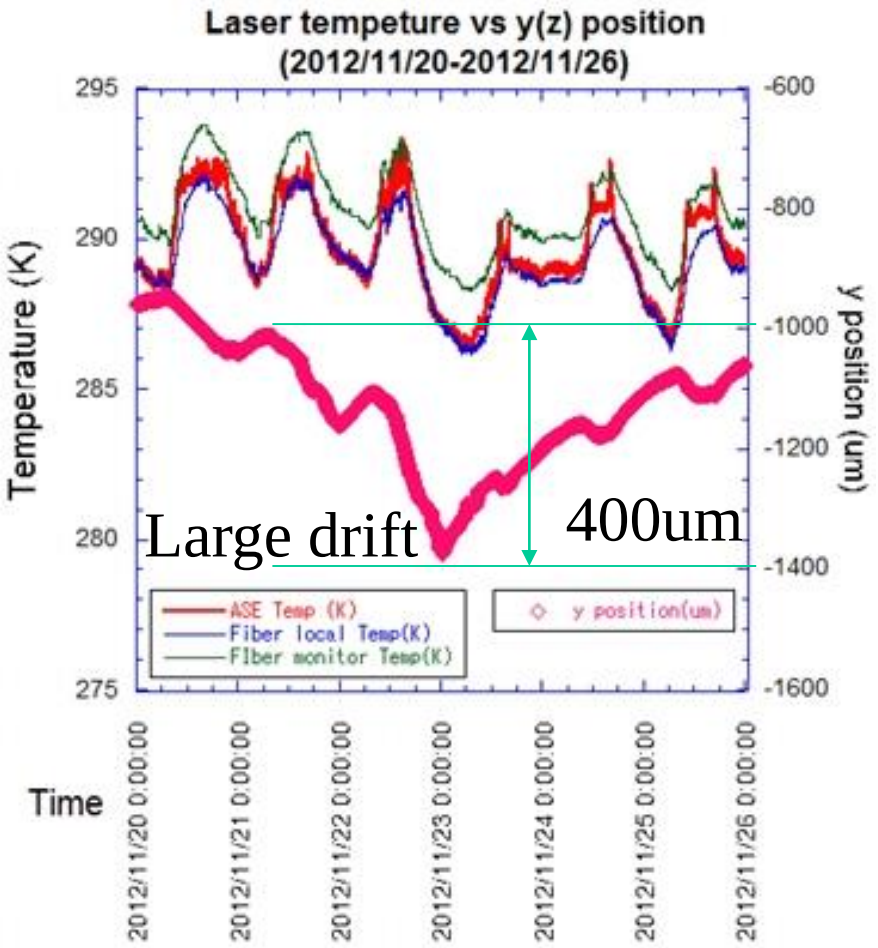
3) Results of displacemetns of cERL main linac cryomodule by WLI monitor



Measurement results of the movements of cryomodule (target #1) respect to the 5K frame temperature for more than 3 weeks. These values almost agreed well with the measurements by the alignment telescope. Superconducting cavity with 5K frame was stably set within +-10 μm for 12 hours and center of cavity was to be set within 0.5mm alignment tolerance.

Need modification to reduce thermal drift



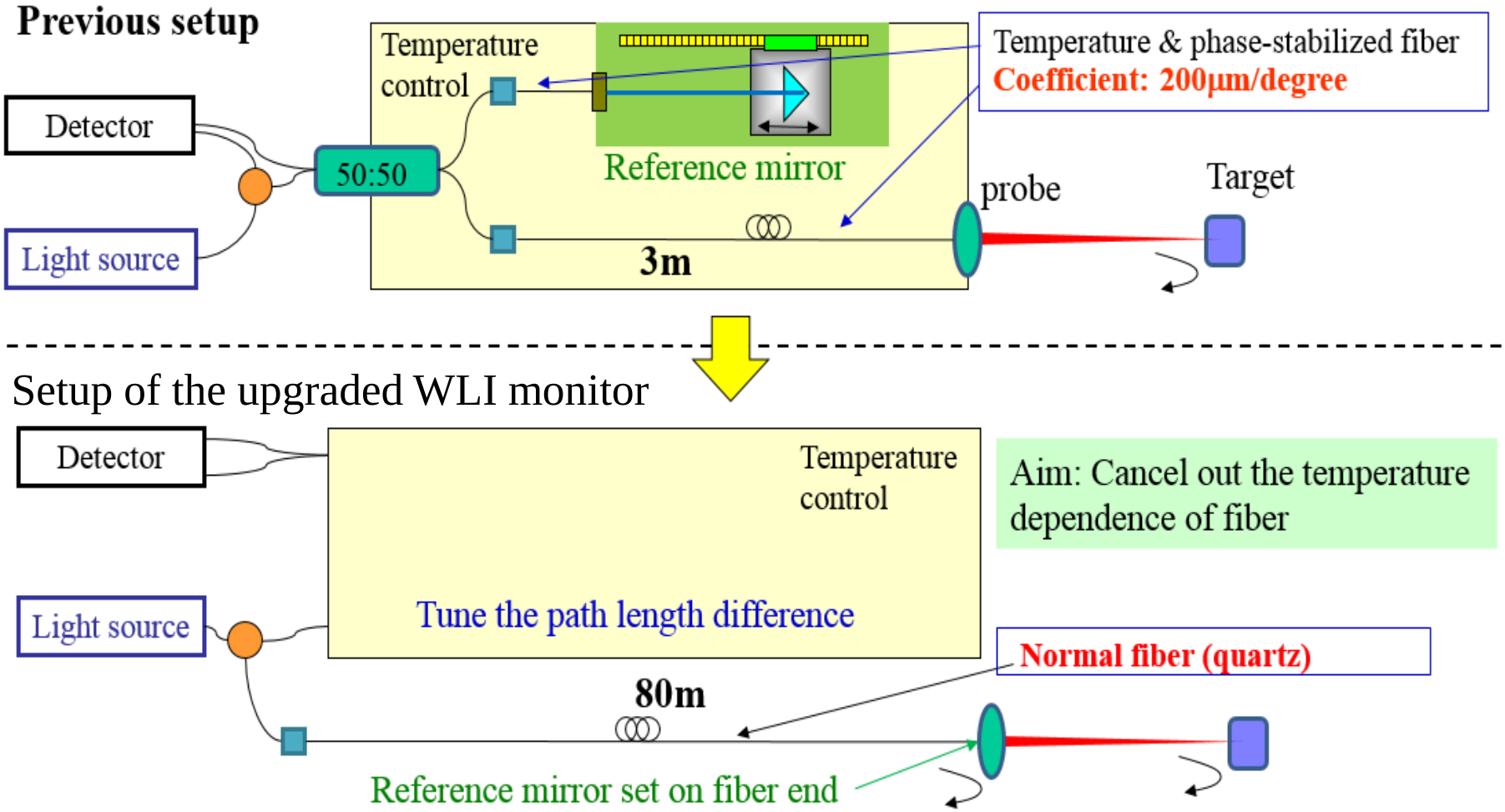


In the first setup, the measured position error was comes from mainly temperature dependence of the optical path lengths between the reference fiber and the target. And During high power test, unfortunately, we had to stop the measurement to escape them from the radiation come from the cryomodule.

4) Upgraded WLI monitor

Parameters	Previous achieved value	Requirements of new WLI monitor
Stability	+-10μm @25°C+-0.5°C	+-10μm @25°C+-5°C
Fiber length	3 m	More than 80 m
Measurement points	2ch (1 position of x-y values)	4ch (2 positions of x-y values)

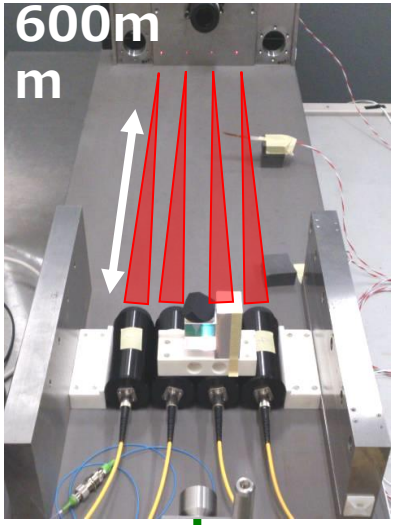
Our idea to improve this WLI monitor is that the reference mirror was set on the same path to cancel the temperature dependence come from the deference path of the reference mirror and the target.



Setup of upgraded WLI monitor at test stand and results

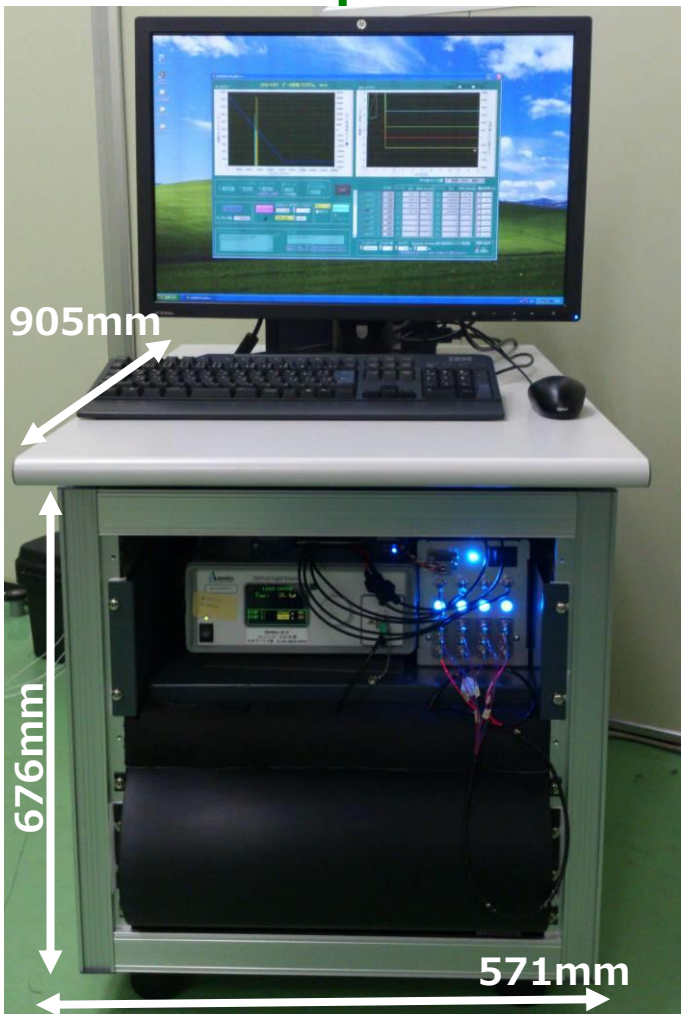
Done by Hayashi

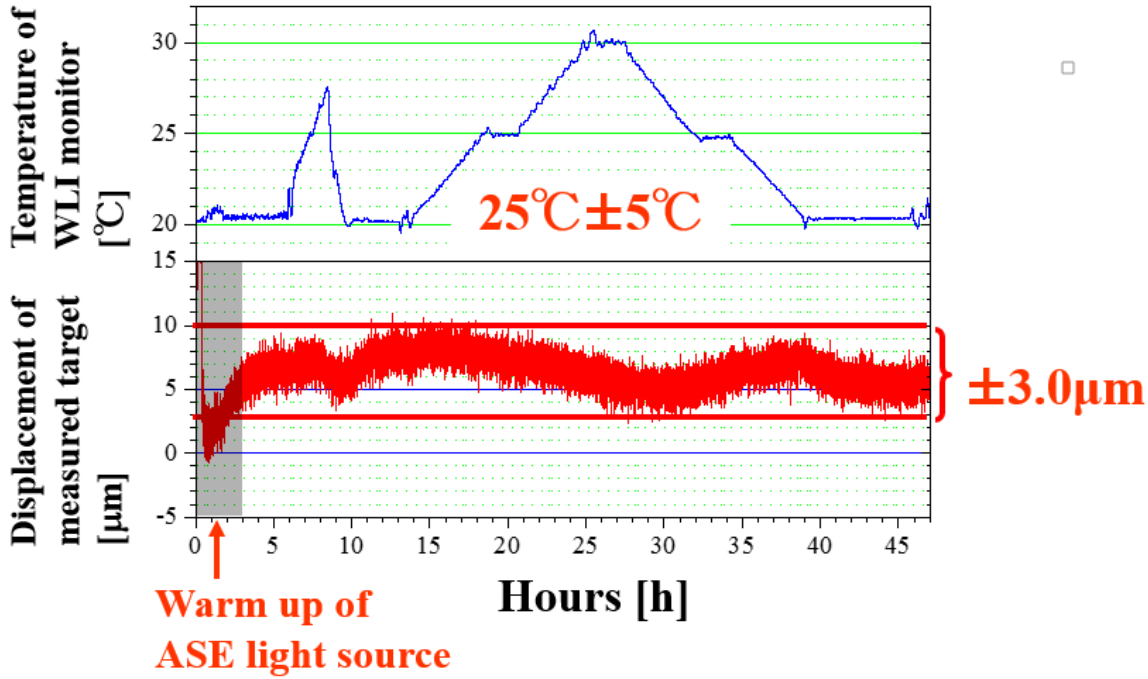
Sensor head : φ30mm



Control system

Optical fiber : 100m





Results : 600mm±3.0um/25℃±5℃

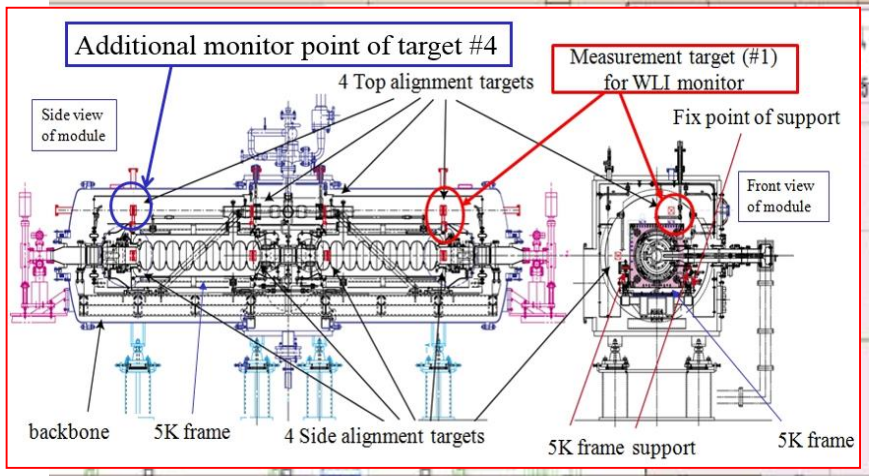
@100m fiber (→ 100m OK.)

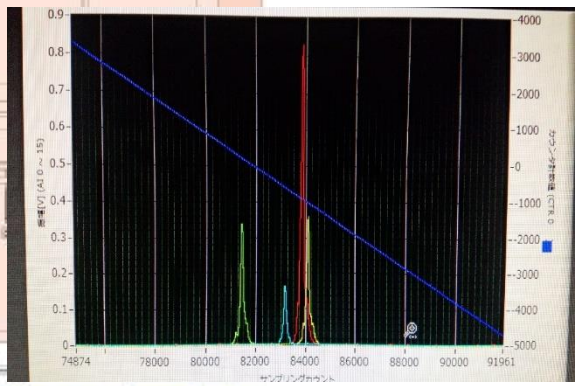
Setup of upgraded WLI monitor for cryomodule

•Not only the target of #1 set on the upstream of the cryomodule but also the target of #4 on the downstream were used

Fiber 80m (4 lines)

Control room



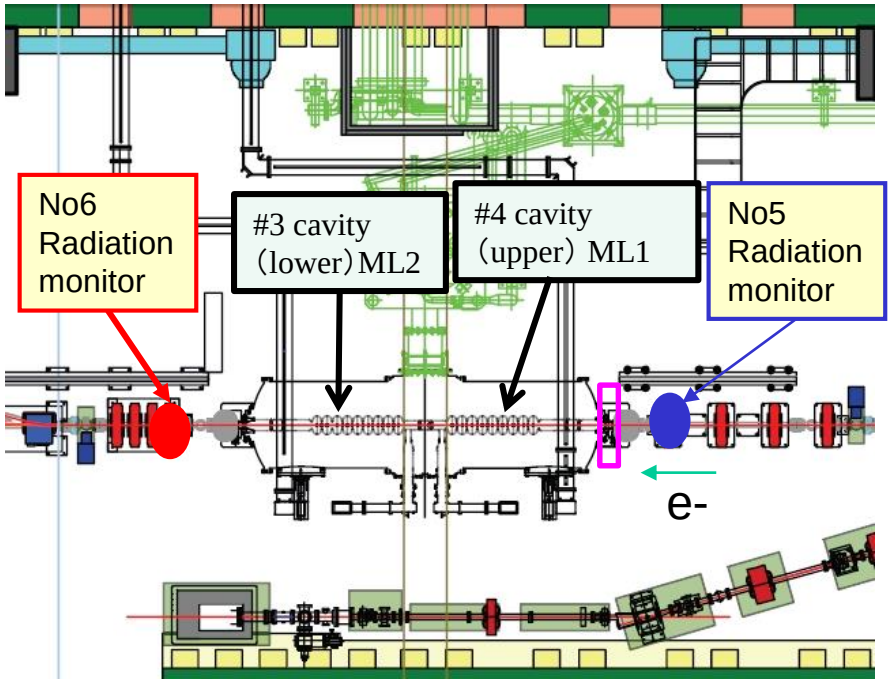


Concrete shield

Main linac cryomodule

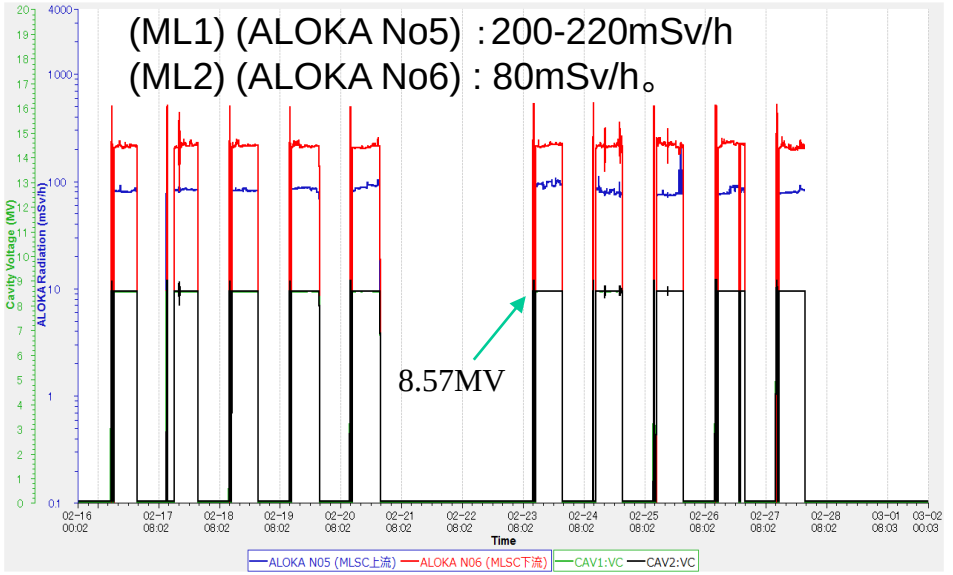
Original scaning data of 4ch

Measurement results by upgraded WLI monitor（2015.Feb under large field emission with CW beam）

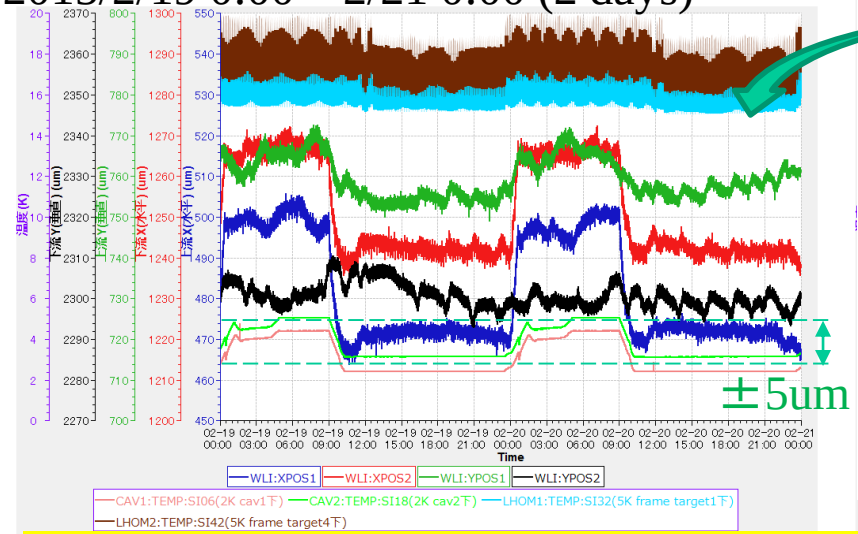


2015/2/16 0:00 – 3/2 0:00

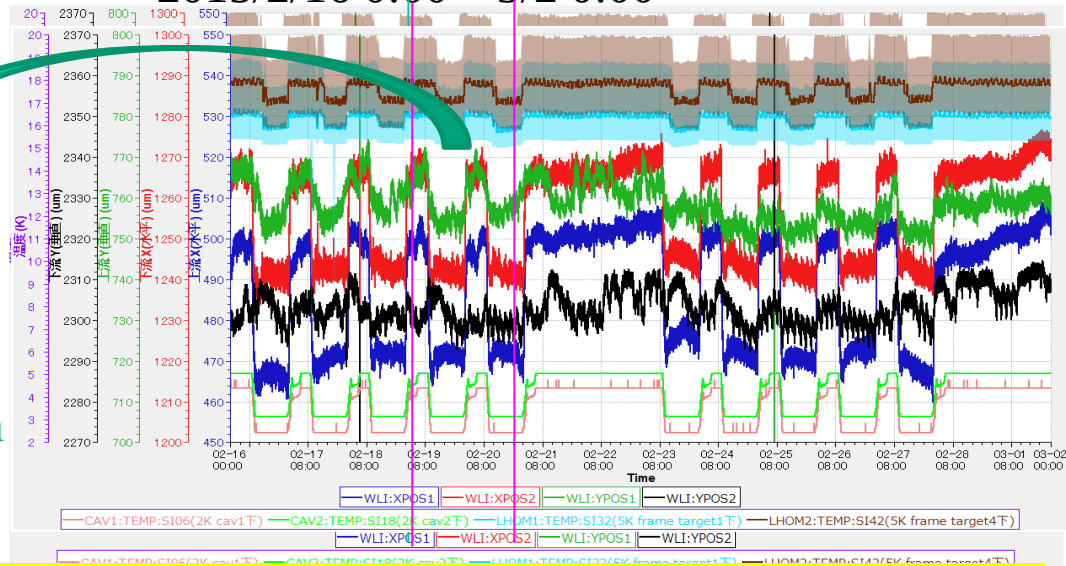
CW 100uA beam operation



2015/2/19 0:00 – 2/21 0:00 (2 days)



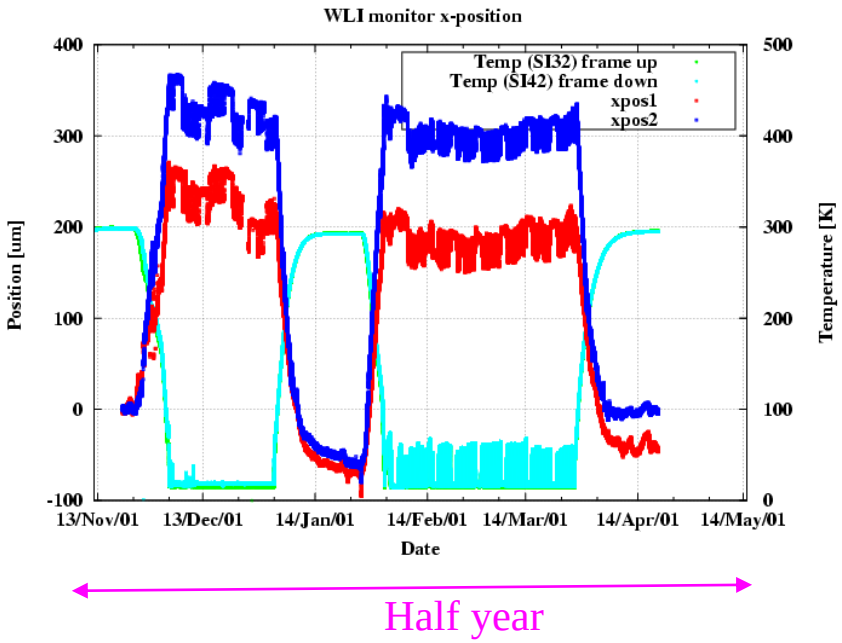
2015/2/16 0:00 – 3/2 0:00



The clear temperature correlations between horizontal displacements and temperature under 2K cooling from 4K were observed. The upgraded WLI monitor could stably monitor the displacements for a long time with +- 5 μm resolutions

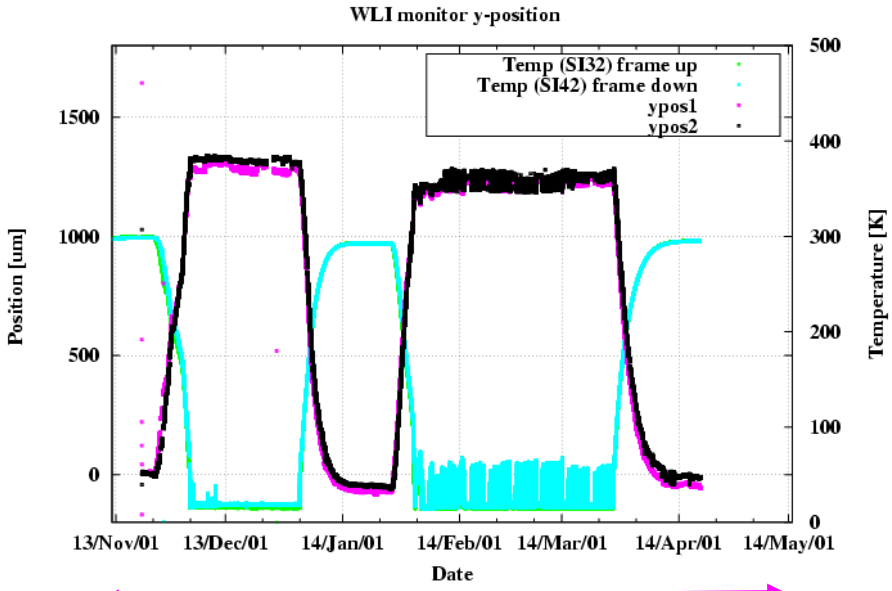
Long term measurement (2013/11/1 – 2014/4/1)

Horizontal displacements of #1&#4



Half year

Vertical displacements of #1&#4



Half year

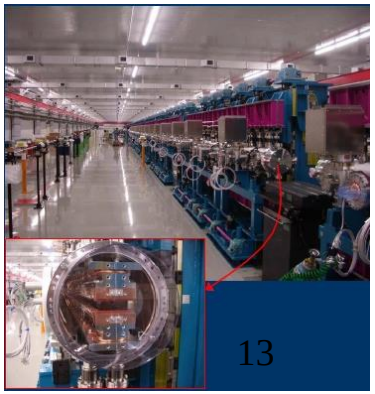
By improving this monitor, we kept monitoring the cryomodule for half year during high power test and beam operation including two-times thermal cycles from room temperature to 2 K. We found that the horizontal and vertical movements of target set in cryomodule from room temperature to 2K were 0.2-0.3 mm and 1.3 mm, and found the reproducibility of the cavity displacements with 50 μm level between after warming up and cooling to 2 K.

5) Summary

- We developed position monitor of cryomodule displacement by using white light interferometer method.
- First test satisfied our requirement of less than 10um resolution under the principle of white light interference method. But we saw thermal drift.
- By setting the reference mirror on the way from the light source to the target, we drastically cancelled thermal drift come from the fiber of the WLI monitor and found that the resolution of this monitor was 3 μm at a test bench, in spite of the fiber length of more than 80 m.
- By improving this monitor, we kept monitoring the cryomodule every 5 seconds for half year during high power test and beam operation including two-times thermal cycles from room temperature to 2 K. We found the reproducibility of the cavity displacements with 50 μm level between after warming up and cooling to 2 K. The upgraded WLI monitor could monitor the displacements for a long time with +- 5 μm resolutions

Future plan and application

- In principle nm level measurement could be carried out by WLI.。
- (Application) measurement of the movement in vacuum
  In-vacuum undulator is one of good application.



(XFEL)In-vacuum undulator