Present status and future prospect on the initial realignment at the KEKB injector linac

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Introduction

- The Super KEK B-Factory project (*SuperKEKB*) is a next-generation B-factory under construction at KEK after the KEKB project, which was discontinued in 2010.
- The KEKB injector linac is concurrently being upgraded for the SuperKEKB and is also in progress of the recovery works from the heavy damage due to the previous earthquake in Mar. 2011.
- The initial realignment is very important in the linac upgrade.
- The initial realignment with the high-precision laser-based alignment system is now ongoing.

The Super KEKB : an electron-positron collider with asymmetric energies

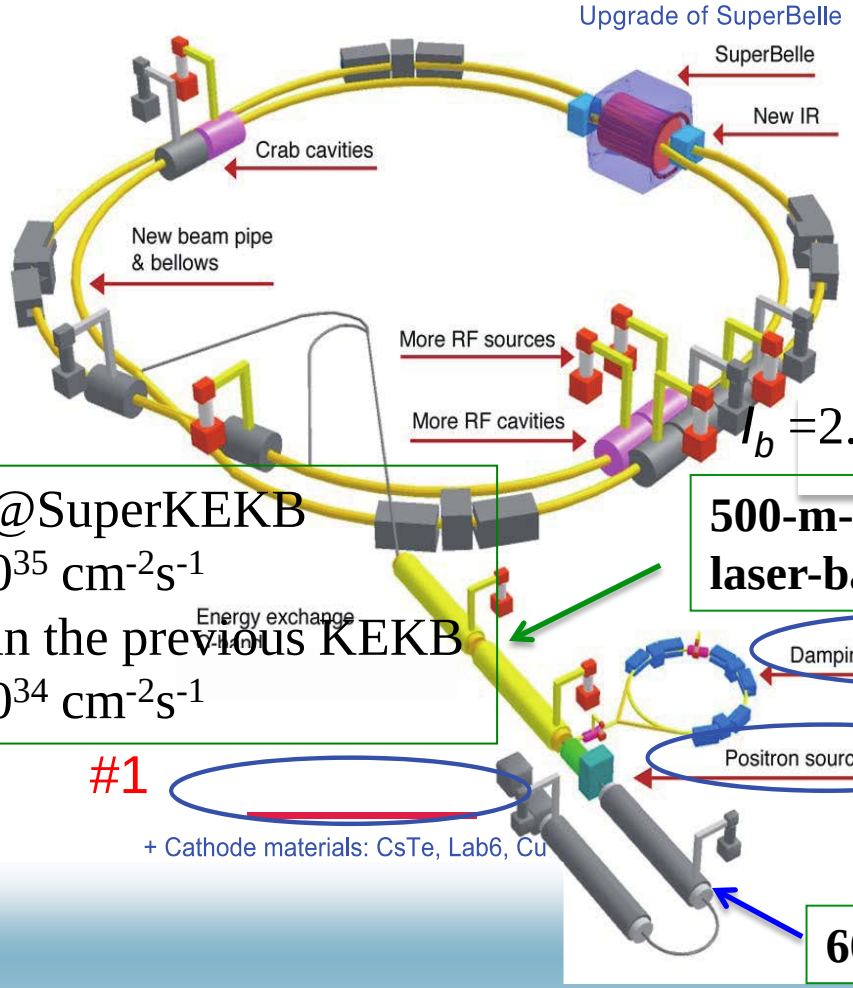
Y. Ohnishi, et al., Prog. Theor. Exp. Phys. 2013 , 03A011.

I_b =3.6A

e^+ E = 4 GeV

e^- E = 7 GeV

I_b =2.6A



Target Luminosity@SuperKEKB

$\mathcal{L} = 8 \times 10^{35}$ cm^{-2}s^{-1}

40 times higher than the previous KEKB

$\mathcal{L} = 2 \times 10^{34}$ cm^{-2}s^{-1}

500-m-long straight section for the laser-based alignment

#2

#3

#1

600-m-long injector linac

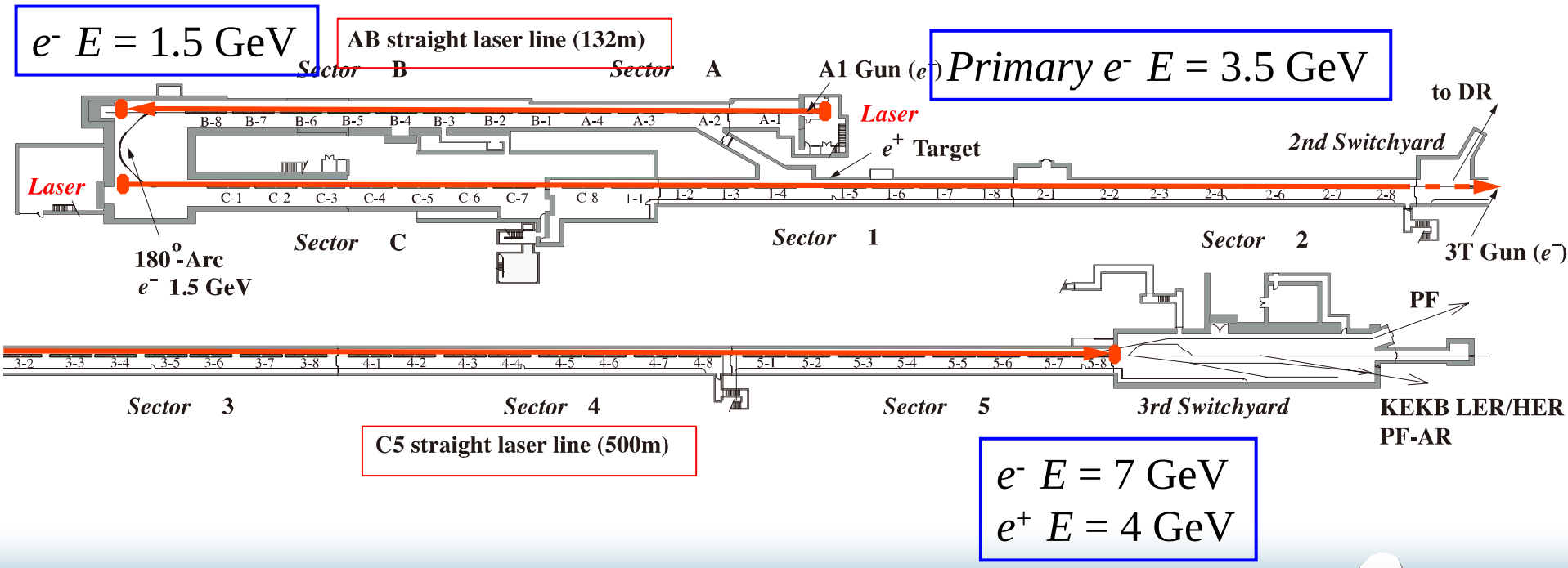
Strategies of the initial realignment

- The required precisions in the initial realignment are 0.1 mm over a sector (~80 m) and 0.3 mm over the long straight section (~500 m).
- For the two long straight sections, independent laser-based alignment systems are applied to the alignments for accelerator girder units.
- Regarding the 180° arc section, the refinement works have been performed in which the arc is smoothly connected to the two straight sections.
- Regarding the accelerator component alignment, target bases for the accelerator structures and quadruple magnets have been newly fabricated and mounted for conventional laser-tracker-based alignment measurements.
- The girder units were improved to increase the earthquake resistance by mounting a new support table for restricting the displacements in both the transverse and axial directions.
- We have observed non-negligible long-term drift of the floor level in the linac tunnel along with daily range of the dynamical displacements due to tidal motion.

KEKB linac layout and two laser fiducial lines

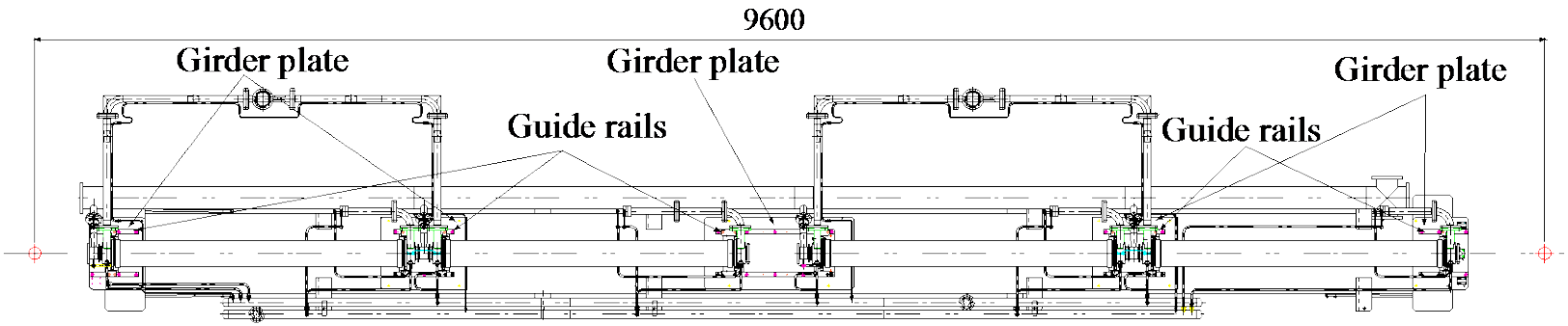
- Two long straight sections, AB (125m) and C5 (475m)
- Two new laser-based alignment systems enable the high-precision alignment for each section independently.

M. Akemoto, et al., Prog. Theor. Exp. Phys. 2013 , 03A002.

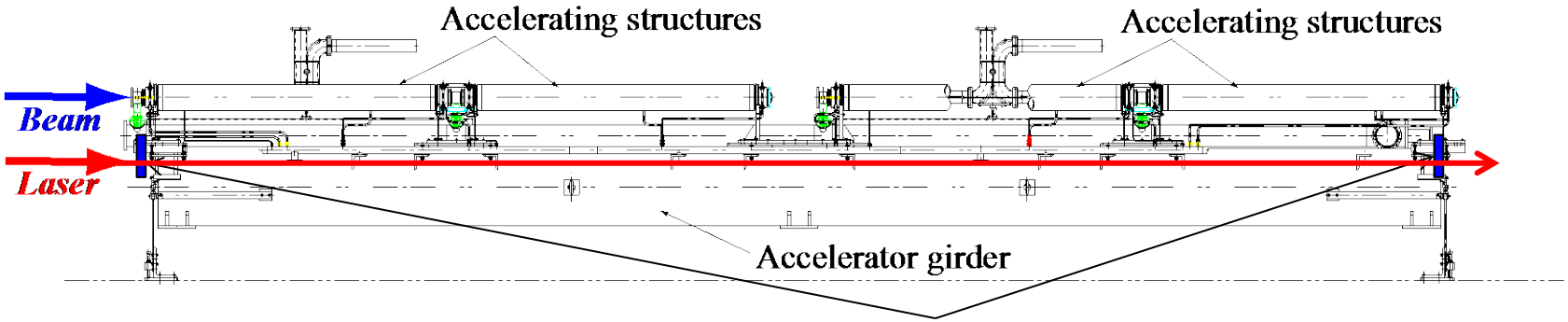


Accelerator girder unit structure

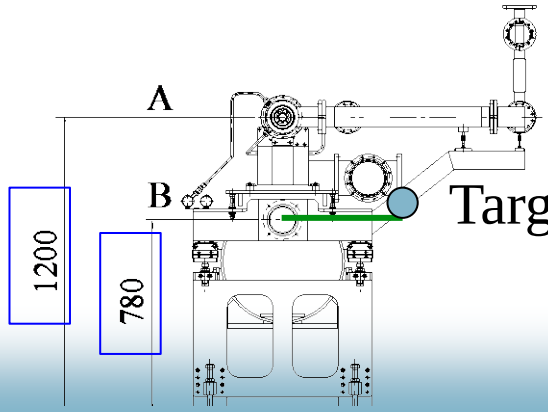
(a)



(b)



(c)



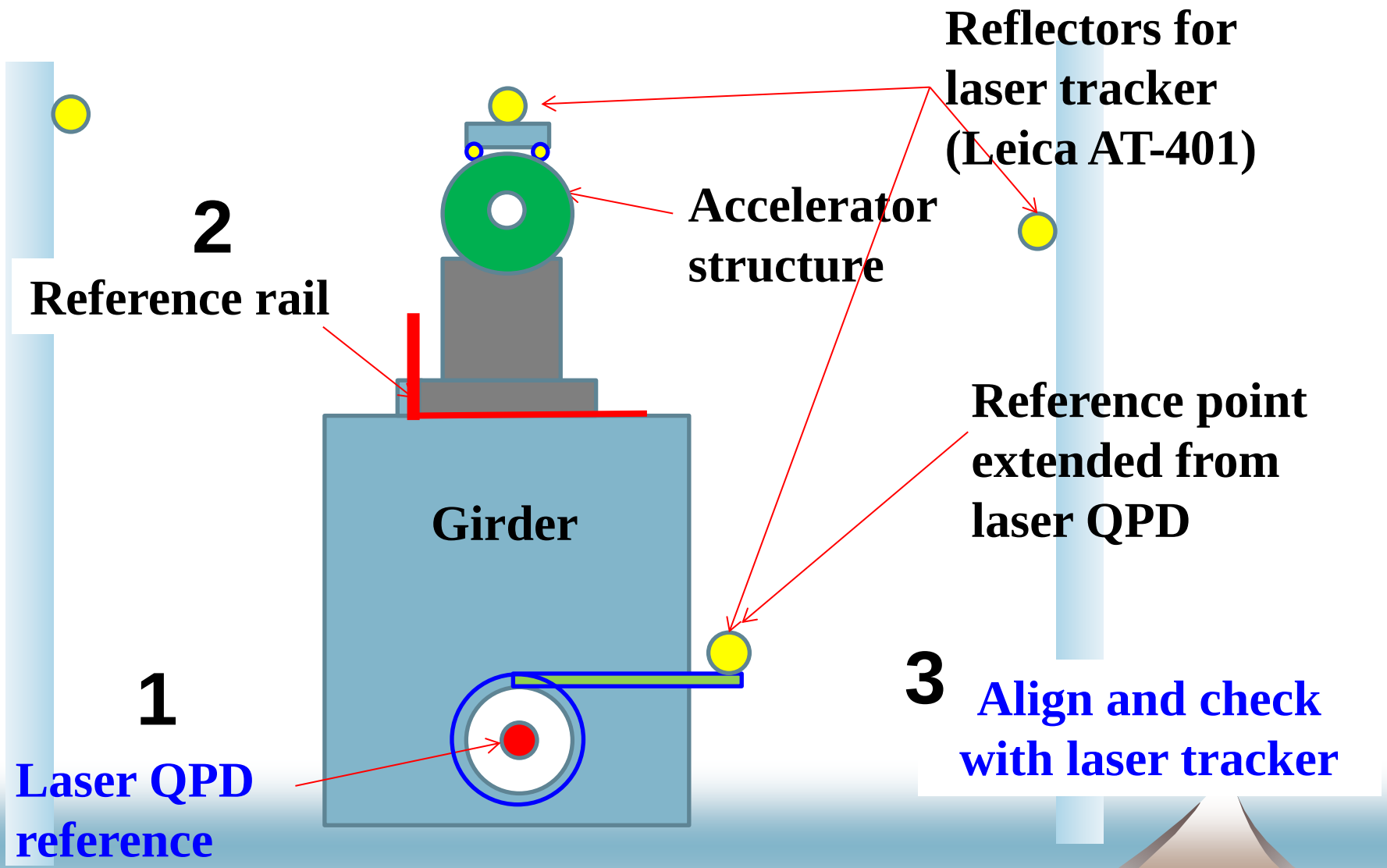
Quadrant silicon Photo-Diode:QPD

A: Beam height
B: Laser height

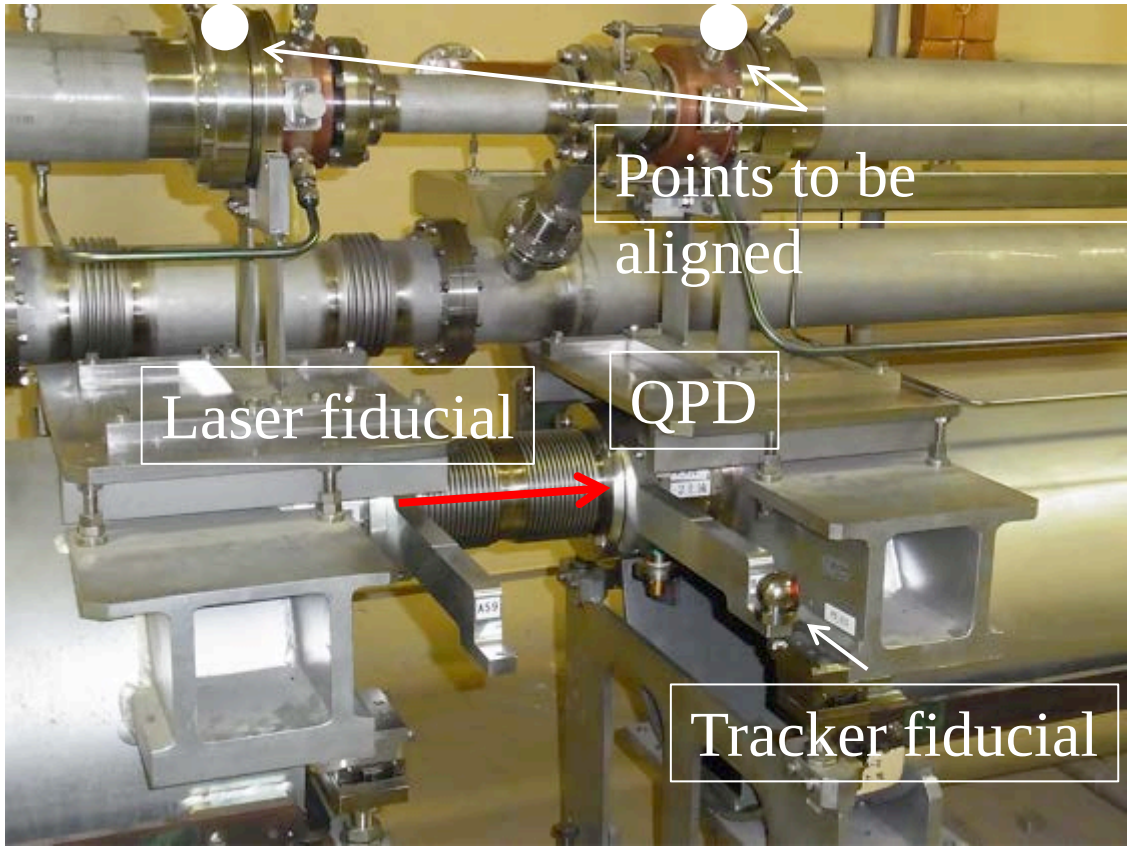
Target for a laser tracker

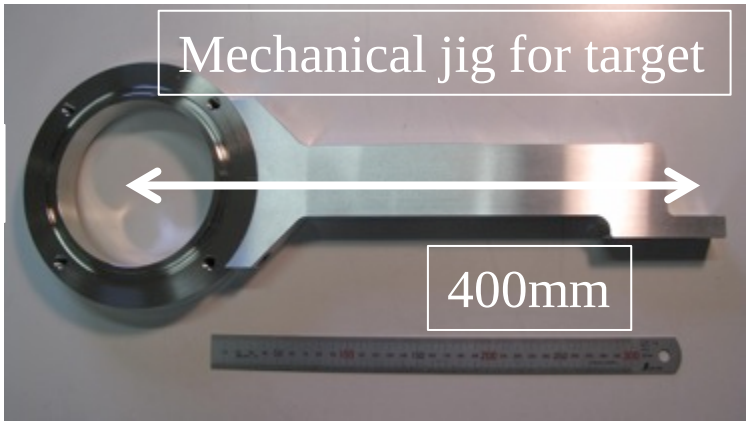
T. Suwada, et al.,Rev. Sci. Instrum 81, 123301 (2010).

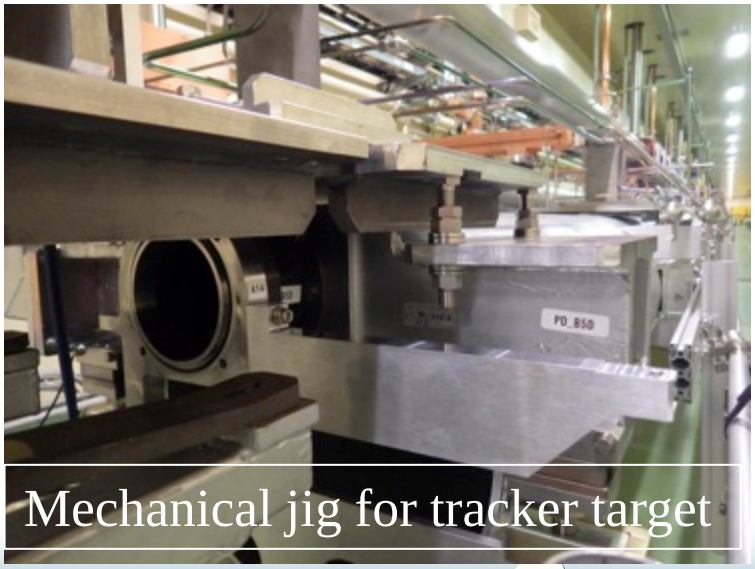
Short-range component alignment on the girder



Fiducial points for the girder unit

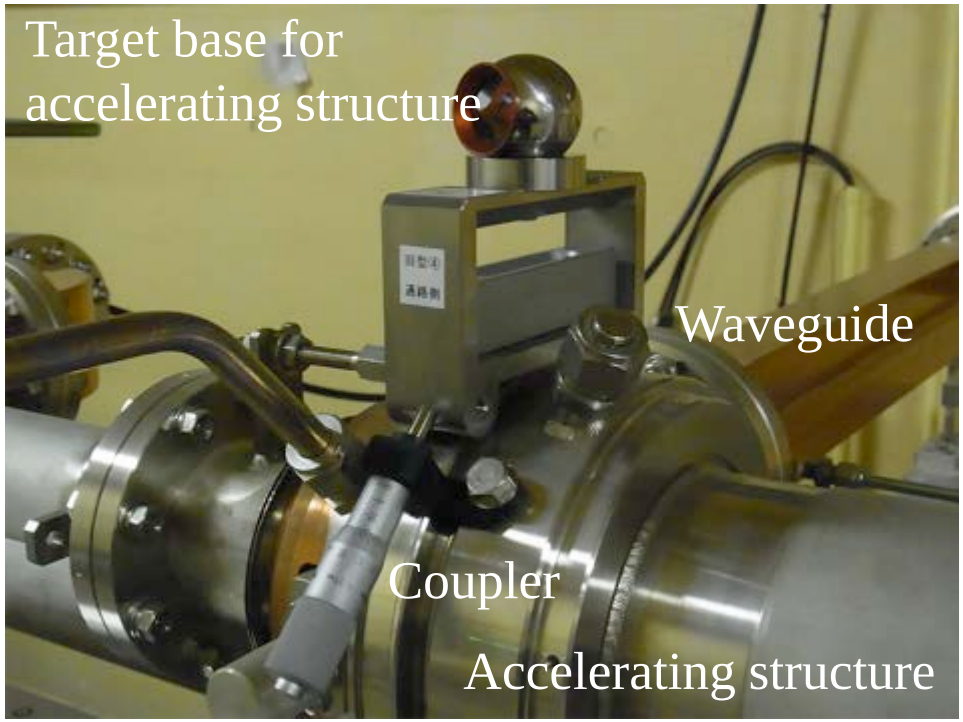




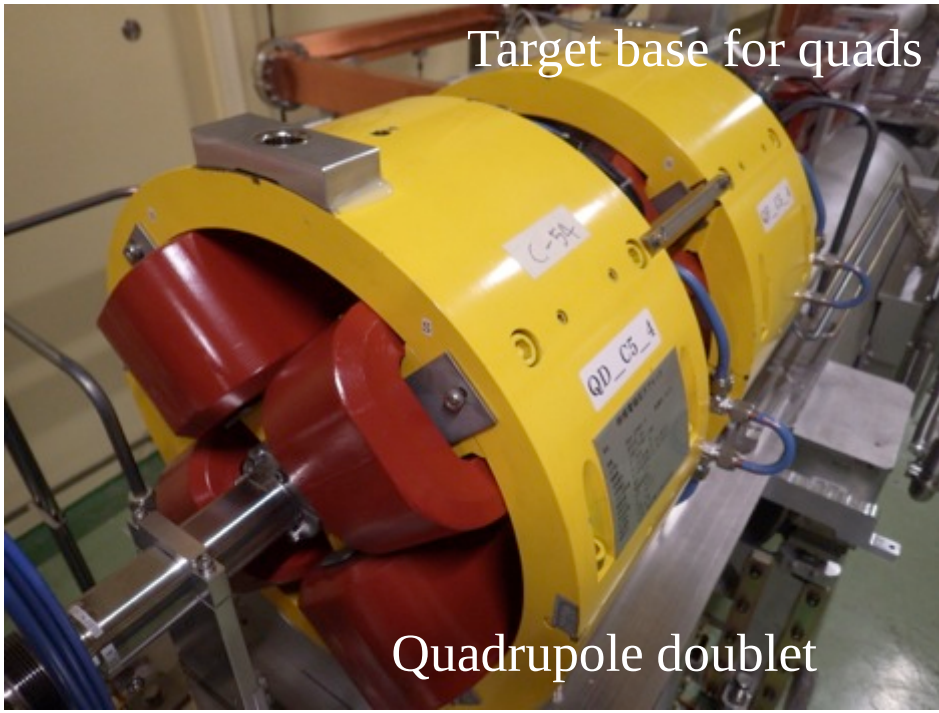


Fiducial points for the accelerator components

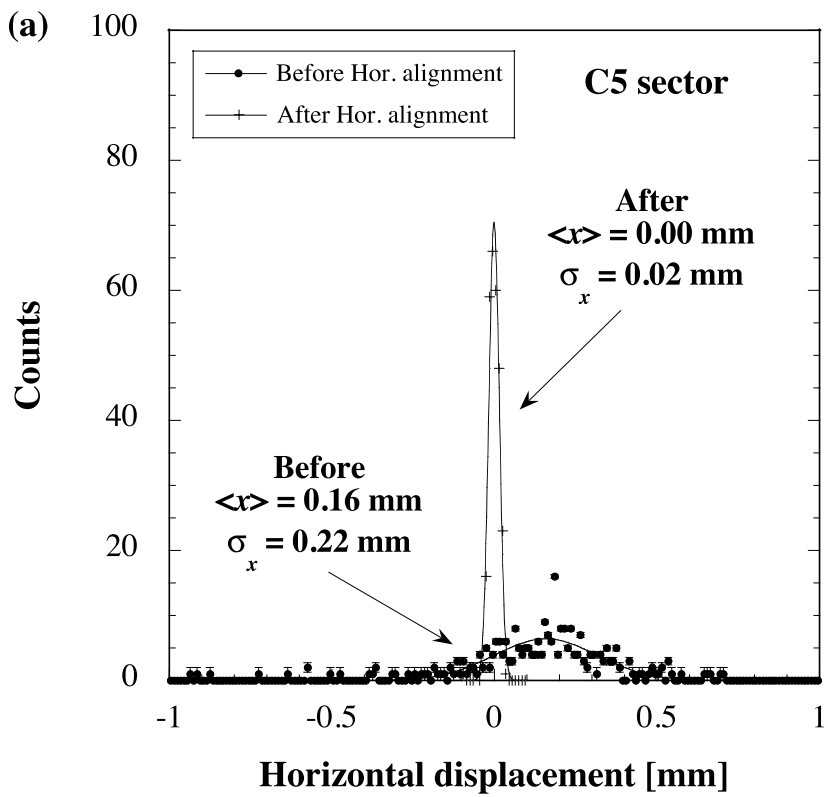
New target base mounted on a coupler surface



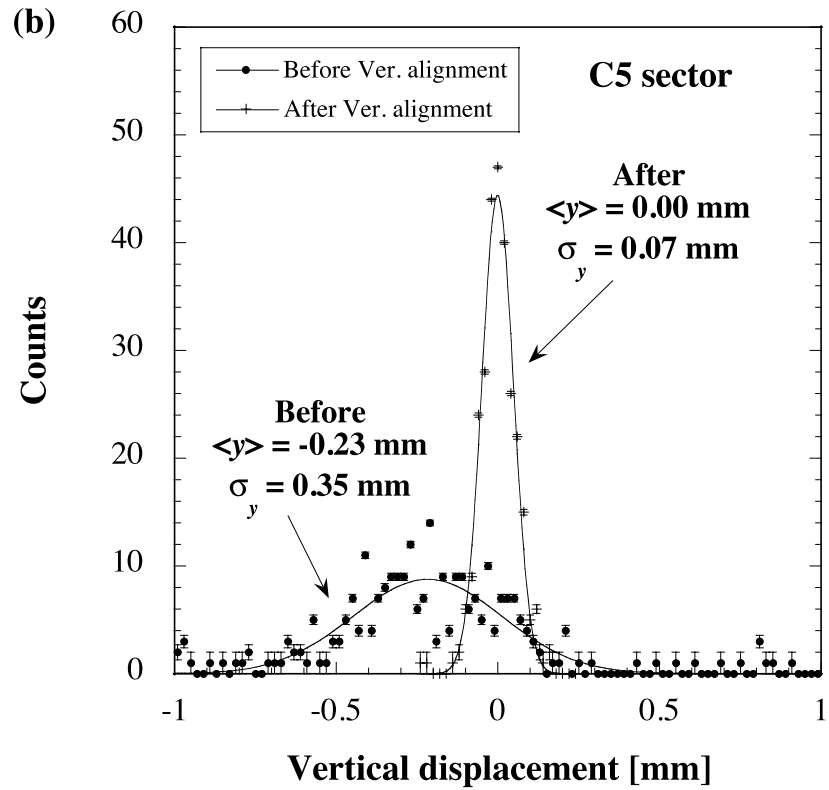
New target base mounted on quadrupole doublet



Alignment results for the accelerating structures at sectors C5

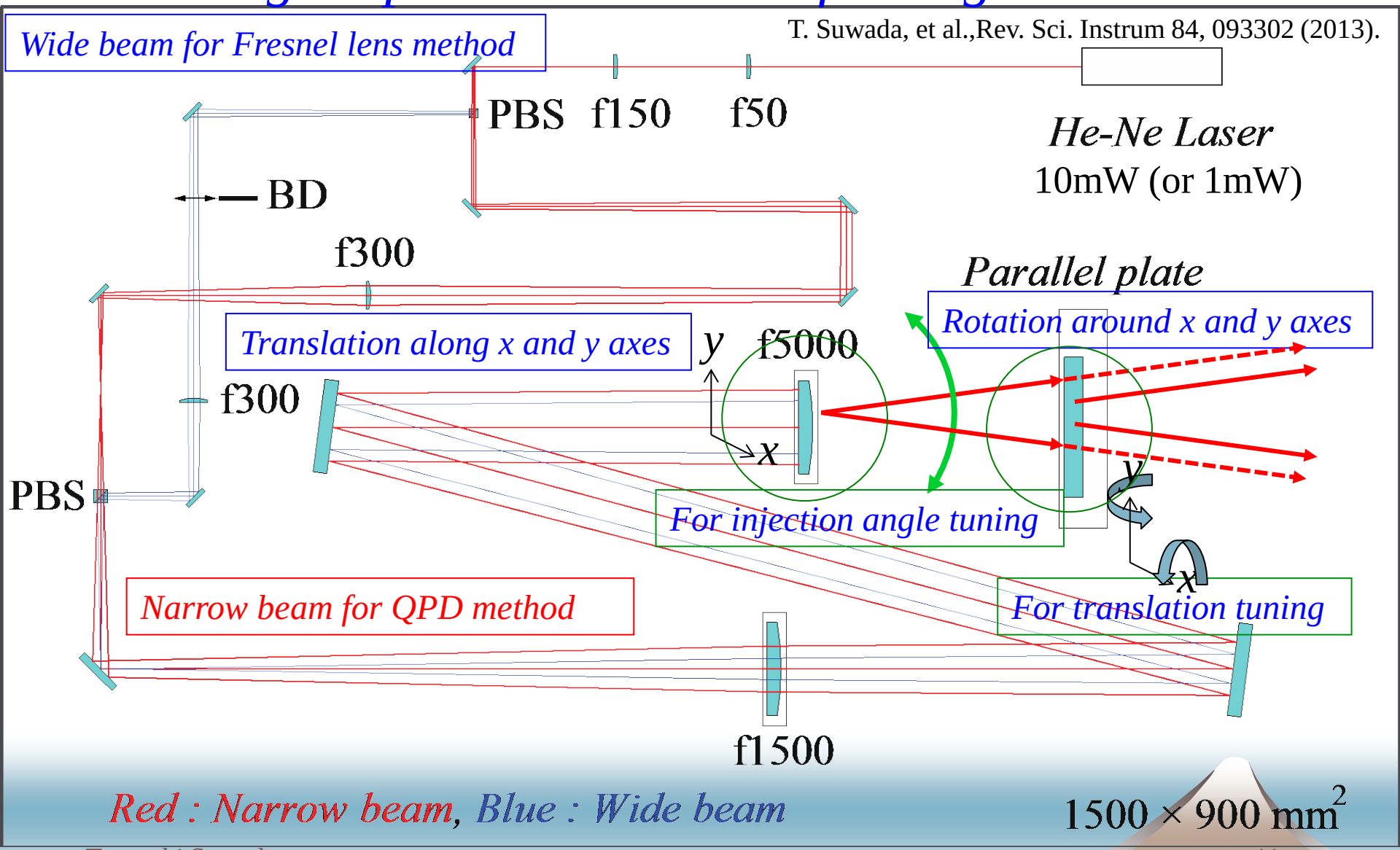


Horizontal

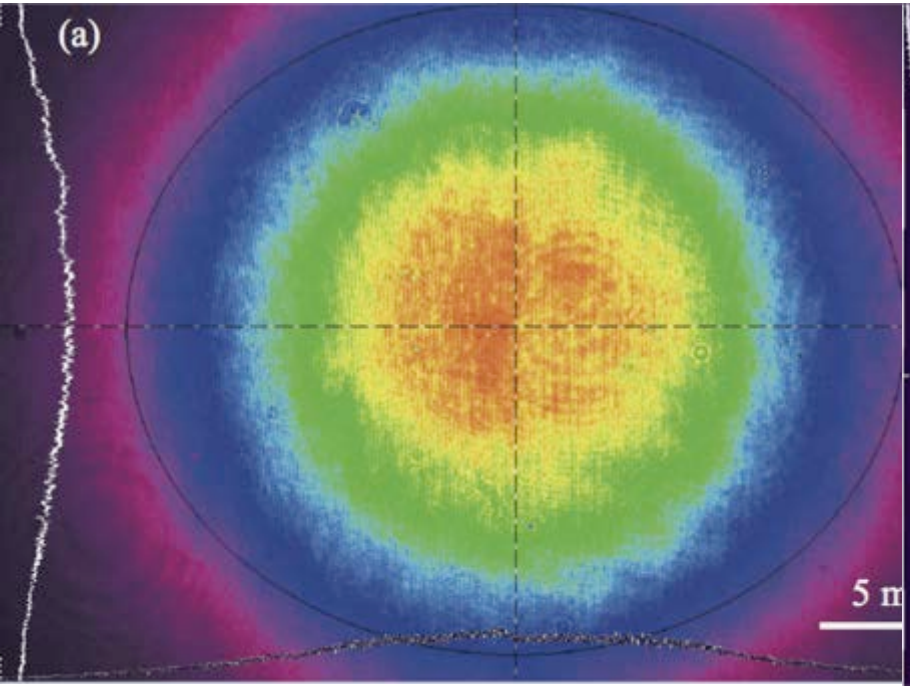


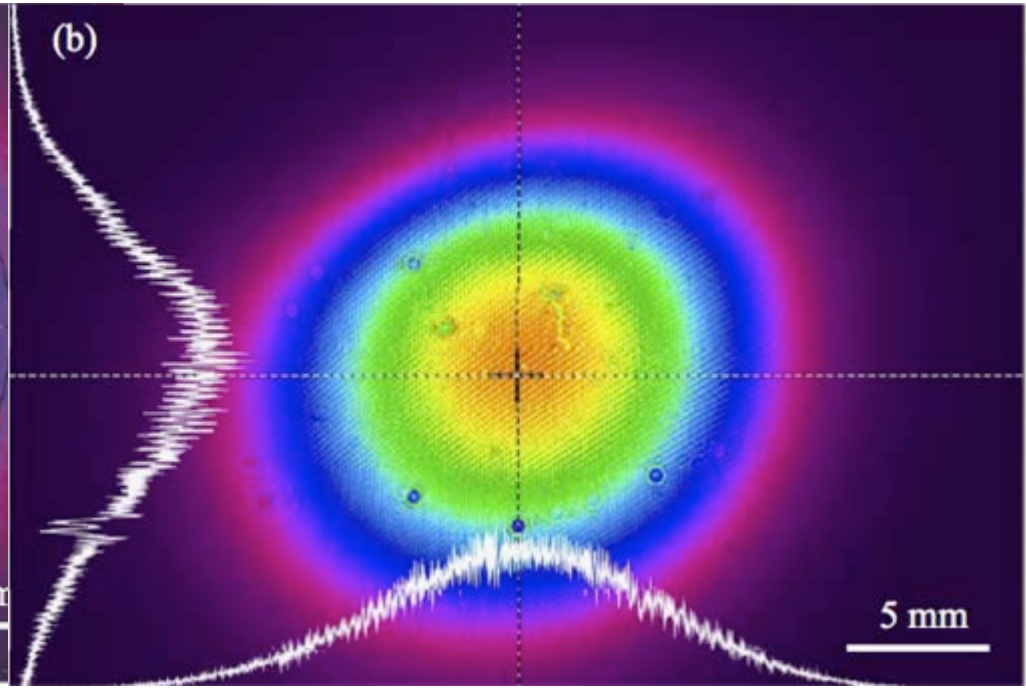
Vertical

Laser optical system – *simple dioptric system using dioptric lenses and reflecting mirrors –*



Laser profiles at the initial and last QPDs



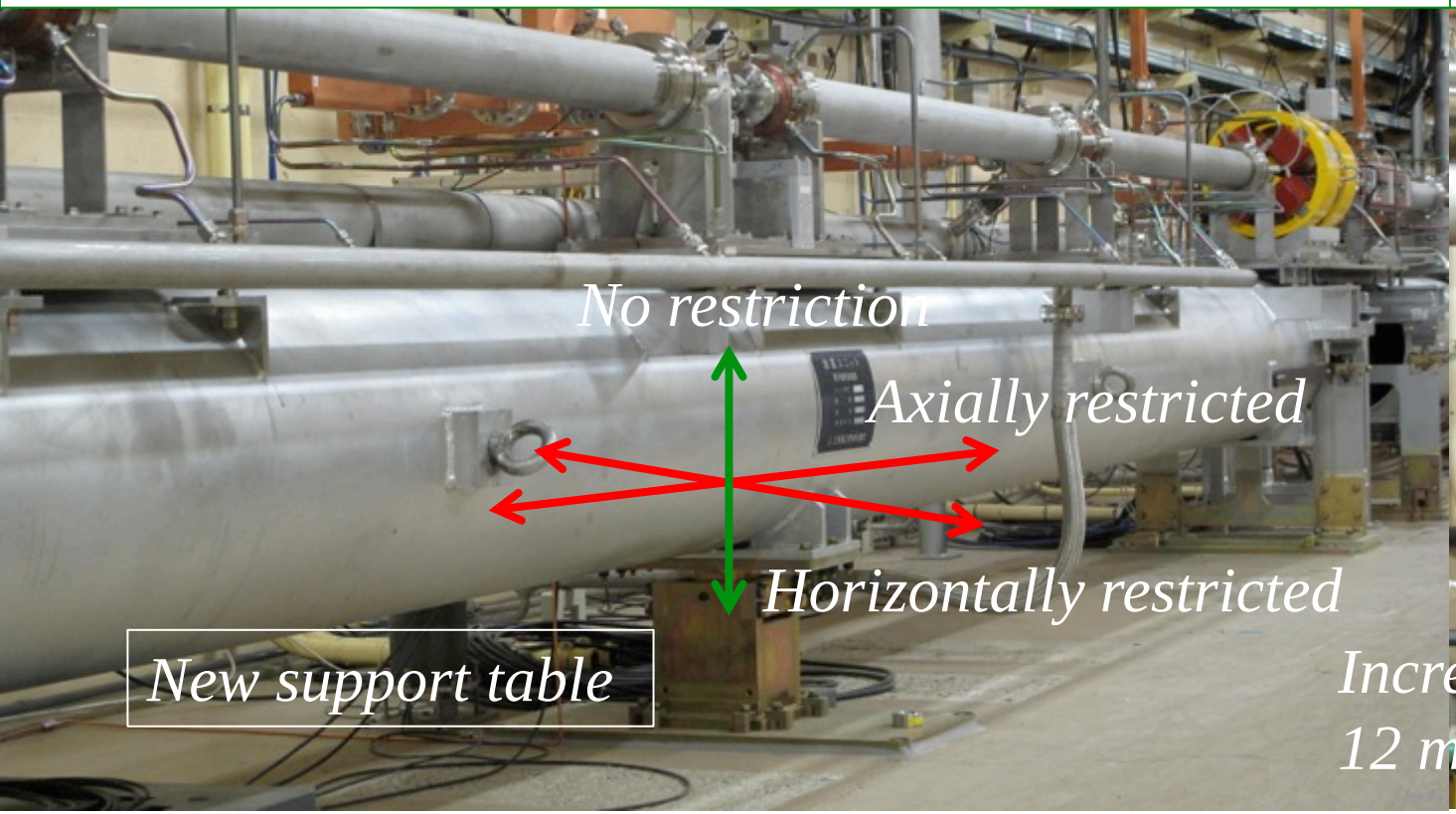


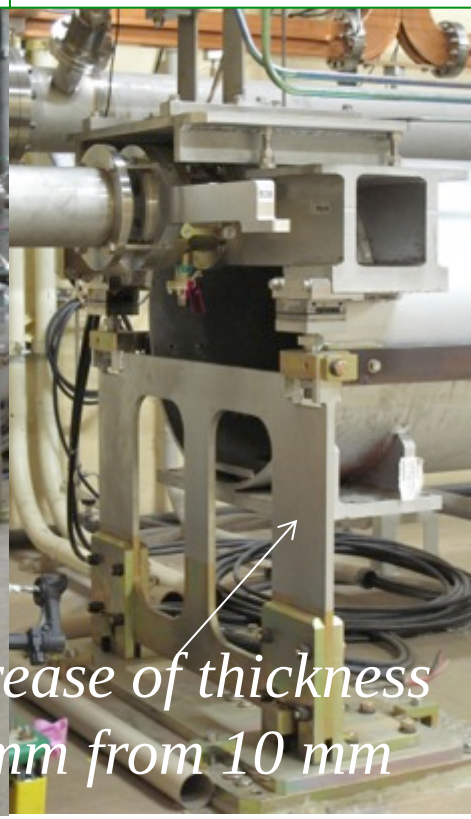
@ Exit of the optical system (z = 0)
$Wx \approx Wy \approx$ 29 mm (4σ width)

@ Last QPD (z = 500 m)
$Wx \approx$ 21.2 mm, $Wy \approx$ 17.8 mm

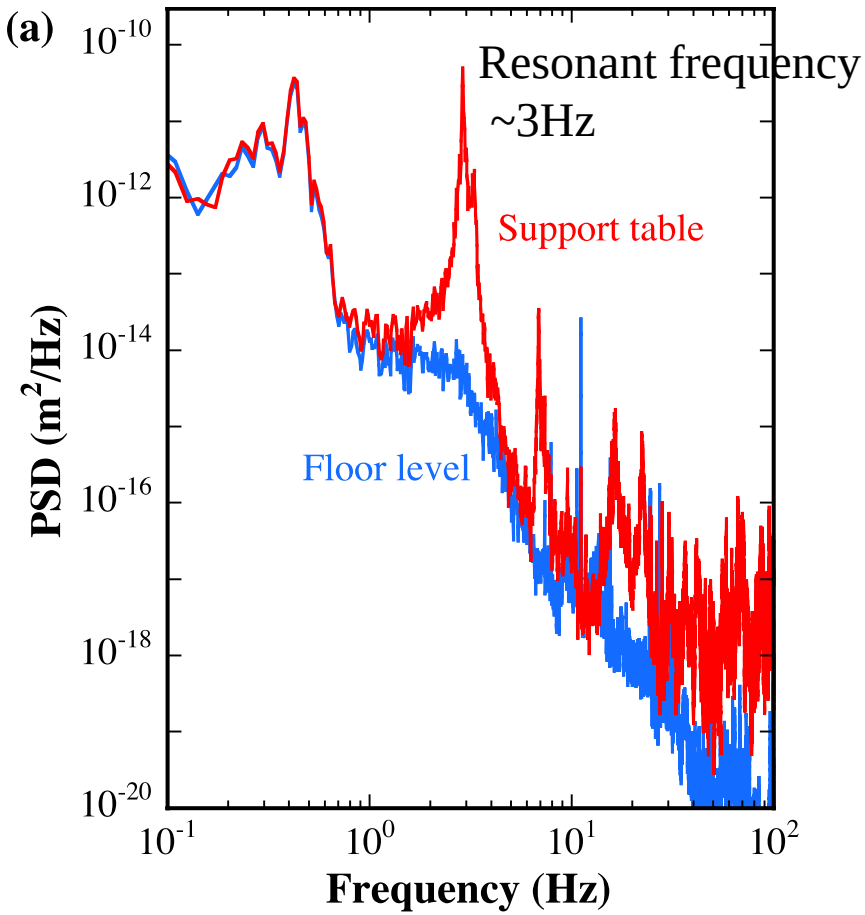
New support table installed for restricting the displacements of the girder unit

Design concept changed from "flexible structure" to "rigid structure"	L-shape support plate

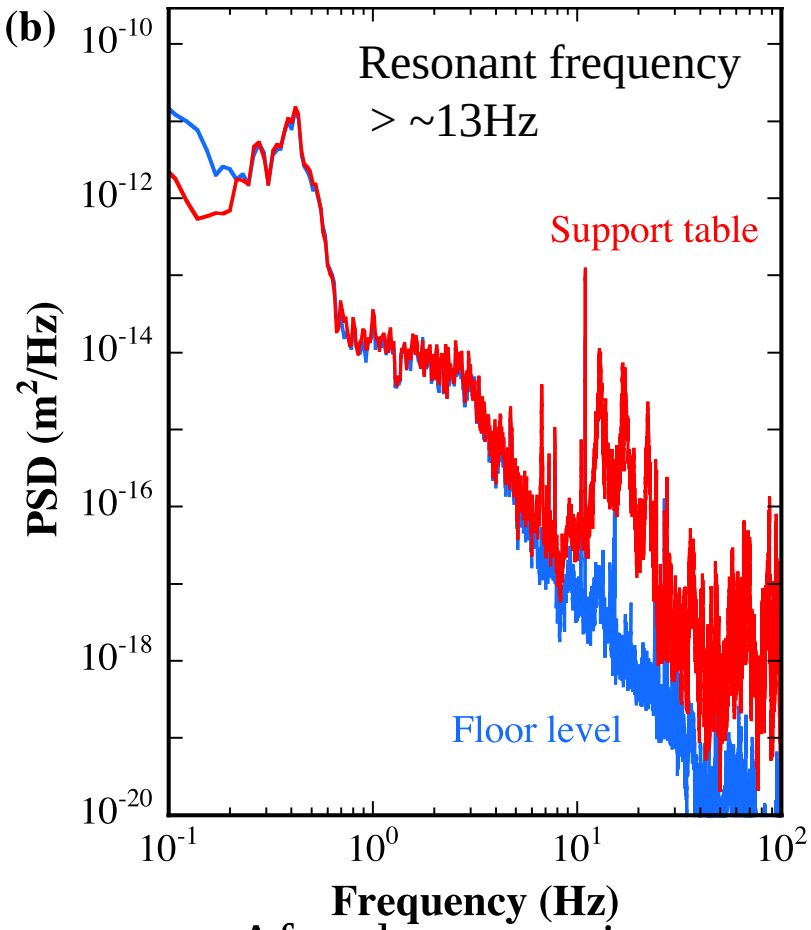




Variational plots of the power spectrum density of the girder unit



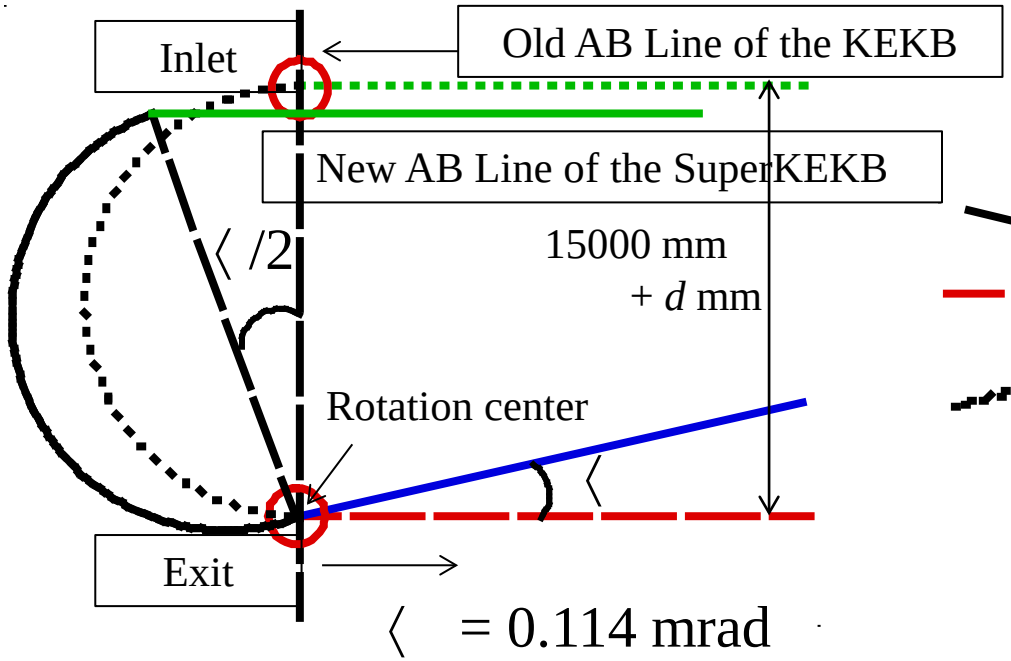
Before the restoration
(“*flexible structure*”)



After the restoration
(“*rigid structure*”)

Initial realignment in the 180-degree arc section

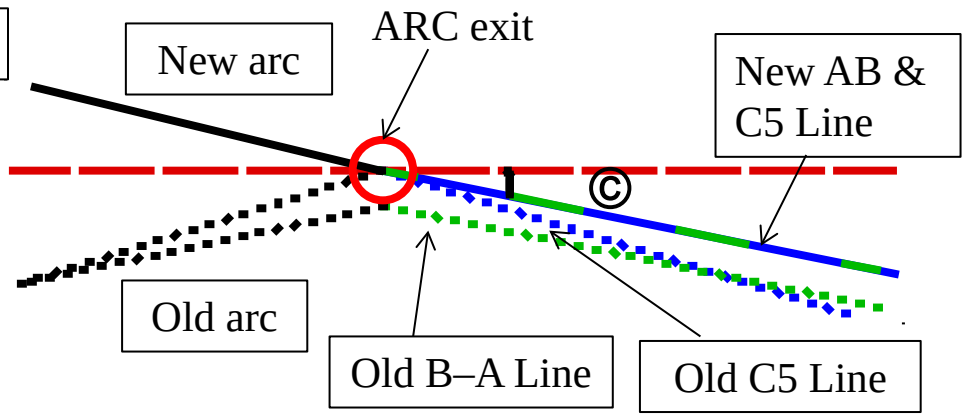
Transverse plane



〈 = 0.114 mrad

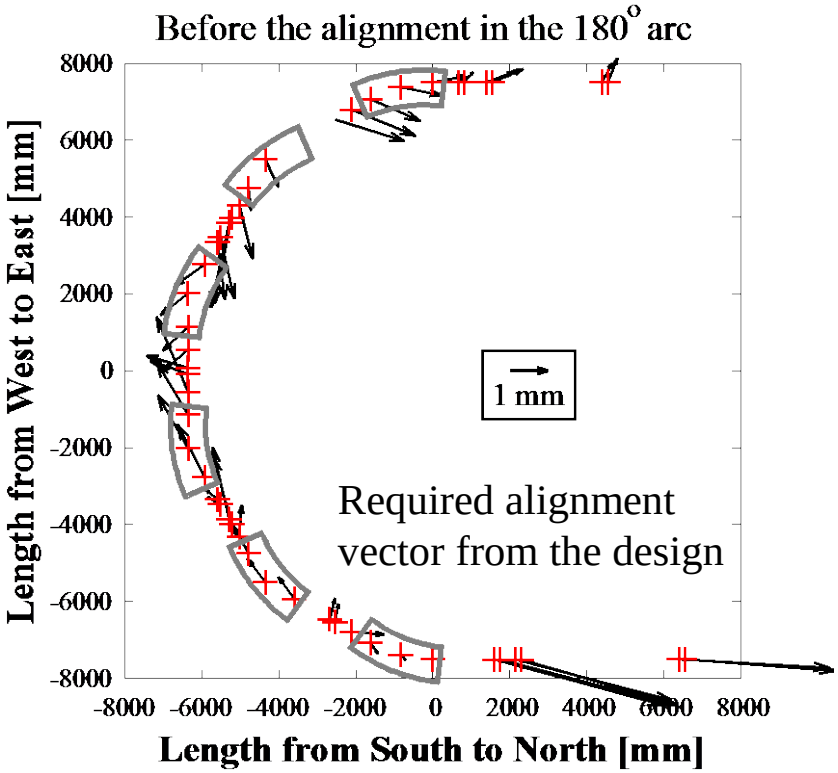
d = 13 mm

Vertical plane

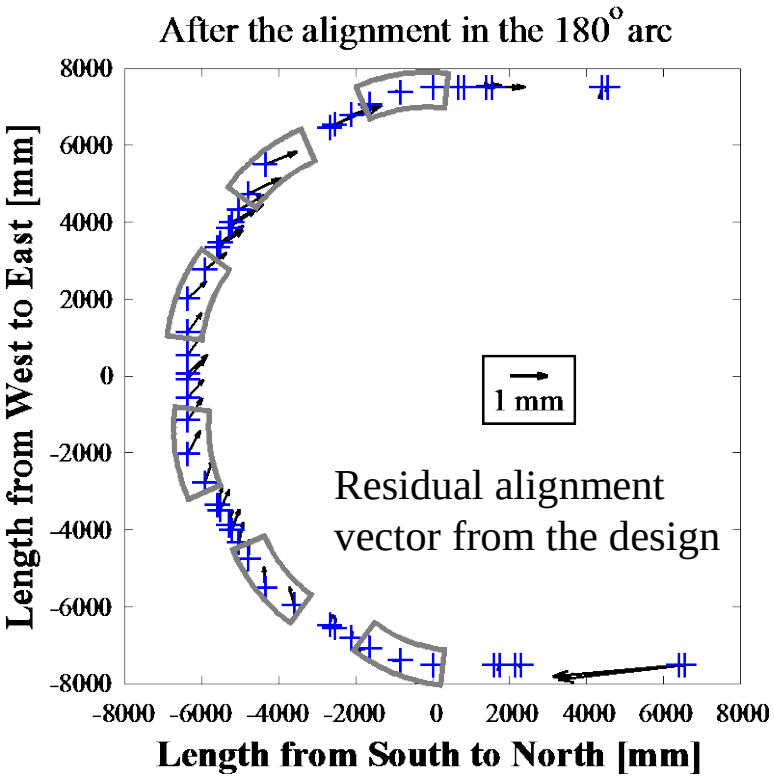


©= 0.0498 mrad

Initial realignment at the 180-degree arc section

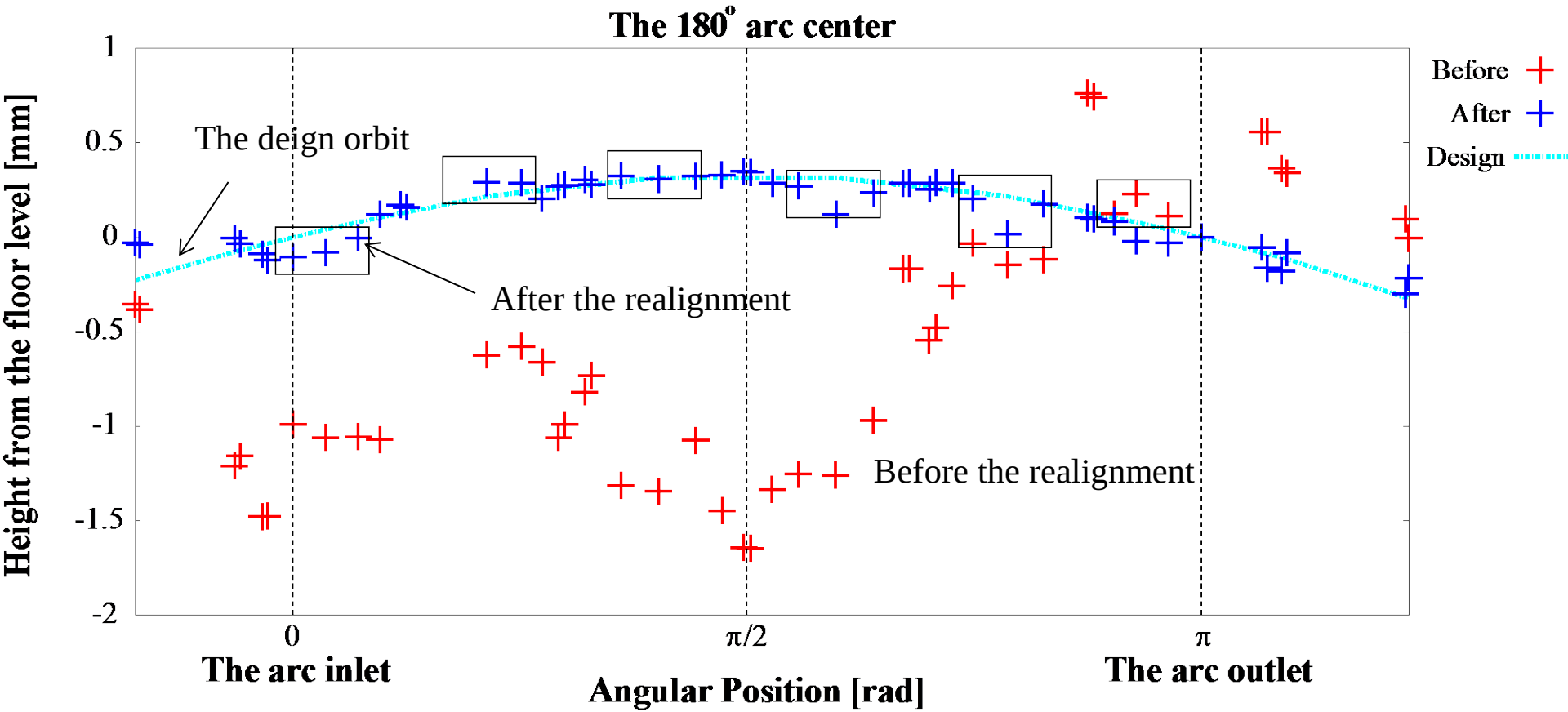


Before the initial realignment



After the initial realignment

Initial realignment in the 180-degree arc section

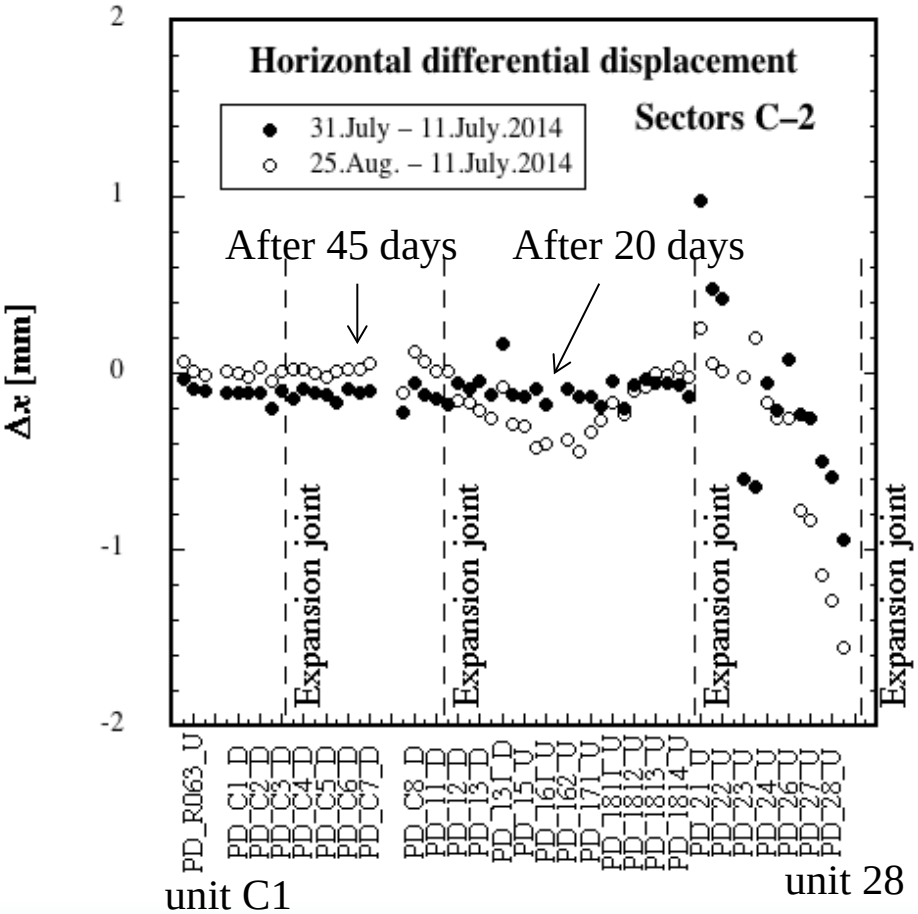


Before and after the initial realignment

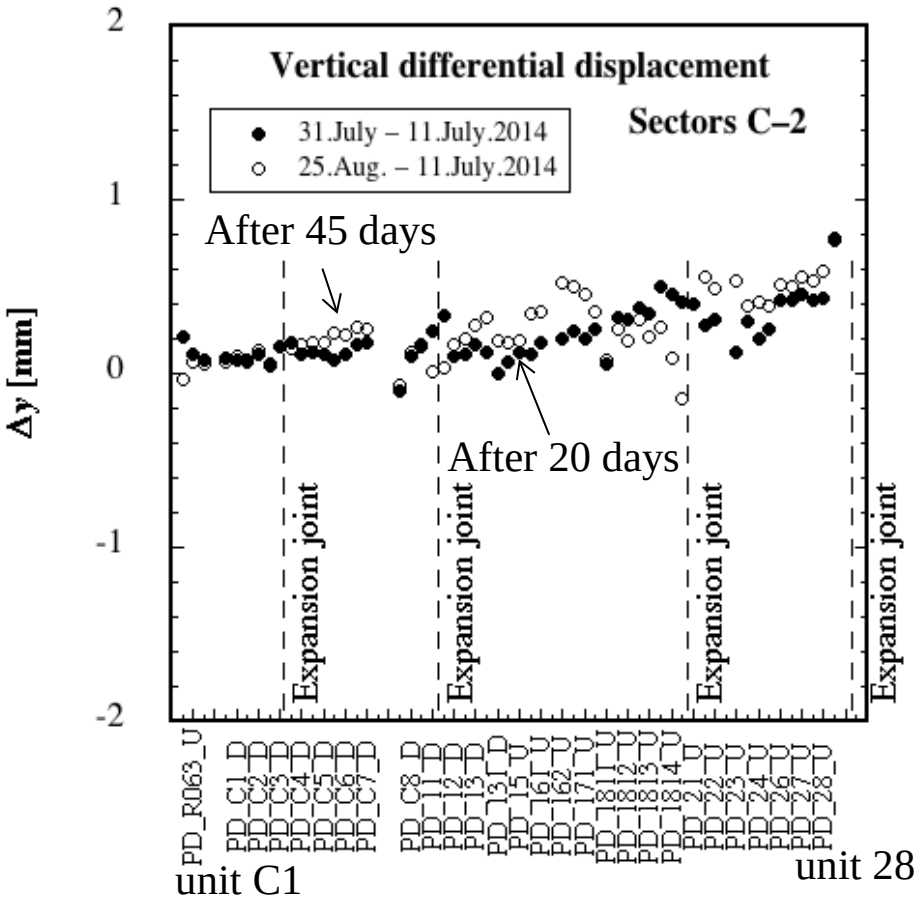
Dynamical motion of the tunnel floor & future prospects

- We have observed dynamical motion of the floor level (or ground motion) in the linac tunnel during the laser-based alignment measurements although the present system is based only on static measurements.
- By using other several methods, *tilt meters*, *micro-gauges*, we also observed the dynamical motion.
- The amount of the displacements is not negligible, and particularly, their directions seem to be in certain systematic directions across expansion joints.
- Now we do not well understand the mechanism of the dynamical motion and the amounts of the displacements along the entire linac.
- In order to investigate such mysterious phenomena, we are now fabricating remote-controlled QPDs.

Variational plots of the x and y displacements of the girder units along the half of the linac

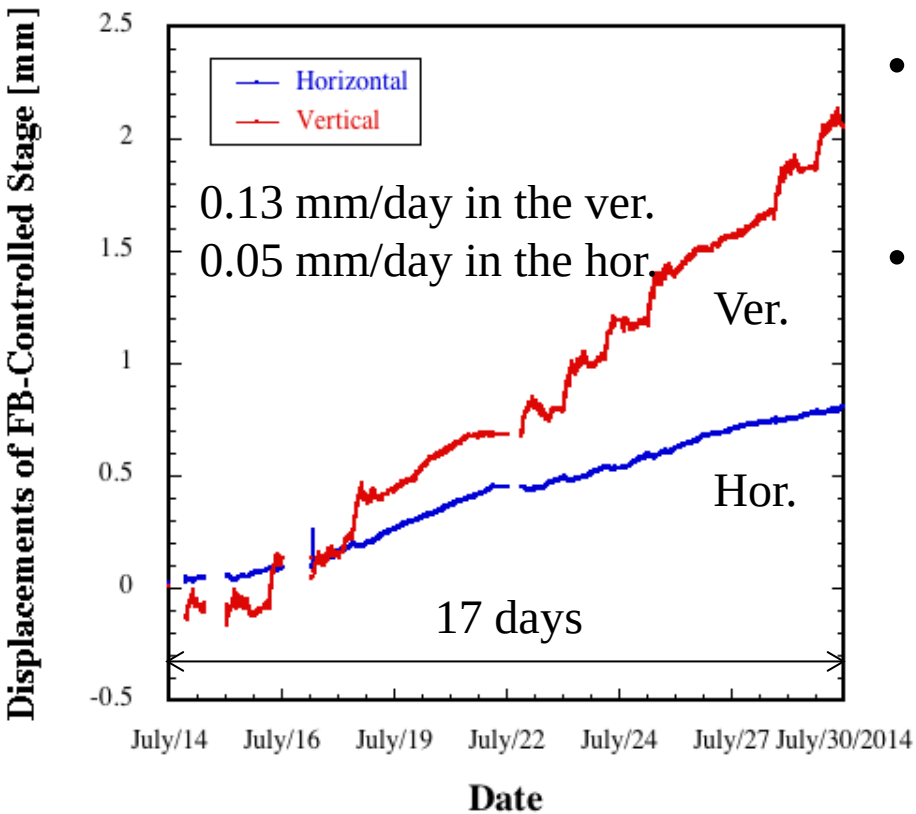


QPD locations from units C1 to 28



QPD locations from units C1 to 28

Variational plots of the x and y displacements of the FB-controlled linear stage



Variations of the FB controlled laser positions at the linac end

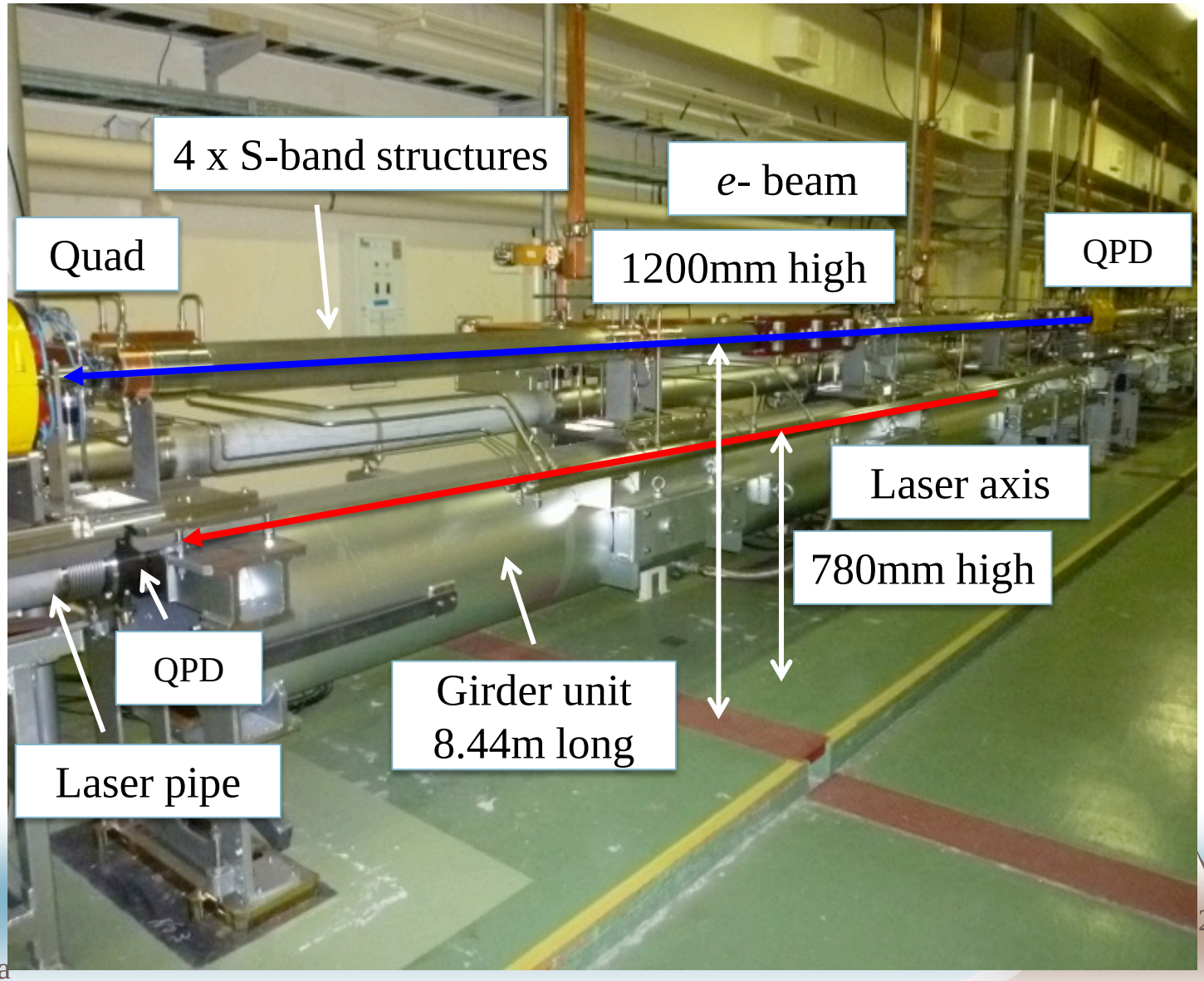
- Variational plots of the FB controlled linear stage at the optical system during 17 days.
- During these days, the laser fiducial was fixed at the center positions of the final QPD at the linac end and the laser-based alignment measurements were well under the feedback control; the injection angles of the laser fiducial could be automatically controlled at the optical system.

Summary

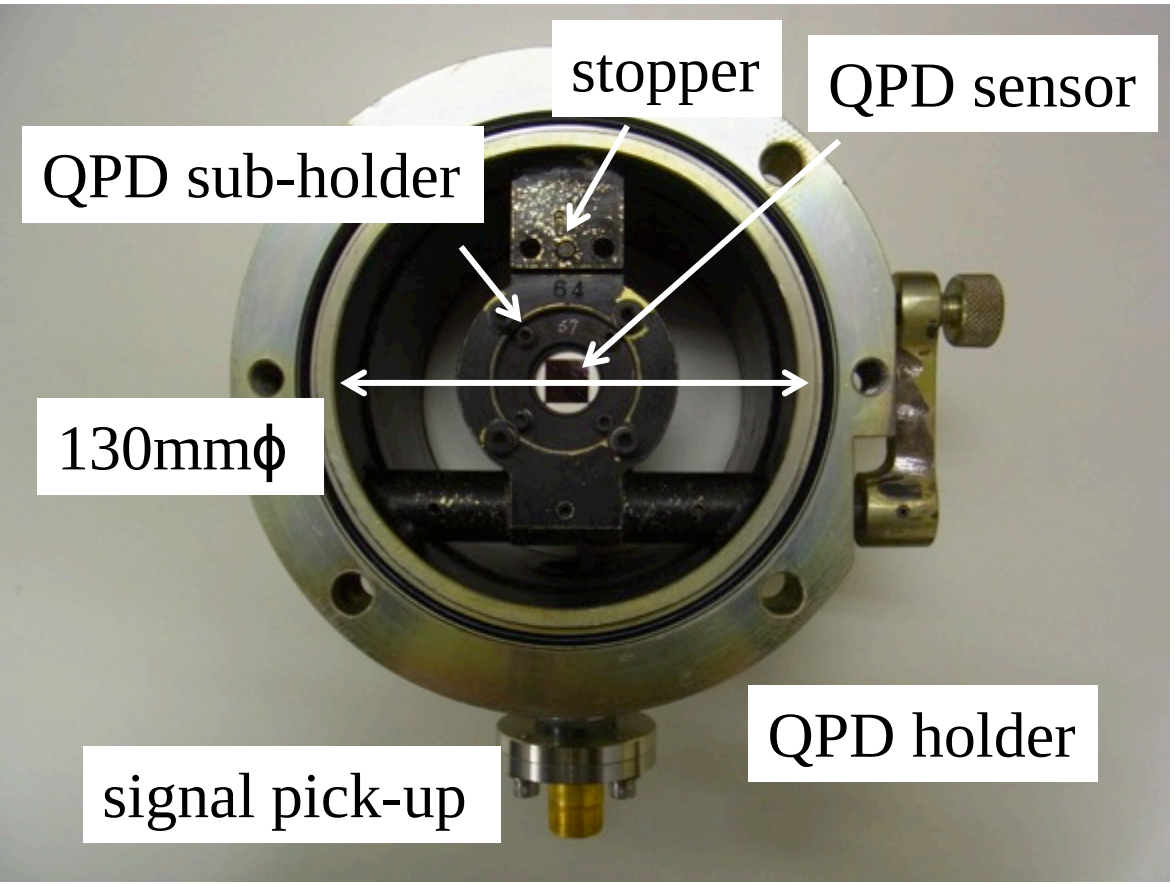
- The initial realignment of the injector linac is successfully in progress for the SuperKEKB. We may need one more rounds to fully complete the initial realignment.
- The laser-based alignment system is now fully operational to the high-precision initial realignment.
- The first realignment of the 180° arc section has been completed, and however, we need one more round.
- Many girder units were restored with increasing the earthquake resistance.
- The initial realignment for the accelerating structures were almost completed with a precision level of 20 μm in one sigma, and that for the quad. magnets is still ongoing.
- In order to investigate the dynamical motion of the tunnel floor level along the entire linac, we have started to fabricate remote-controlled QPDs.

Back-up files

Girder unit for accelerating structures



Quadrant Silicon Photo-Diode (QPD)

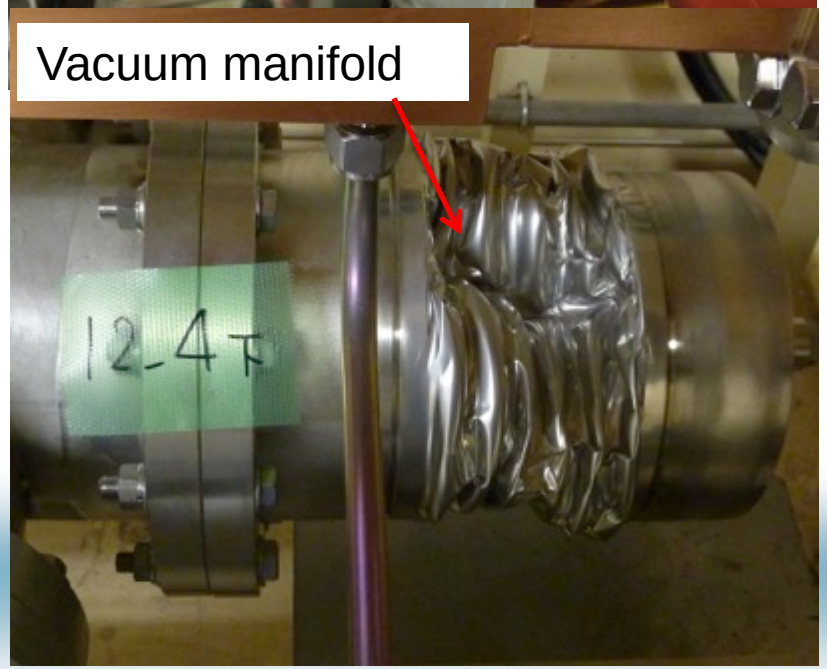


QPD target

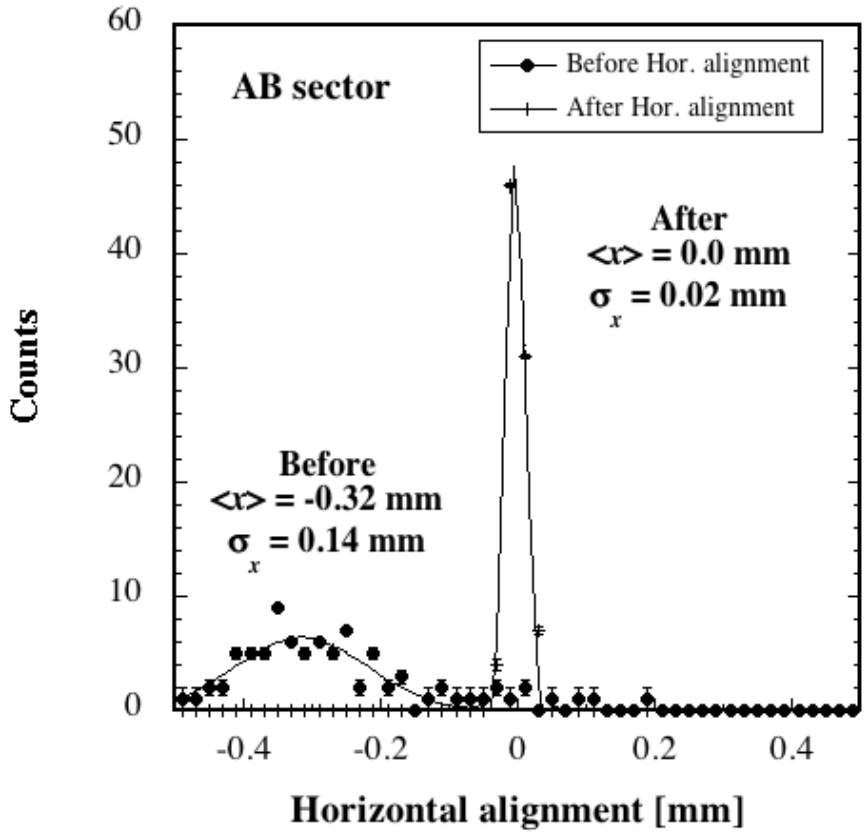
QPD: OSI Optoelectronics
SPOT-9D (D=10mmϕ)

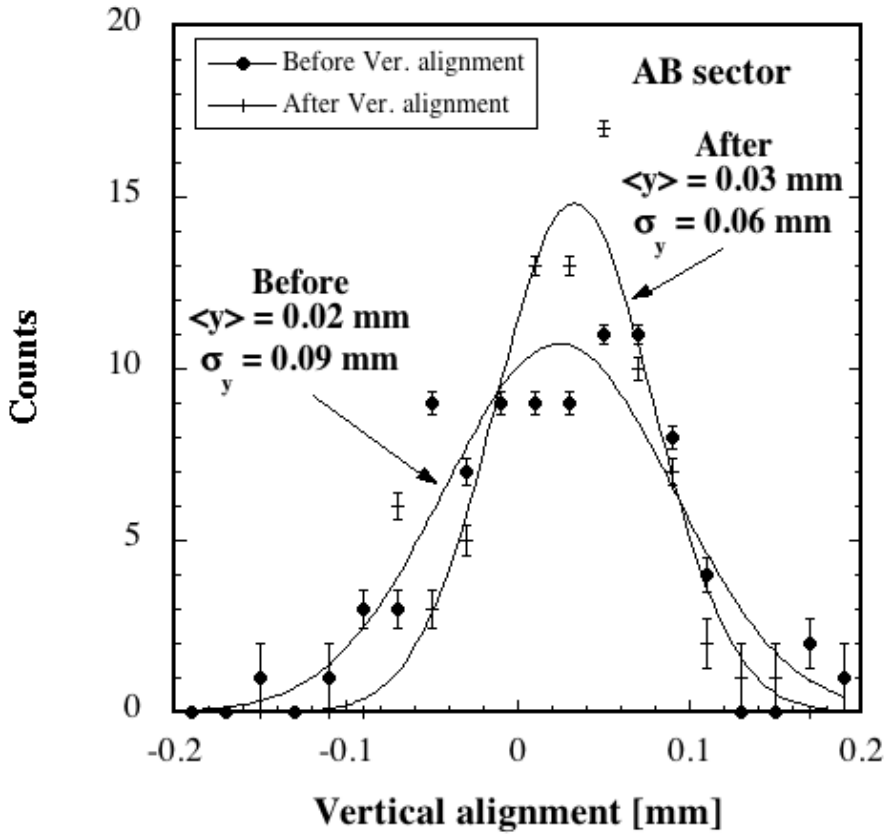
- QPD is mounted in the center of a sub-holder.
- The sub-holder can stand upright by rotation of a lever through hinge structure. The inner diameter of the holder is 130mmϕ.
- The QPD holder is connected to a laser pipe (SUS) by flange-flange joining.

Heavy mechanical damages in 11 Mar. 2011)



Alignment results for the accelerating structures at sectors AB

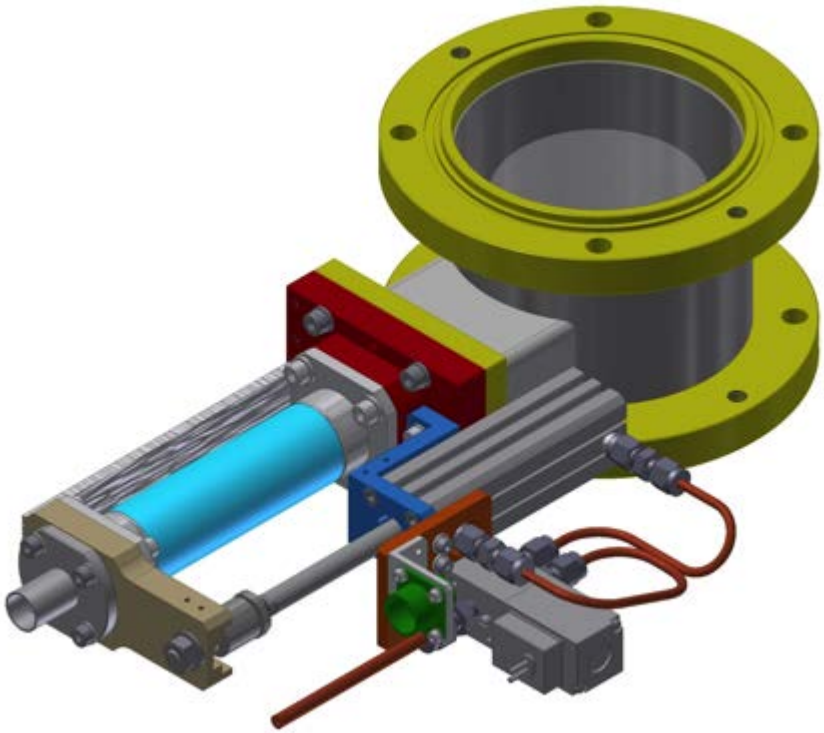




Horizontal

Vertical

Remote-controlled QPD

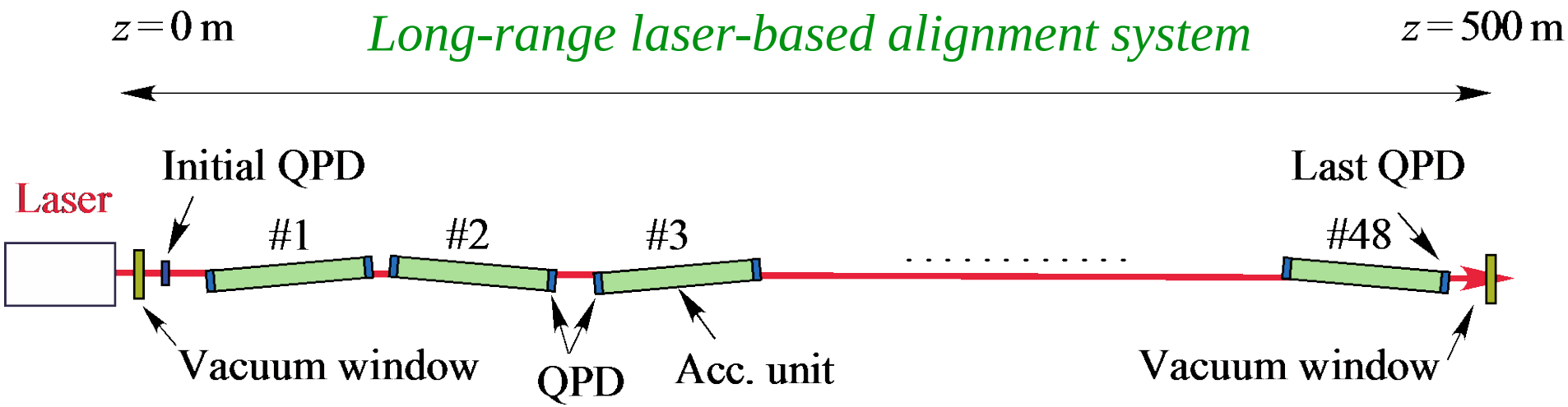


- The purpose with the use of remote QPDs is to investigate the dynamic displacements of the girder units along the entire linac beam line.
- A new remote-controlled QPD is under development.
- They are controllable based on push-pull mechanism of an air cylinder drive.

Developments for the laser-based alignment system

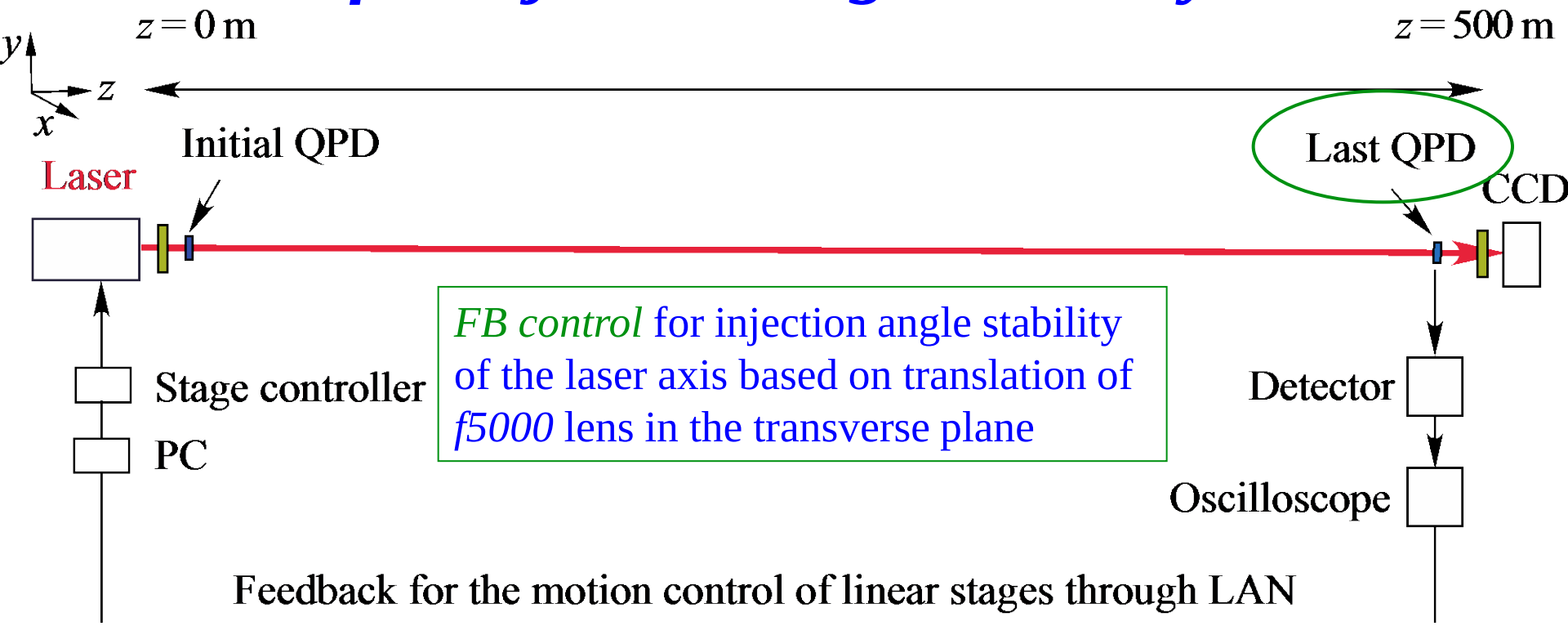
- Our laser-based alignment system was first implemented at the construction stage in 1982; however, the high stabilization of the laser-based fiducial line has not been realized until now.
- At long last, a laser line with high stabilization has been implemented as a 500-m-long fiducial line for alignments in March 2013.
- We experimentally investigated the propagation and stability characteristics of the laser line passing through metallic pipes in vacuum.
- Pointing stability at the last fiducial point with the transverse displacements of ±40 μm level in one standard deviation by applying a feedback control was successfully obtained. This pointing stability corresponds to an angle of ±0.08 μrad. This system is now fully exhibiting the successful results for the high-precision alignment of the injector linac currently in progress.

Two alignment systems for girders and components



- *Long-range alignment system for girders* (accuracy σ ~ 100μm)
  The girder units are aligned based on the laser-based alignment.
- *Short-range alignment system for components* (accuracy σ ~ 50μm)
  The accelerator components on a girder unit are aligned based on a standard laser-tracker technique.

Feedback control for laser axis – for injection angle stability –



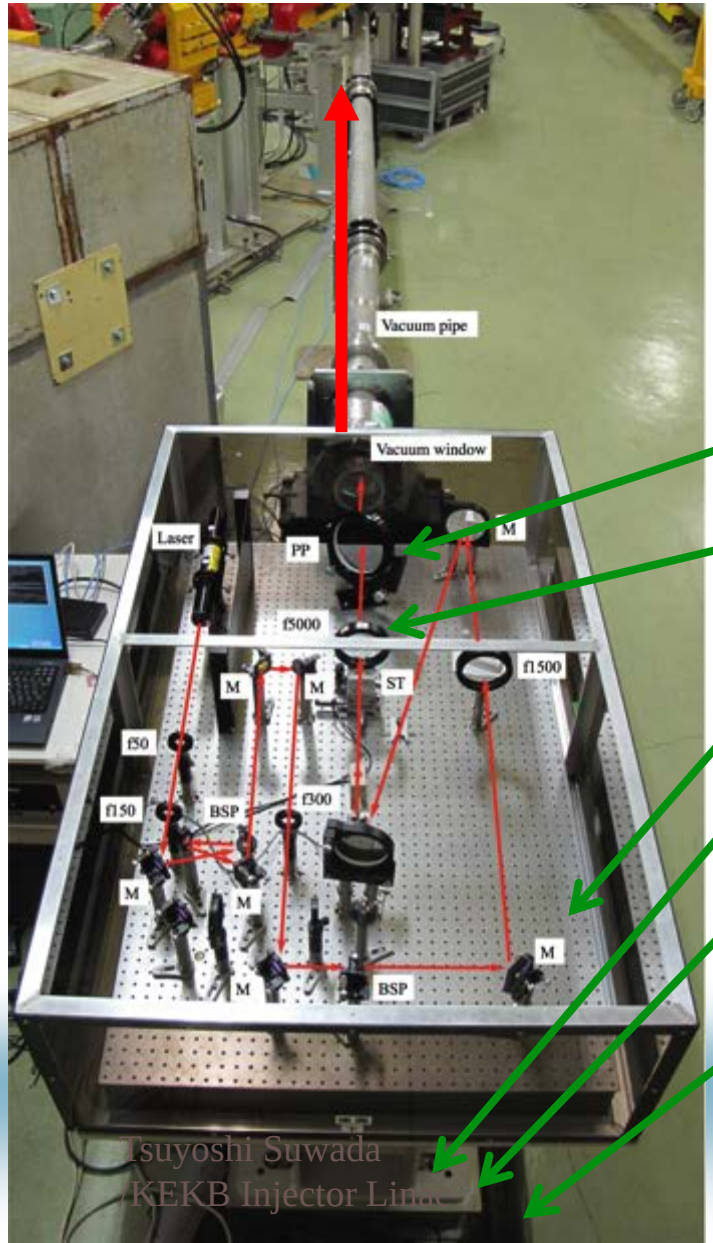
FB control for injection angle stability of the laser axis based on translation of *f5000* lens in the transverse plane

Stage with pico-motors for f5000 lens (Crucial for stable laser axis)

- M-562-XYZ/Newport, translational resolution 30nm/step → ~1nrad/step
- The drive shaft is rotated by frictional force of piezoelectric element and the stage translates in the transverse plane.

Ultrafine stage to stabilize the laser pointing

Optical system



Optical system

- 10-mW He-Ne laser
- Solid and large optical table

Vacuum system

- Two scroll pumps (1000*l*/min)
- Vacuum level ~3 [Pa]

Parallel plate for translation tuning

f5000 lens for injection angle tuning

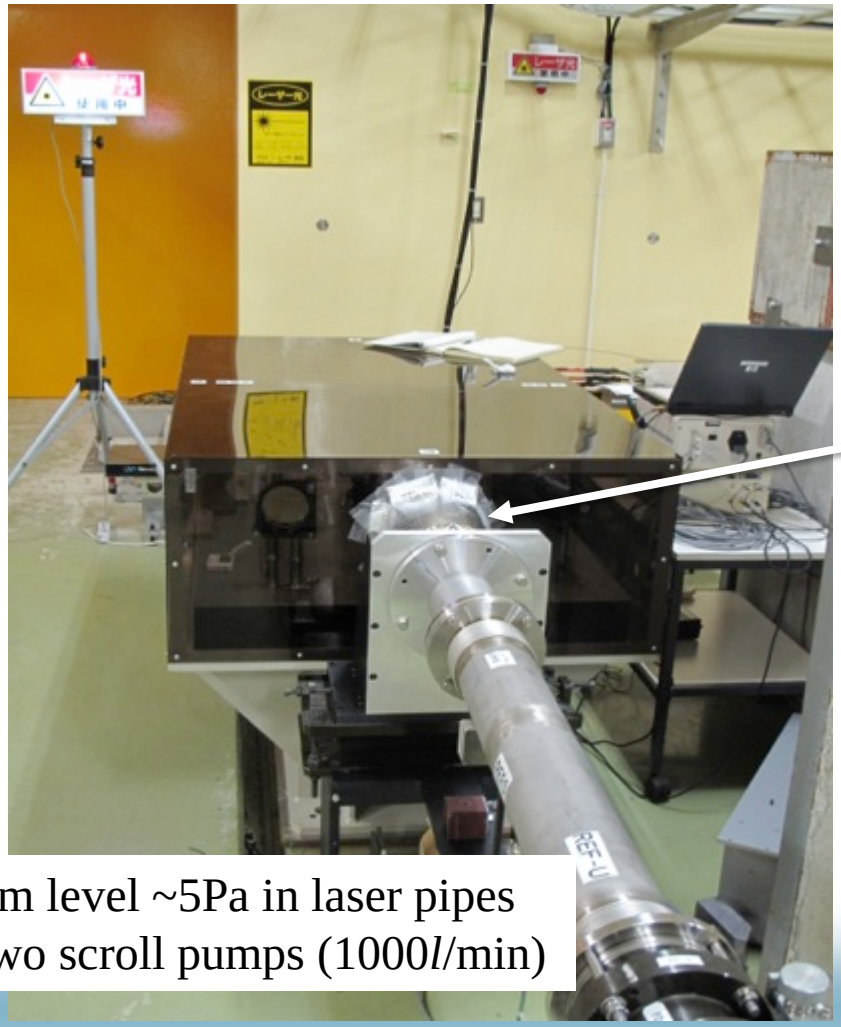
Optical table (1500×900×112^{t}mm^3)

Girder (*Fe*)

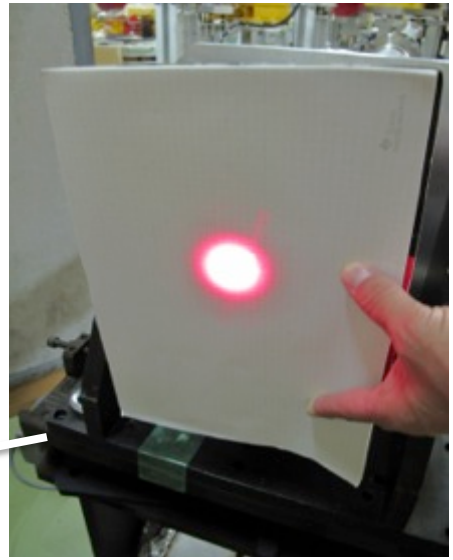
Iron plate (1510×500×20^{t}mm^3)

Isolated floor separated from the tunnel floor by a 100-mm gap (1510×500mm^2)

He-Ne Laser beam first successful delivering up to 500 m in 20 July 2012

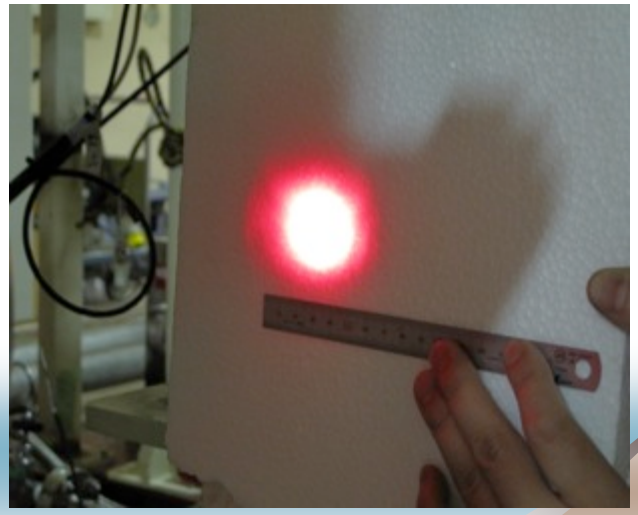


Vacuum level ~5Pa in laser pipes with two scroll pumps (1000*l*/min)



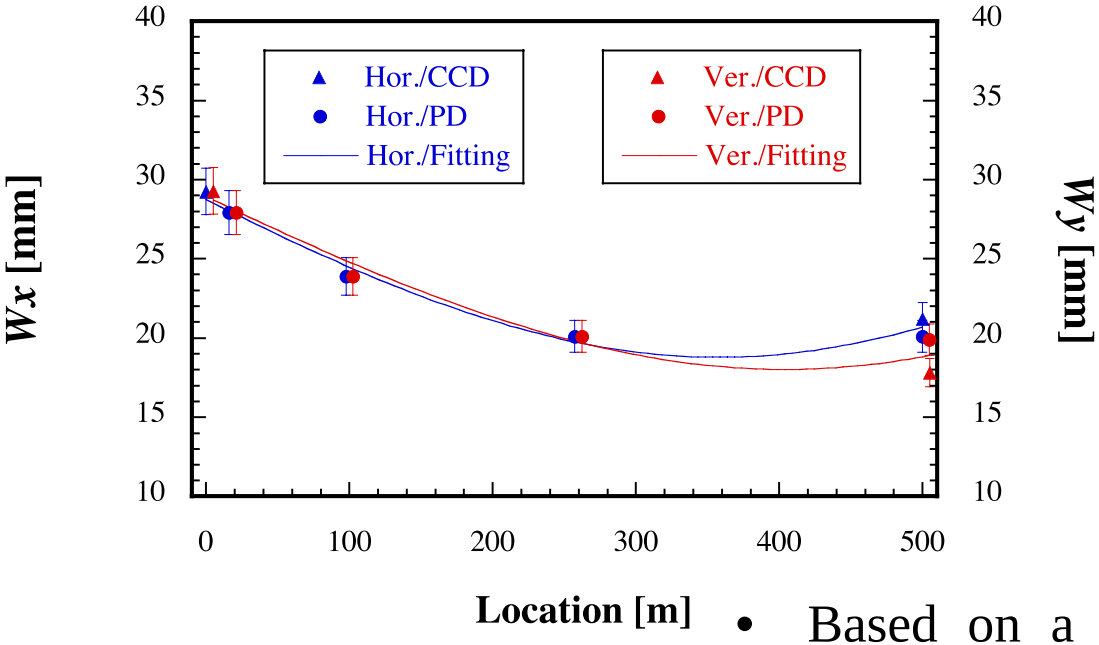
W~30mm (FW)
at the injection point

W~30mm (FW)
at the 500m-long linac end point



Laser system under operation

Results of the laser size measurements along the linac



- *Direct beam size meas.*
  Δ: with CCDs at two end points
- *Indirect beam size meas.*
  •: by a mapping with a movable QPD in the *x* and *y* directions at the middle locations, while the laser axis is fixed

Fitting function

$$W_x(z) = W_{x0}\sqrt{1+\left(\frac{z-z_{x0}}{z_{Rx}}\right)^2},$$

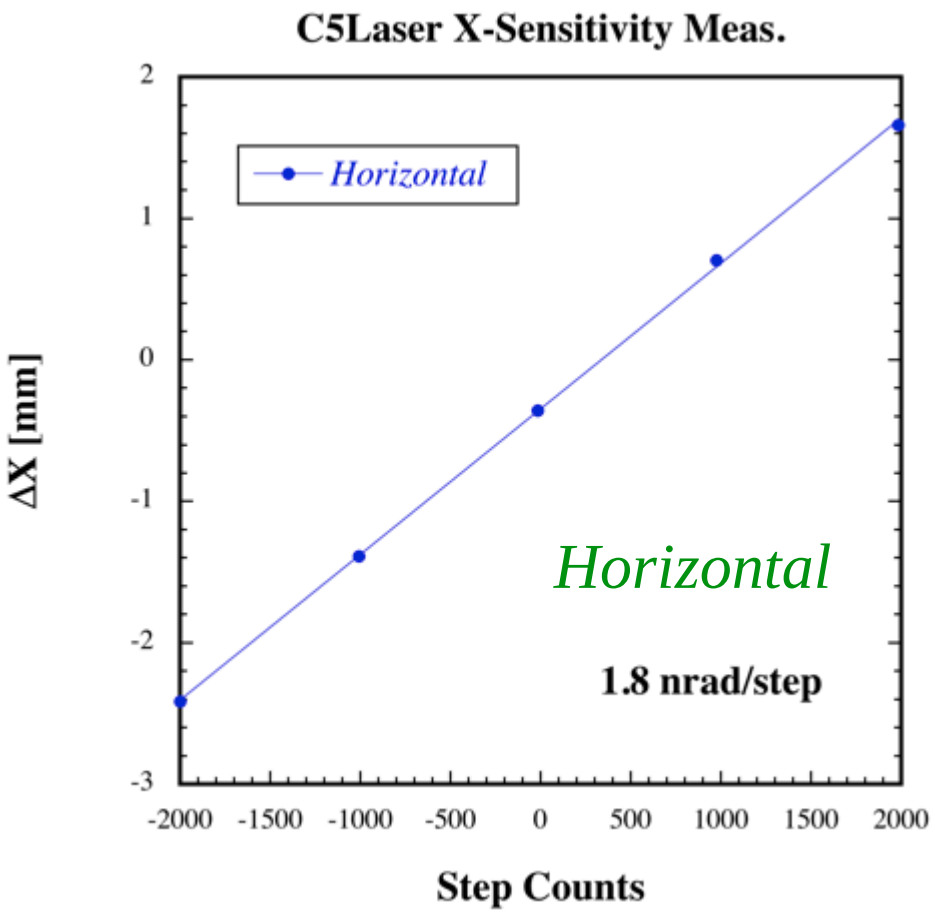
- Based on a least-square fitting procedure with standard Gaussian laser optics, the widths propagating along the *z*-axis were obtained as follow:

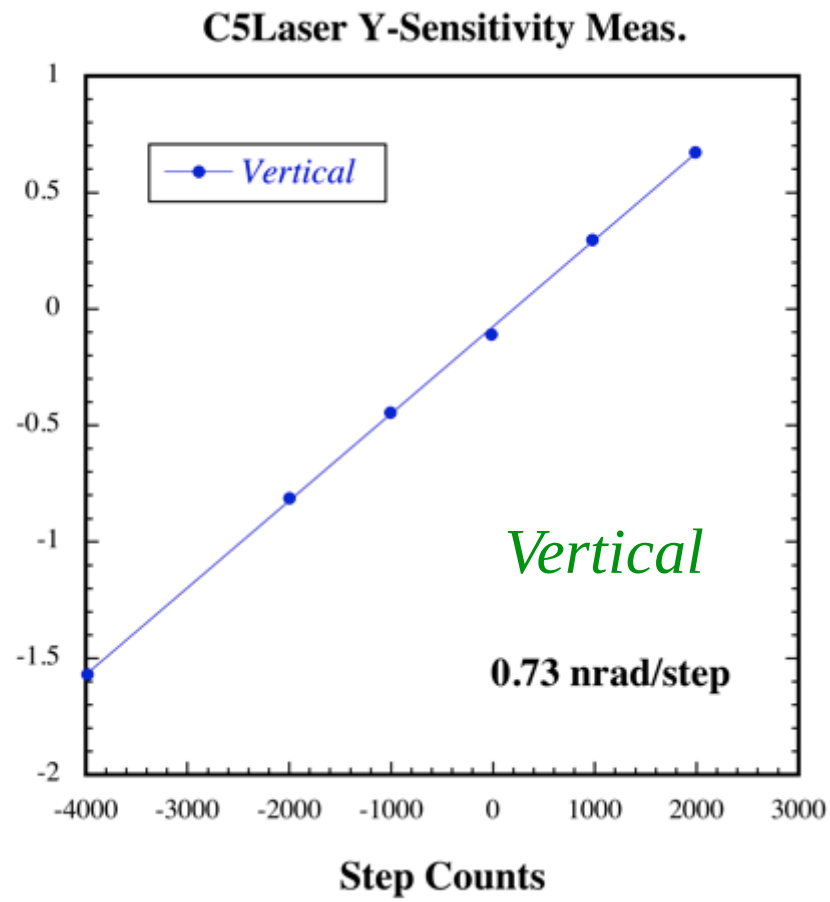
  Rayleigh lengths z_{Rx} ~ 308 m, z_{Ry} ~ 321 m,

  Waist locations z_{x0} ~ 358 m, z_{y0} ~ 399 m,

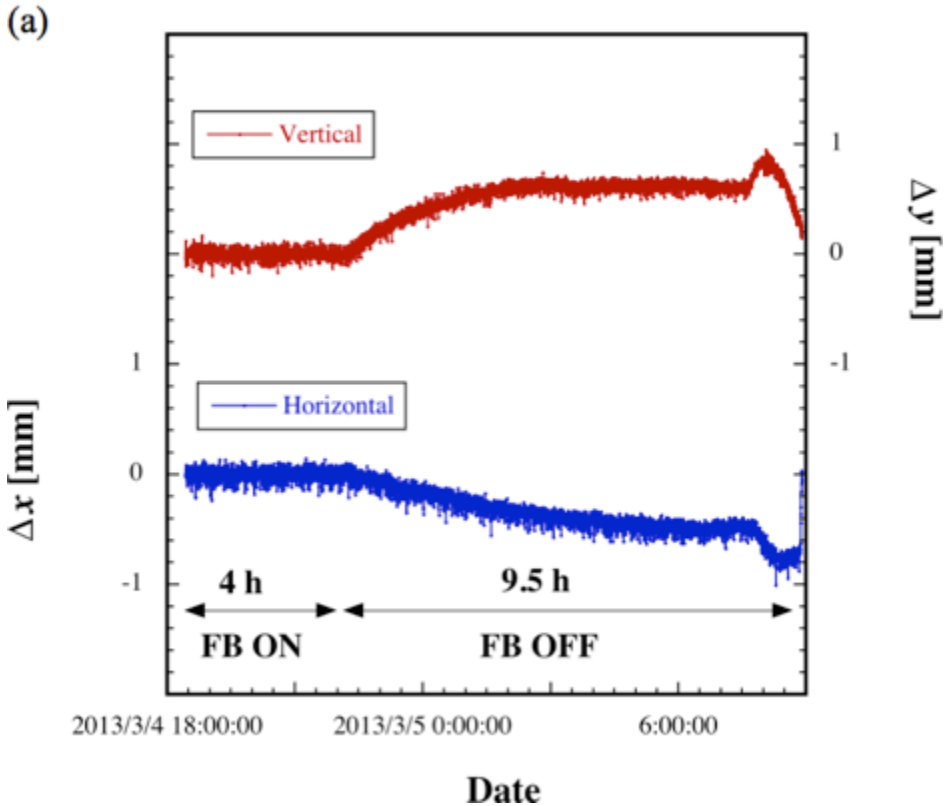
  Beam sizes at waist locations W_{x0} ~ 18.8 mm, W_{y0} ~ 18.0 m,

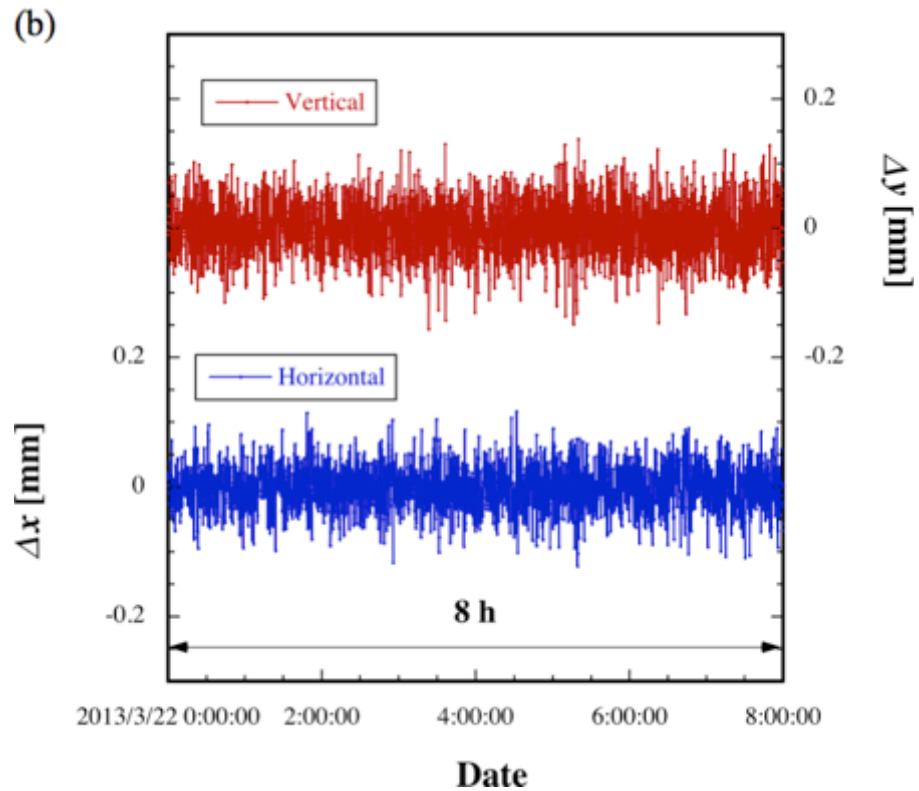
Sensitivity measurements of the laser axis at z = 500m





Stability measurements of the laser axes at z=500 m

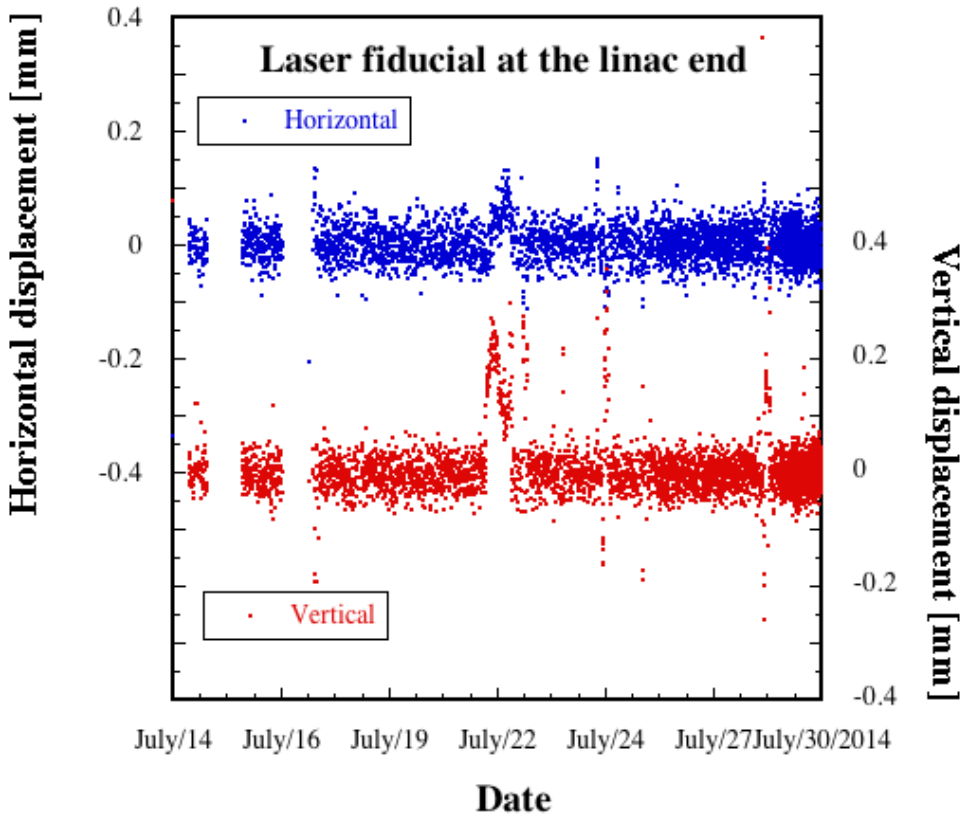




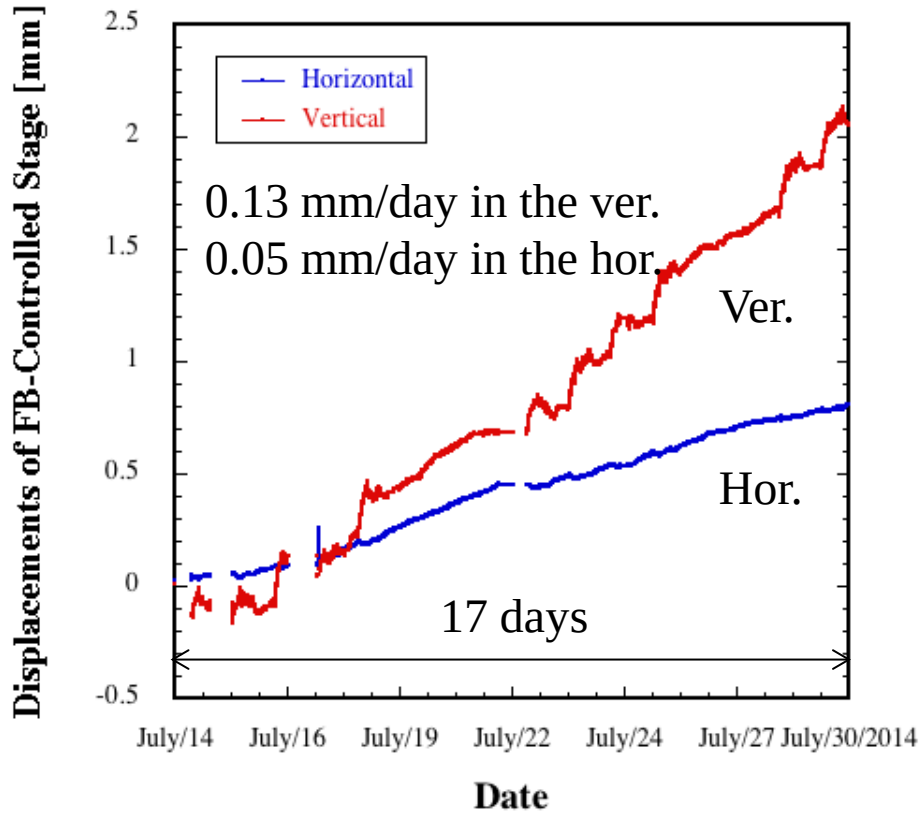
Time traces of the horizontal and vertical position displacements of the laser beam at the last QPD (a) with the feedback control on and off during 13.5 h

Time traces of the horizontal and vertical position displacements of the laser beam at the last QPD (b) with the feedback control on during 8 h.

Variational plots of the x and y displacements of the FB-controlled linear stage

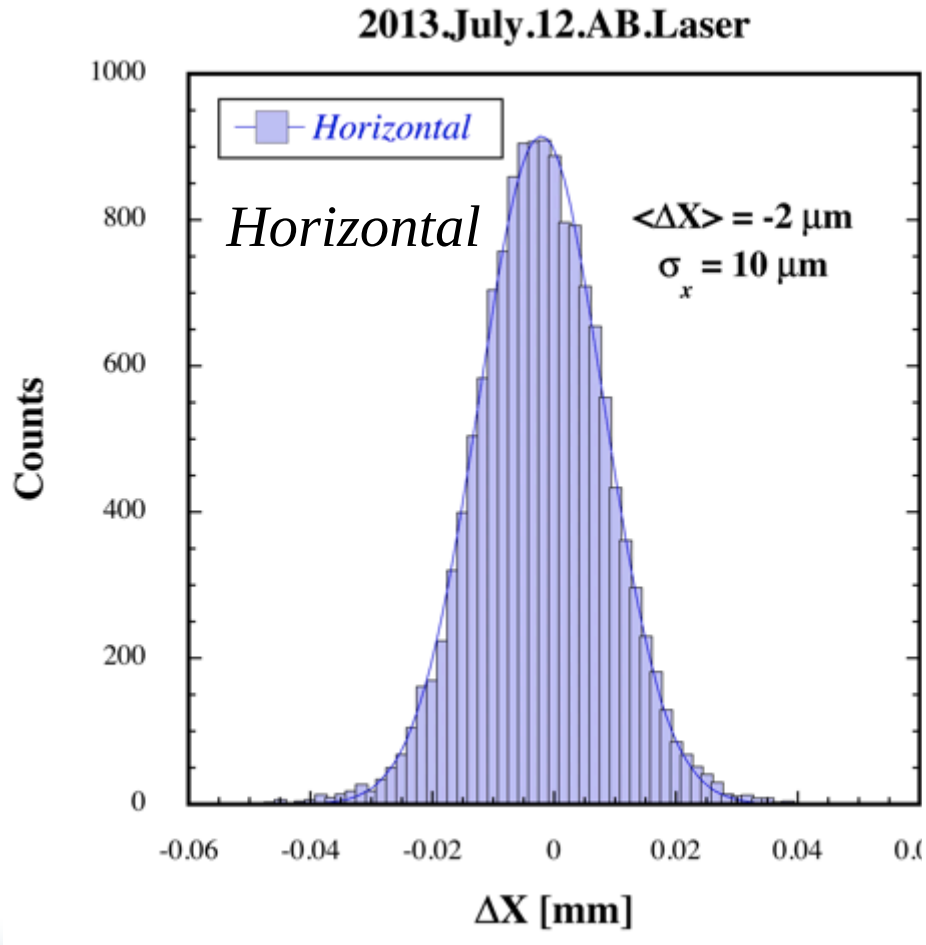


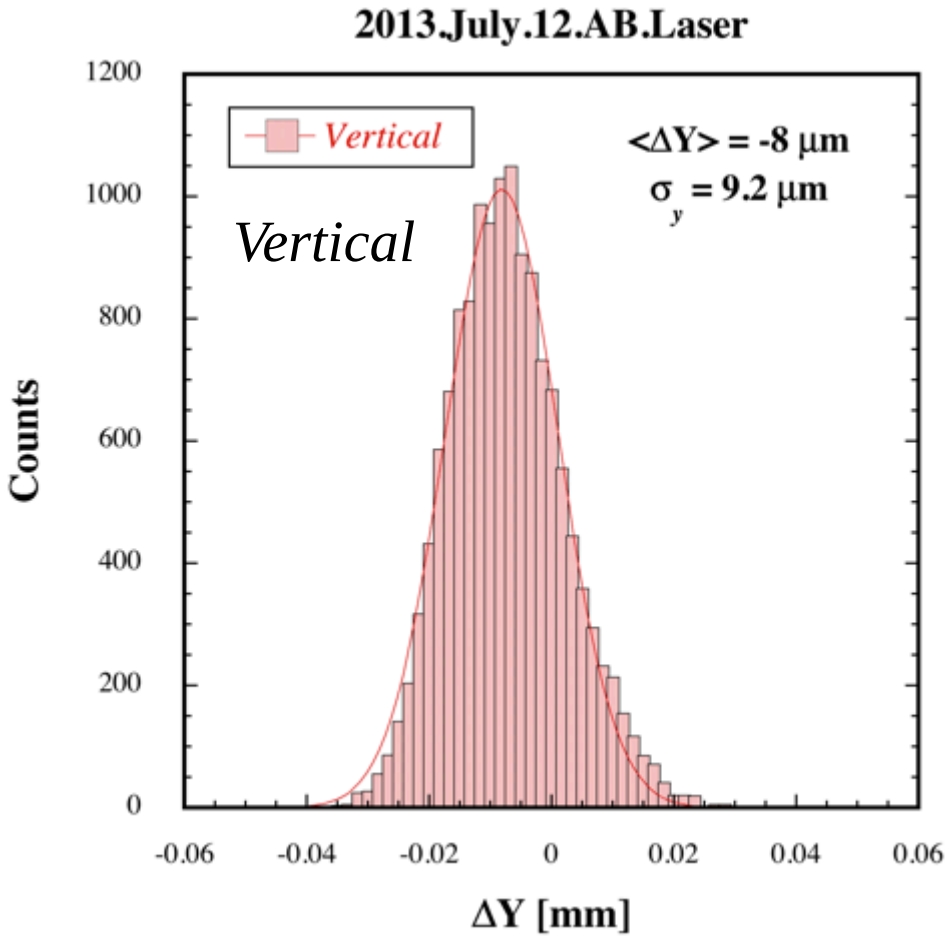
Variations of the FB controlled laser positions at the linac end



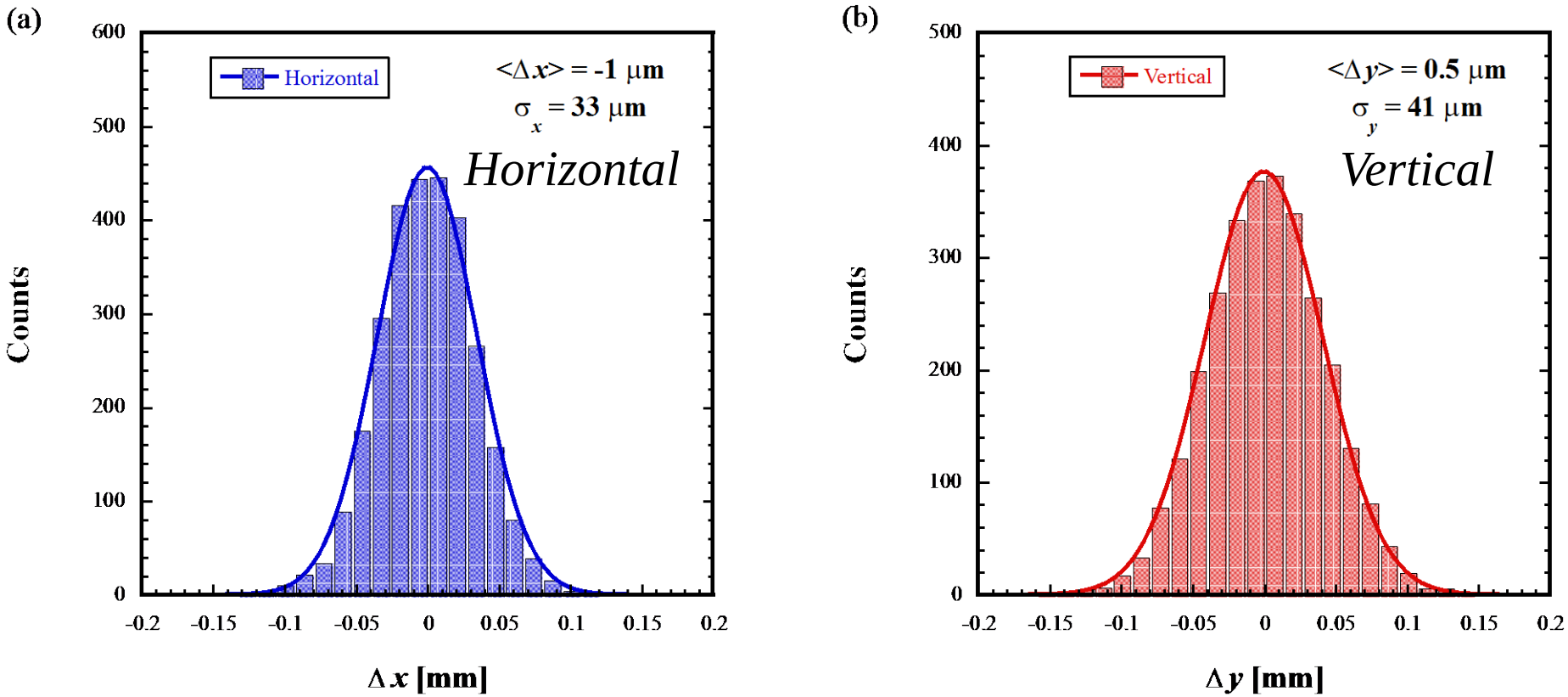
Variations of the FB controlled linear stage at the optical system

Position displacement distribution of the laser axes for 132-m-long straight line





Position displacement distributions of the laser axes for 500-m-long straight line



Expected error sources and estimations for the laser fiducial

Errors	Source of errors	rms error (μm)
Systematic error	*Mechanical*	
	• Mounting error of QPD	10
	• Mounting error of QPD holder	30
	• Reproducibility of QPD position	30
	Electrical	
	• Detection (offset) error of QPD	12
	Laser Shape	
	• Profile error	10
	Summation (rms sum)	46
Statistical error	*Laser stability*	
	• Laser axis stability	± 40

Near future

- Our present laser-based alignment system was basically constructed more than 30 years before (very old).
- There are several drawbacks, for example, this system is not radiation-hard, and also not transparent for the QPD targets.
- Another laser-based alignment system based on the SLAC method is more excellent because the system itself is radiation-hard, transparent and very stable without any feedback controls.
- We are also preparing a similar laser-based alignment system.

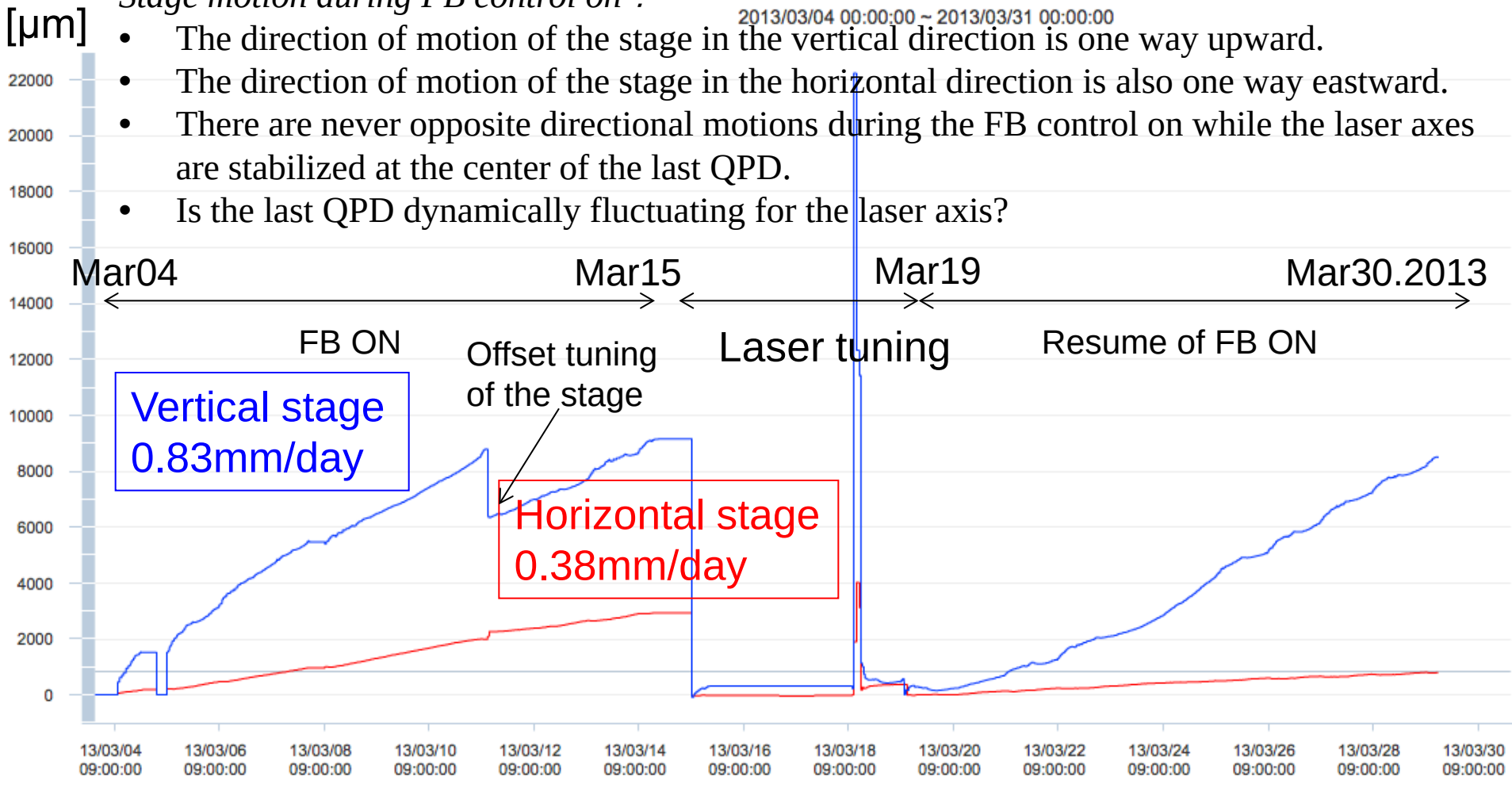
Laser size measurements along the linac

- The beam widths were directly measured at the two fiducial points (z=0 and z=500m).
- At other locations, they were analyzed by taking mapping data obtained with the help of mechanically movable QPDs while the laser beam was fixed. The mapping data were obtained by measuring the variations in the signal levels obtained from the QPD depending on the transverse displacements with respect to the fiducial line.
- The beam widths were analyzed by a least-square fitting procedure with a two-dimensional Gaussian function for the obtained mapping data.

Long-term motions of the stage of f5000 lens with FB control on

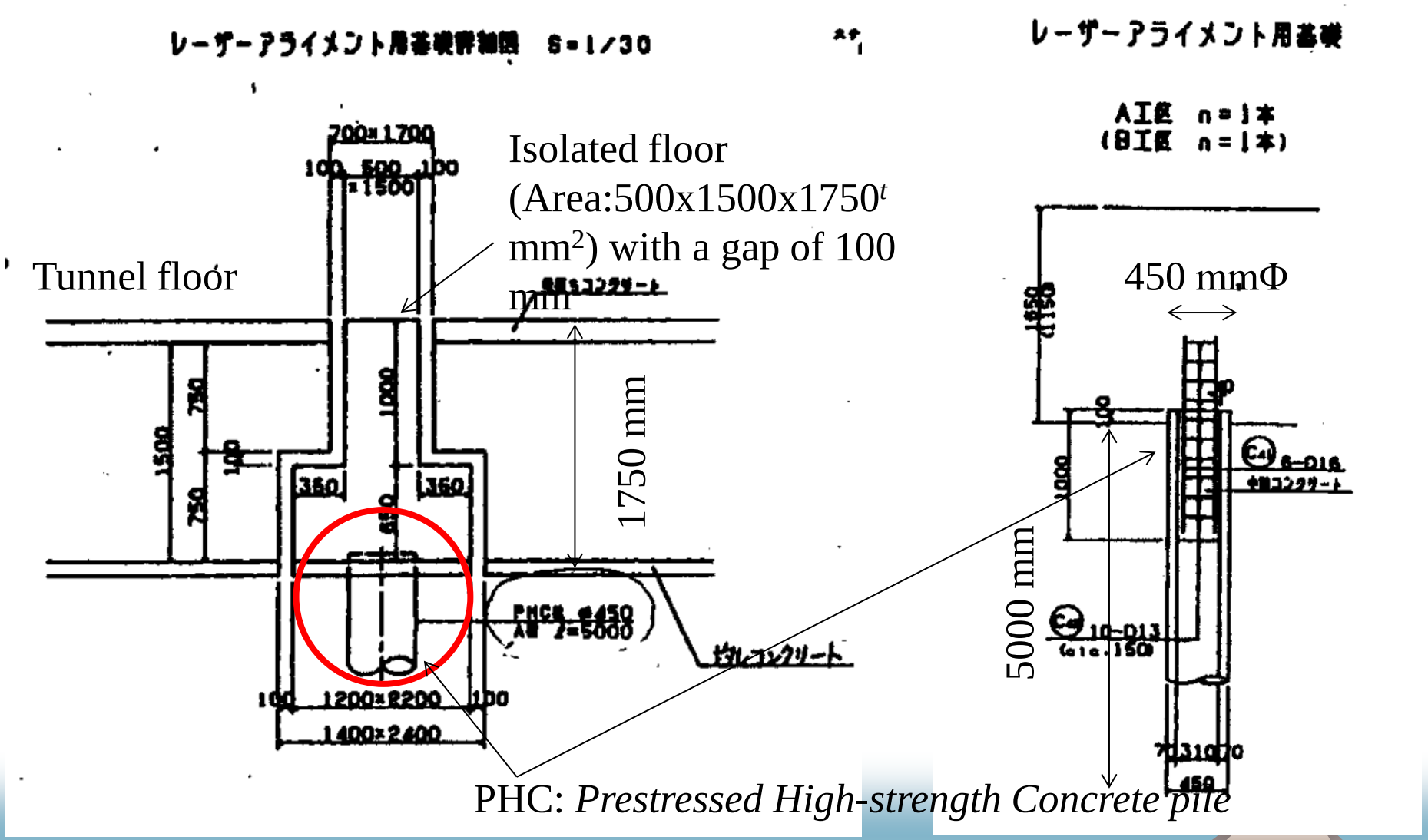
Stage motion during FB control on :

- The direction of motion of the stage in the vertical direction is one way upward.
- The direction of motion of the stage in the horizontal direction is also one way eastward.
- There are never opposite directional motions during the FB control on while the laser axes are stabilized at the center of the last QPD.
- Is the last QPD dynamically fluctuating for the laser axis?

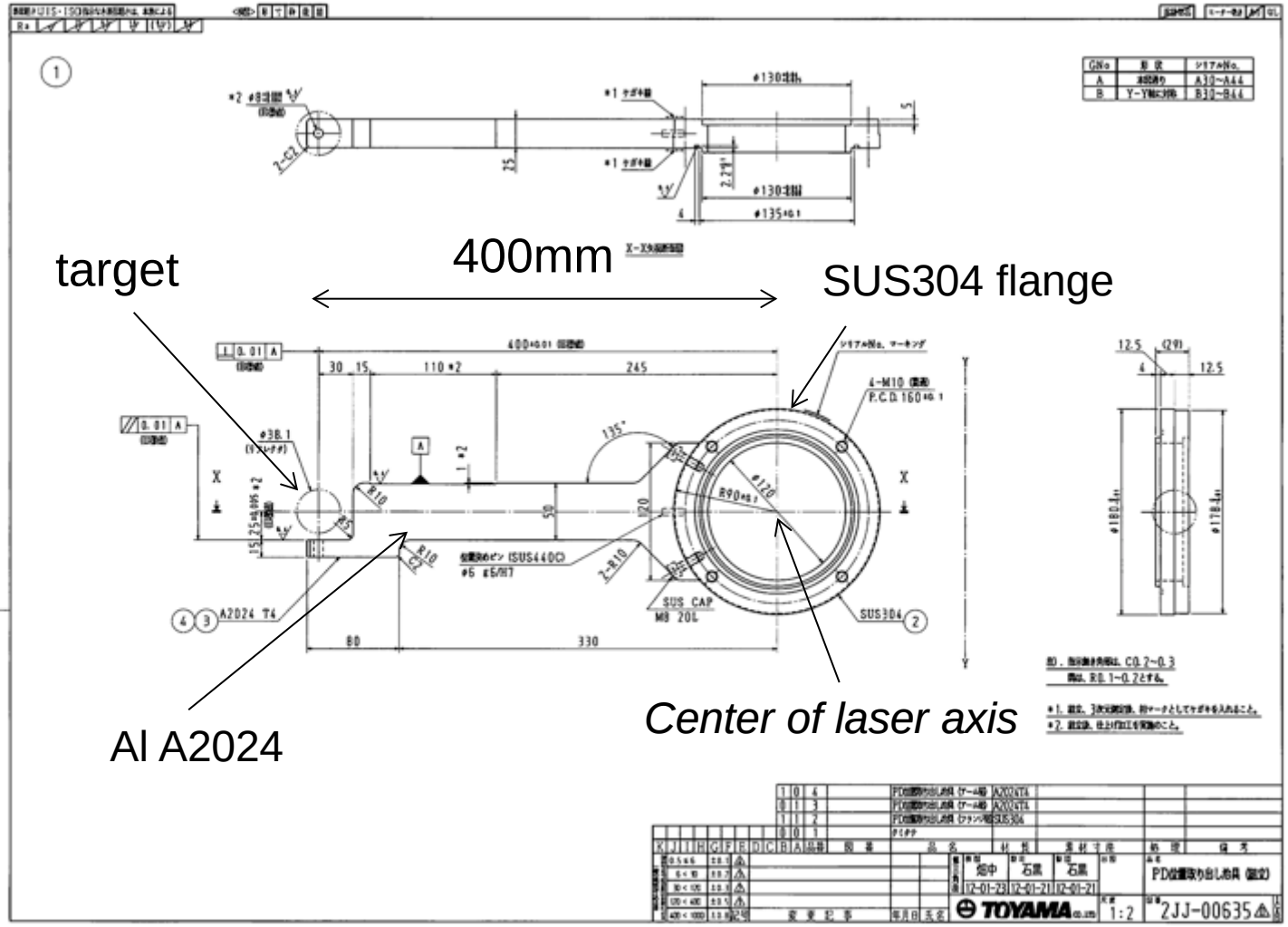


Date

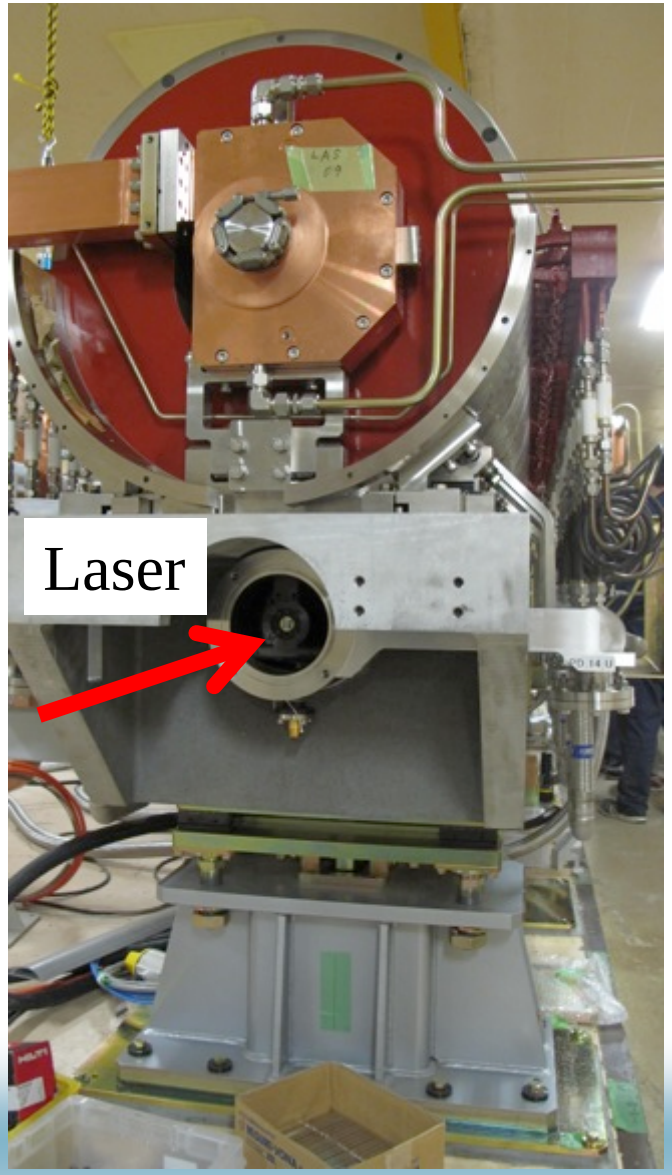
Isolated floor structure at the optical ystem

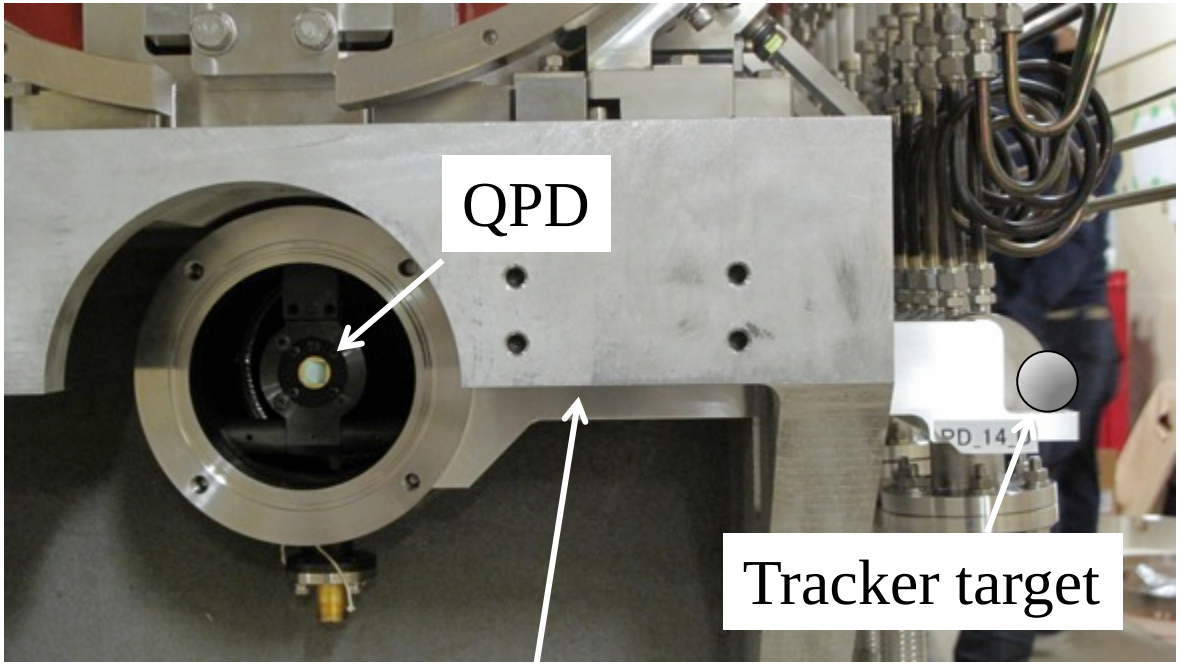


Mechanical jig for fiducialization of tracker target



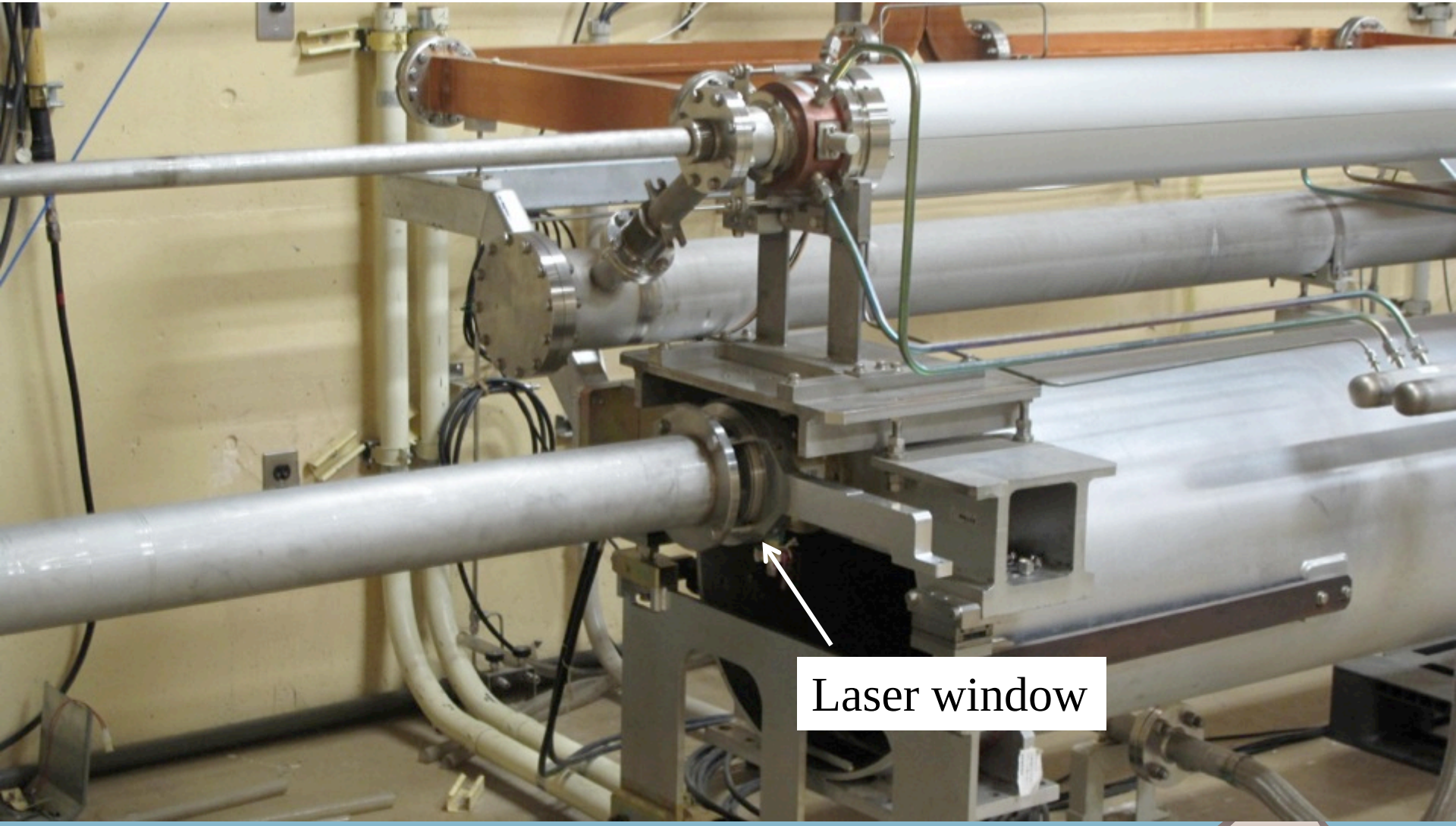
Component alignment on the girder



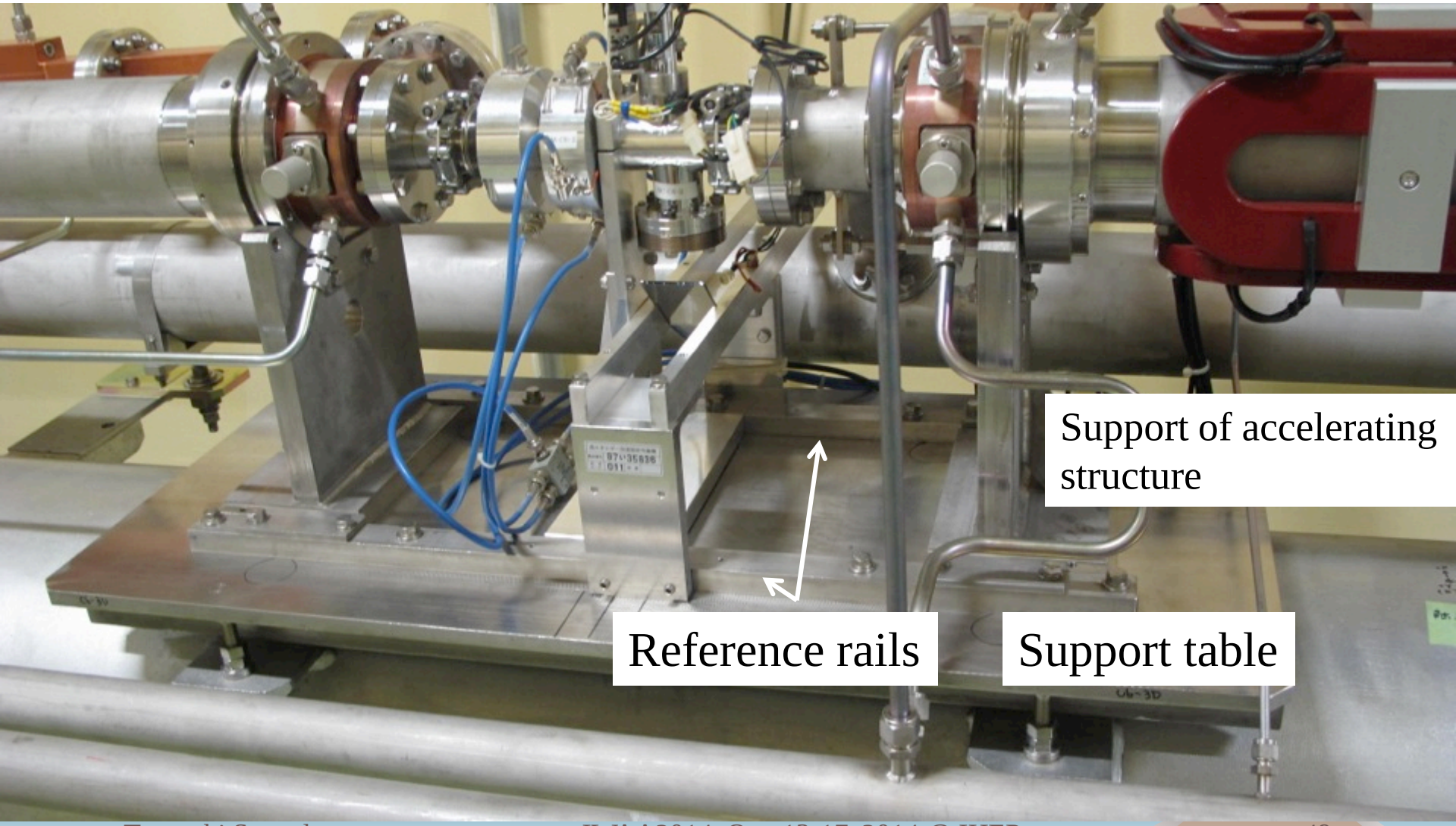


Special jig for fiducialization of tracker target

Laser pipe with a viewing port

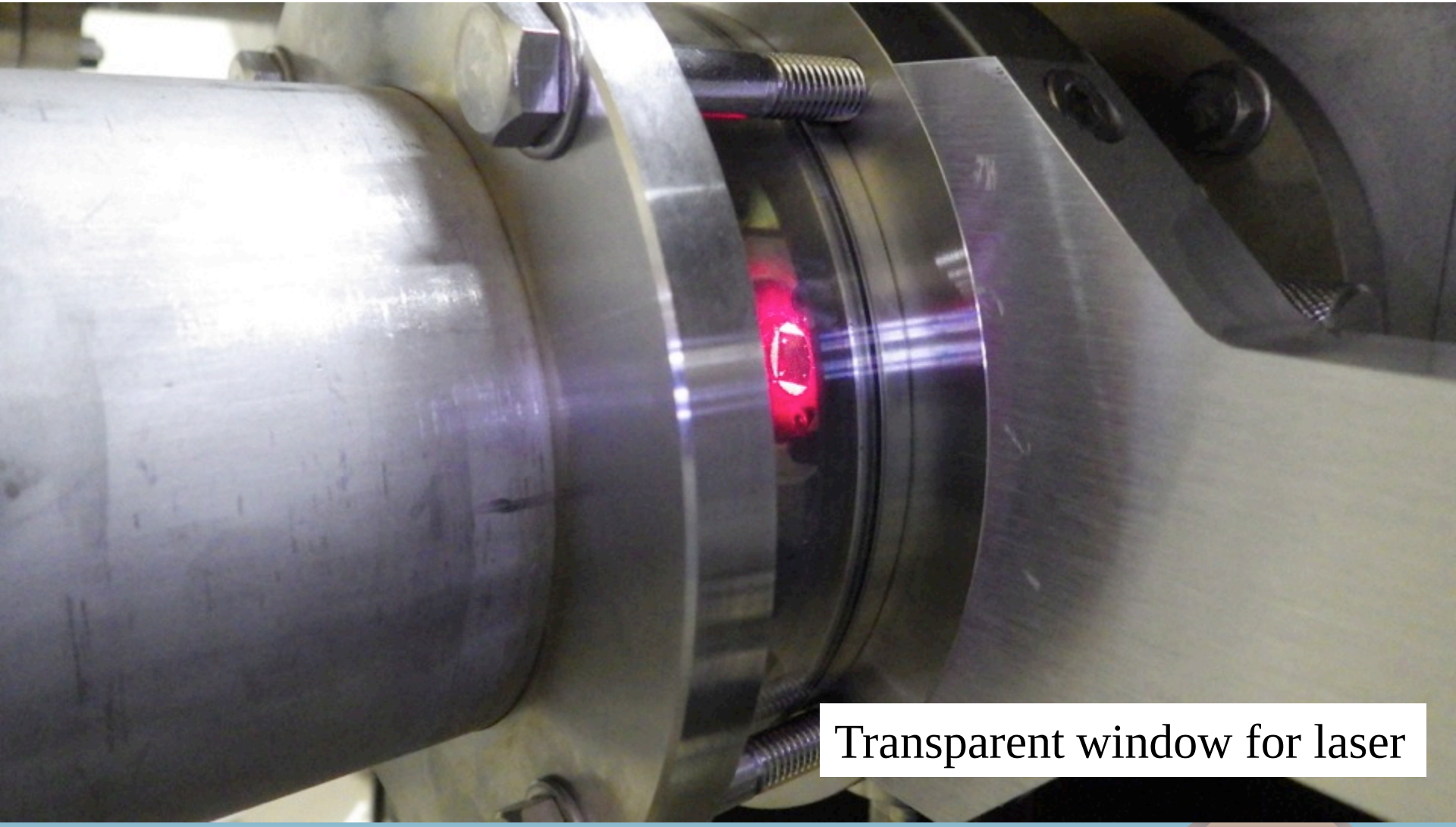


Support of accelerating structures

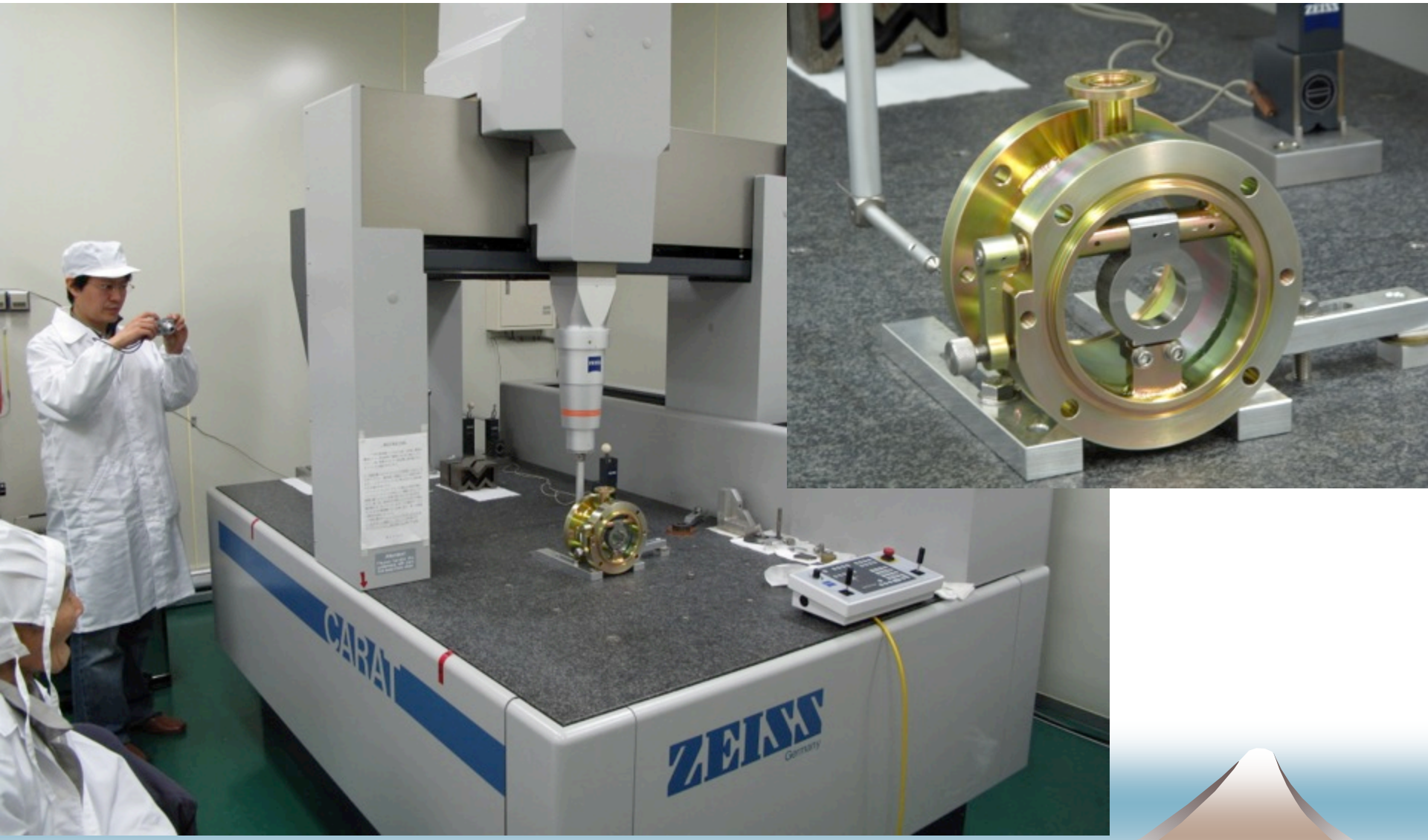


Connection between accelerating structure and Quad

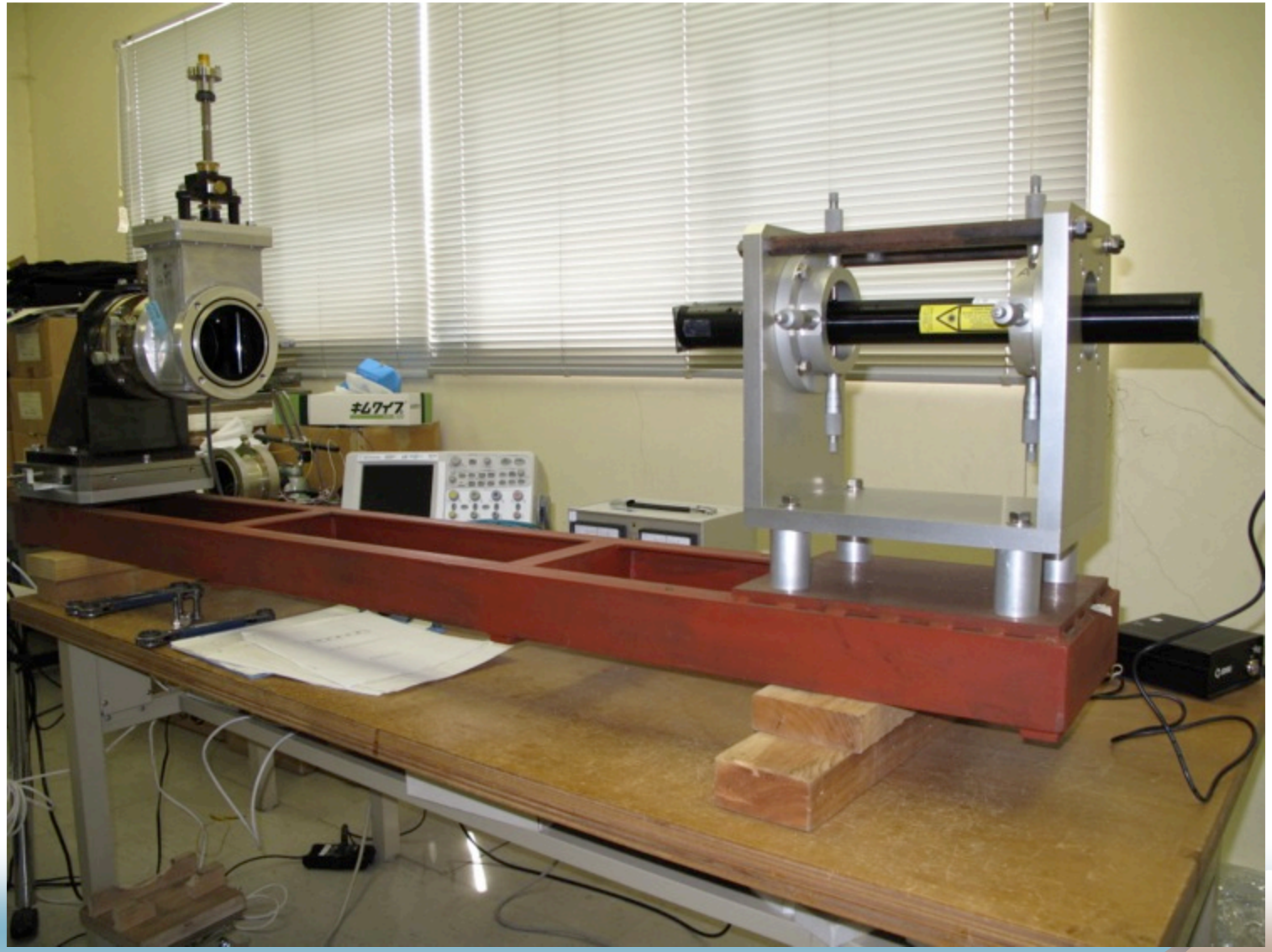
Laser window



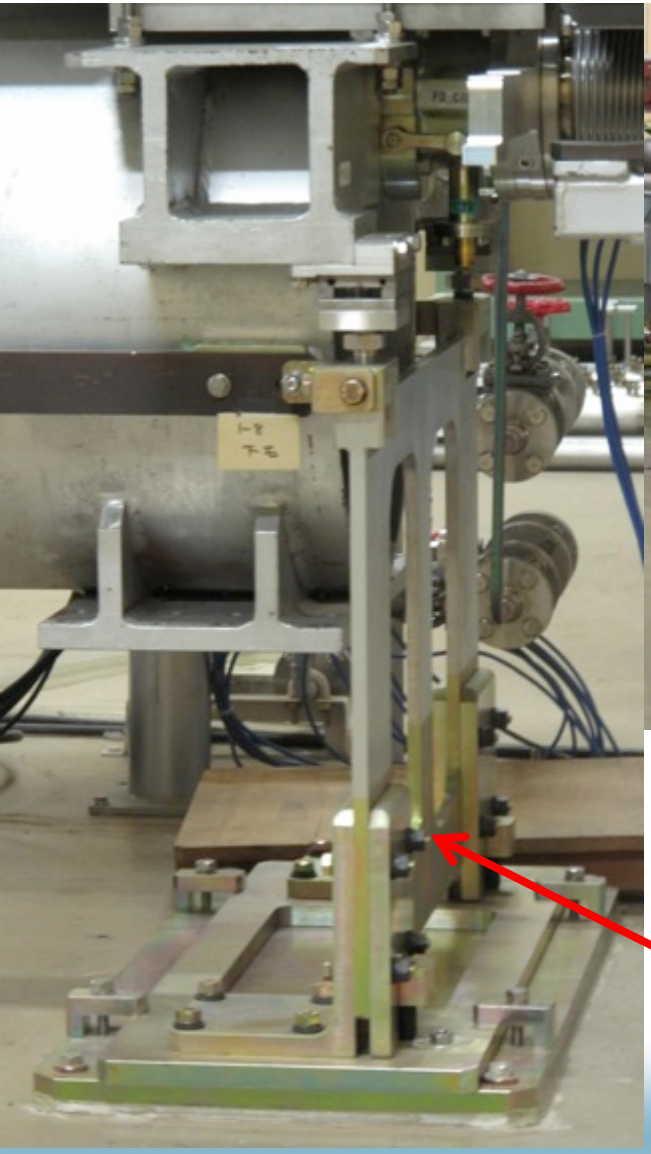
3D mechanical precision measurement in QPD holder

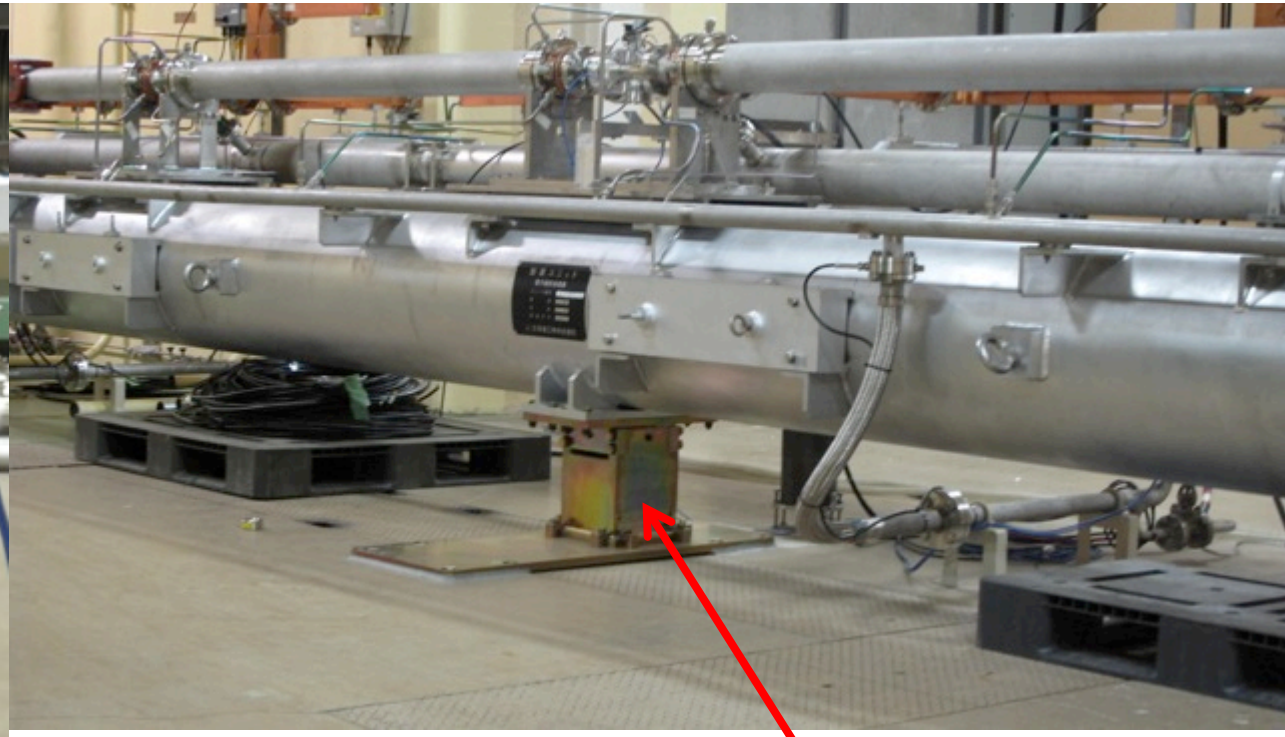


Test bench in QPD setting calibration



Reinforced girder unit





Center support added

L-shape leg reinforced