Alignment and support
(Injector linac)

5 March 2013

KEKB Injector group

T. Higo

Contents

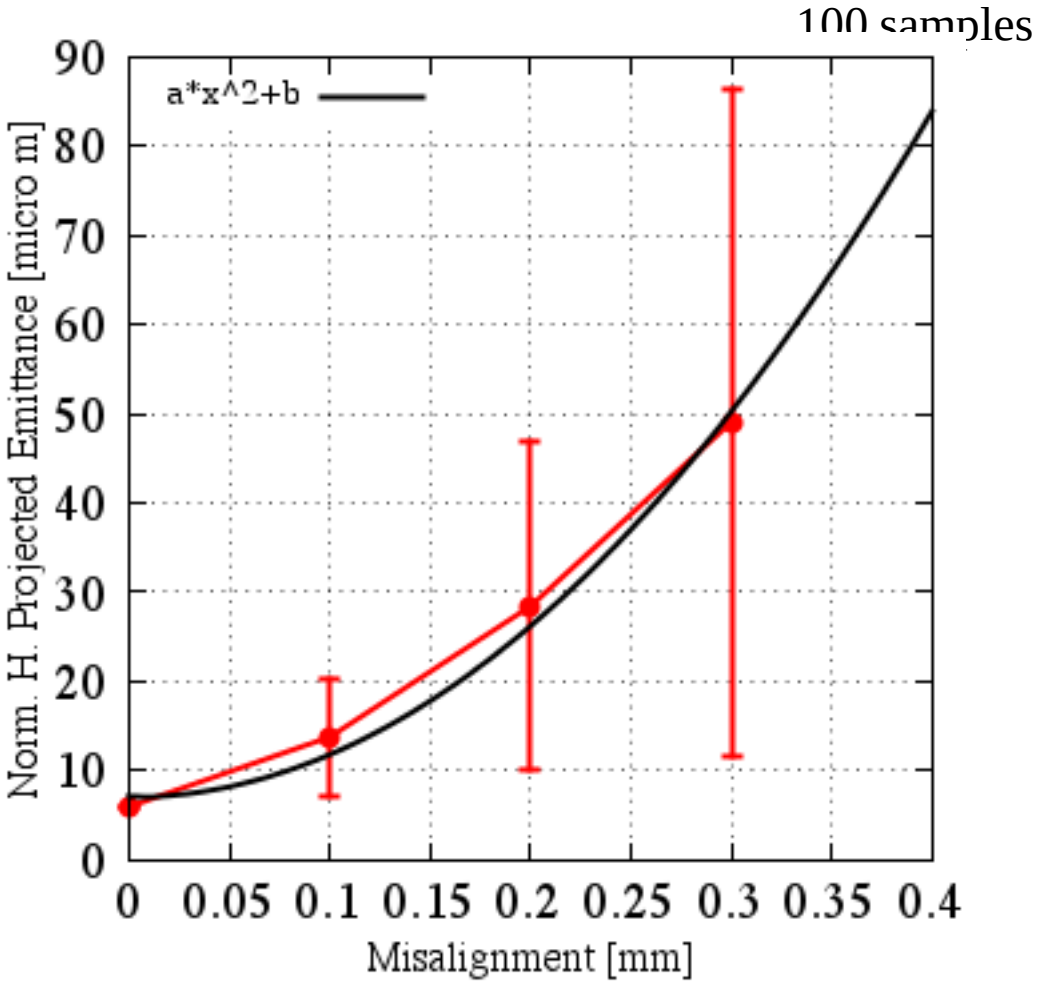
- Requirements
- Alignment status
  - Laser PD (photo detector) for long-distance
  - Laser tracker for local but also for long distance
  - Cross checking two methods
  - Alignment tool over a long period
- Perspective and conclusion

Requirement on alignment

- KEKB
  - 0.1mm but not kept established to date
  - Actually big misaligments were observed such as
    - A few mrad kink along linac
    - Misaligned Q's, ACC's and girder of mm order
- SuperKEKB
  - It depends on σ_z, ϕ_{RF}, correction, etc.
  - Requirement
    - Global (long-distance) σ=0.3mm(rms)
    - Over a sector σ=0.1mm(rms) / 100m length

Sector Cto5: -10 deg rf phase
R56 =-0.20

Emittance & Misalignment (Typical example)



Presentation
by M. Satoh

Qualitatively consistent with a famous formula derived by A.W. Chao.

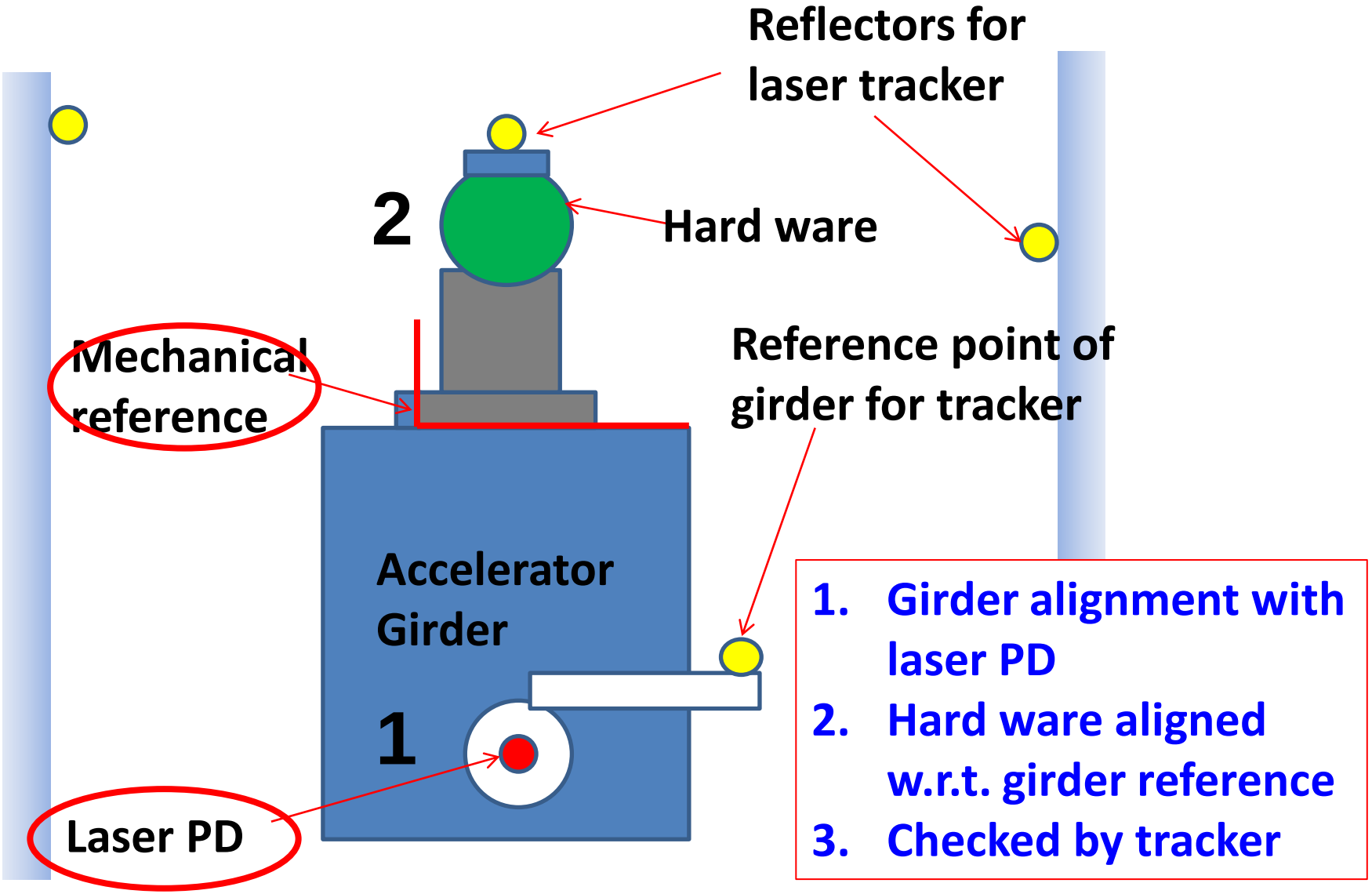
Strategy to meet this requirement

- Long-distance alignment
  - Use laser straight line to align accelerator girders
- Local alignment
  - Precisely set hard wares mechanically on the girder
  - Laser tracker to check hard ware alignment w.r.t. girder reference
  - Improve smooth local alignment with laser tracker
- Refinement
  - In addition to the above tools
  - Beam information is used

Shifting from recovery phase to SuperKEKB

- Recovery reported in the last year review (2012)
  - Girder rigidity increased
  - Started beam acceleration for Photon Factory
- Now toward better alignment (2013-2014)
  - Recover the upstream part of the linac
  - Re-establish the alignment method basically the same for KEKB
- Established alignment technique (2014)
  - Confirmation through beam study
  - As a tool useable for a long period of years
- Further development? (2015 --)
  - Intermittent alignment will be done
  - Develop as needed

Girder alignment and hard wares on the girder

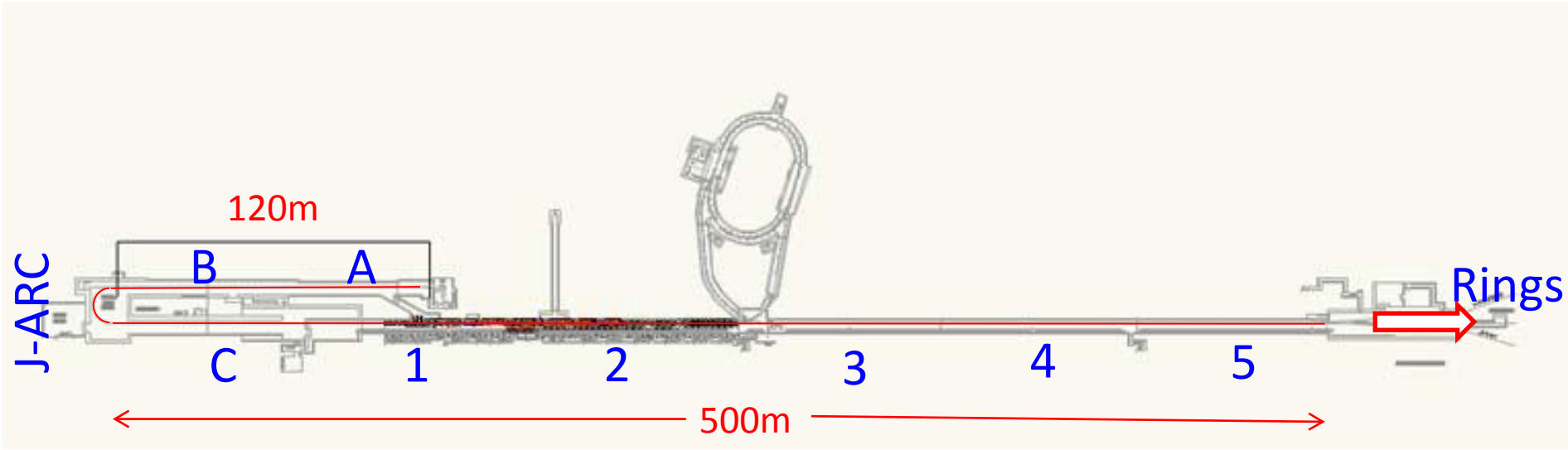


1. Girder alignment with laser PD
2. Hard ware aligned w.r.t. girder reference
3. Checked by tracker

Development in practice

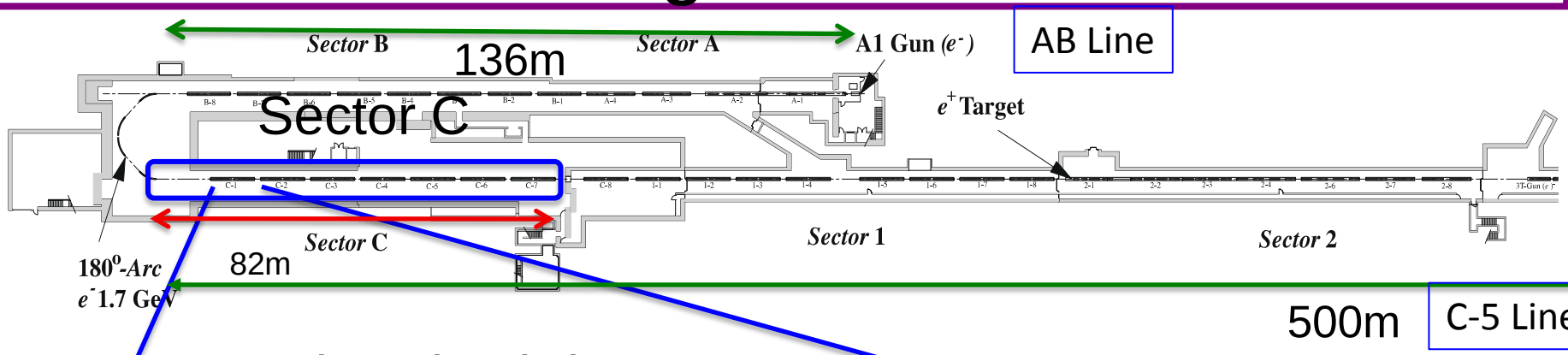
1. Re-establish laser PD system in a long distance
2. Based on this, proceed initial alignment of girders
3. Hard wares are set on each girder mechanically and checked by laser tracer
4. Cross check between laser PD and laser tracker for a long-distance measurement
5. Beam introduction (2013)
6. Explore the better method for long-term usage
7. Reduce local misalignment by laser tracker
8. More beam transmission (2014-2015)
9. Further introduce beam-based techniques
10. Reaching to goal (2015--)

Linac layout and alignment philosophy

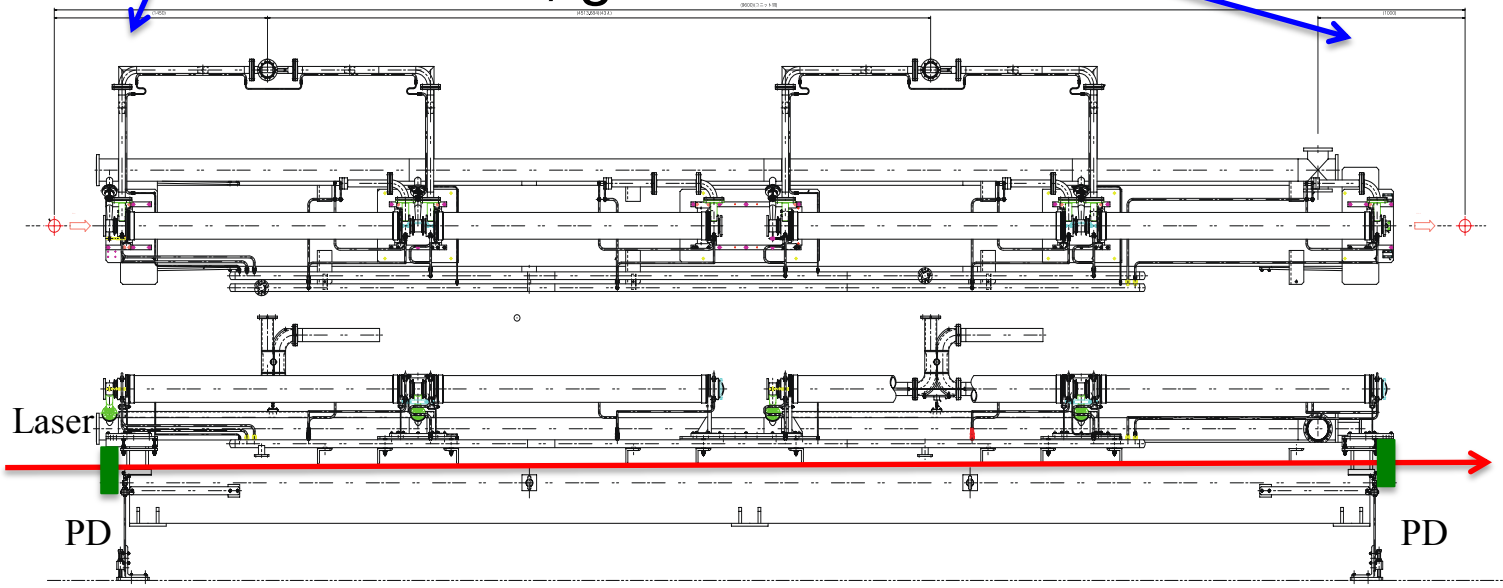


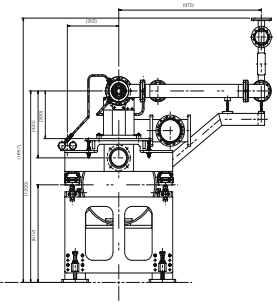
1. Establish method at AB sector
2. Establish full length C-5 500m line

Philosophy: Accelerator structure girder as an alignment unit

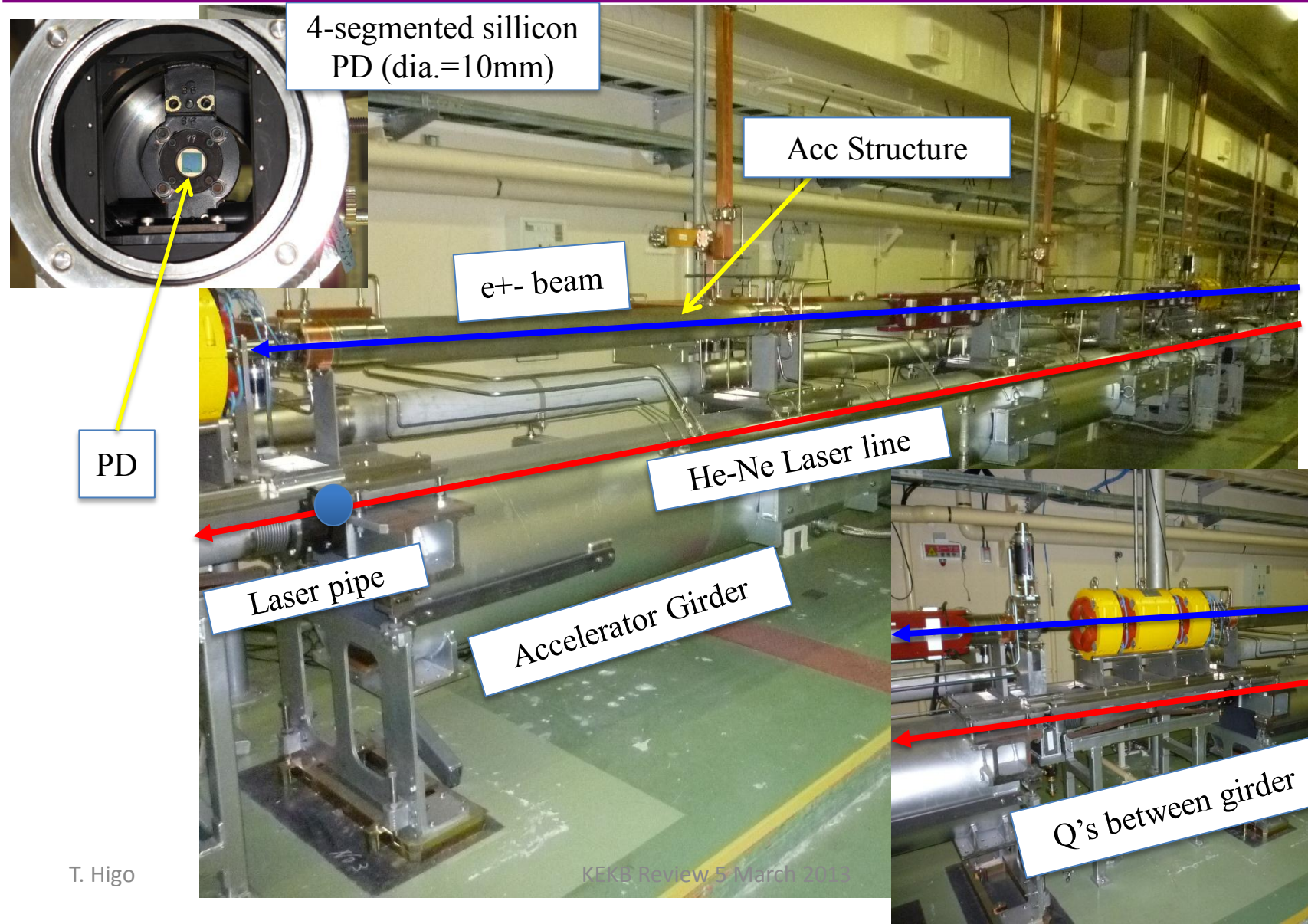


Basic unit, girder 9600mm

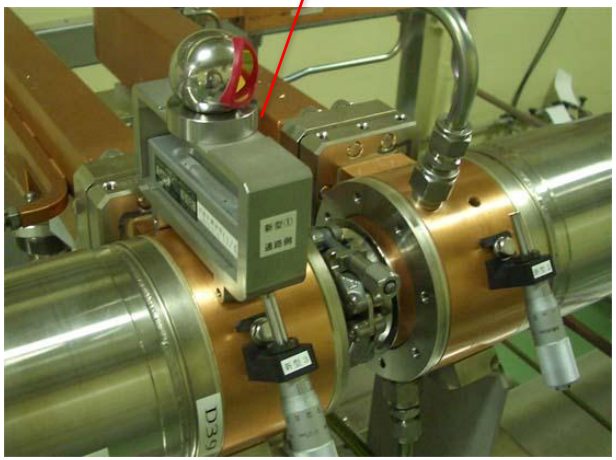


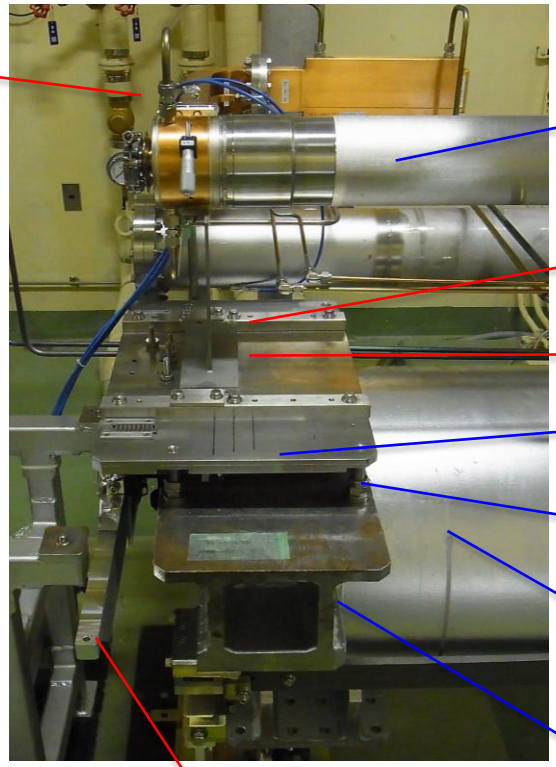


Hard wares around beam line and alignment reference line



Alignment method on the girder





Laser tracker mount

ACC Structure

Reference bar

Reference plane

Sub-support

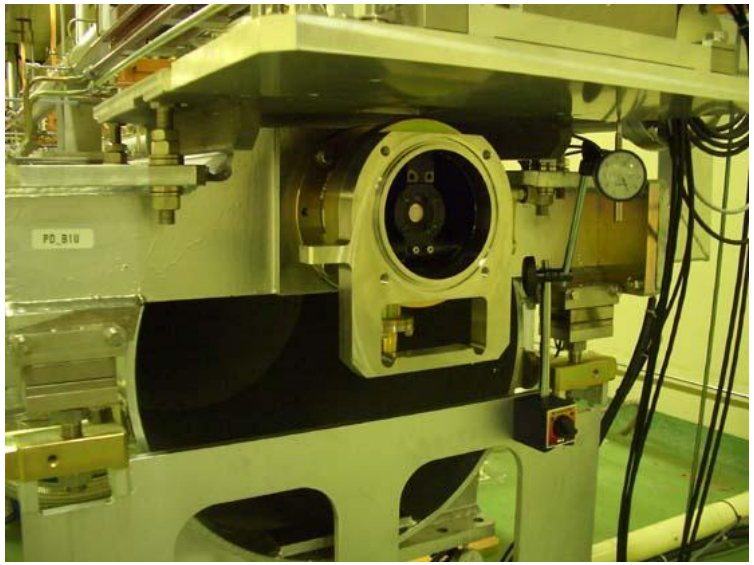
Adjustment screw

Girder

Girder table

Laser tracker reference precision-aligned to the laser PD line

Two basic alignment tools in hand



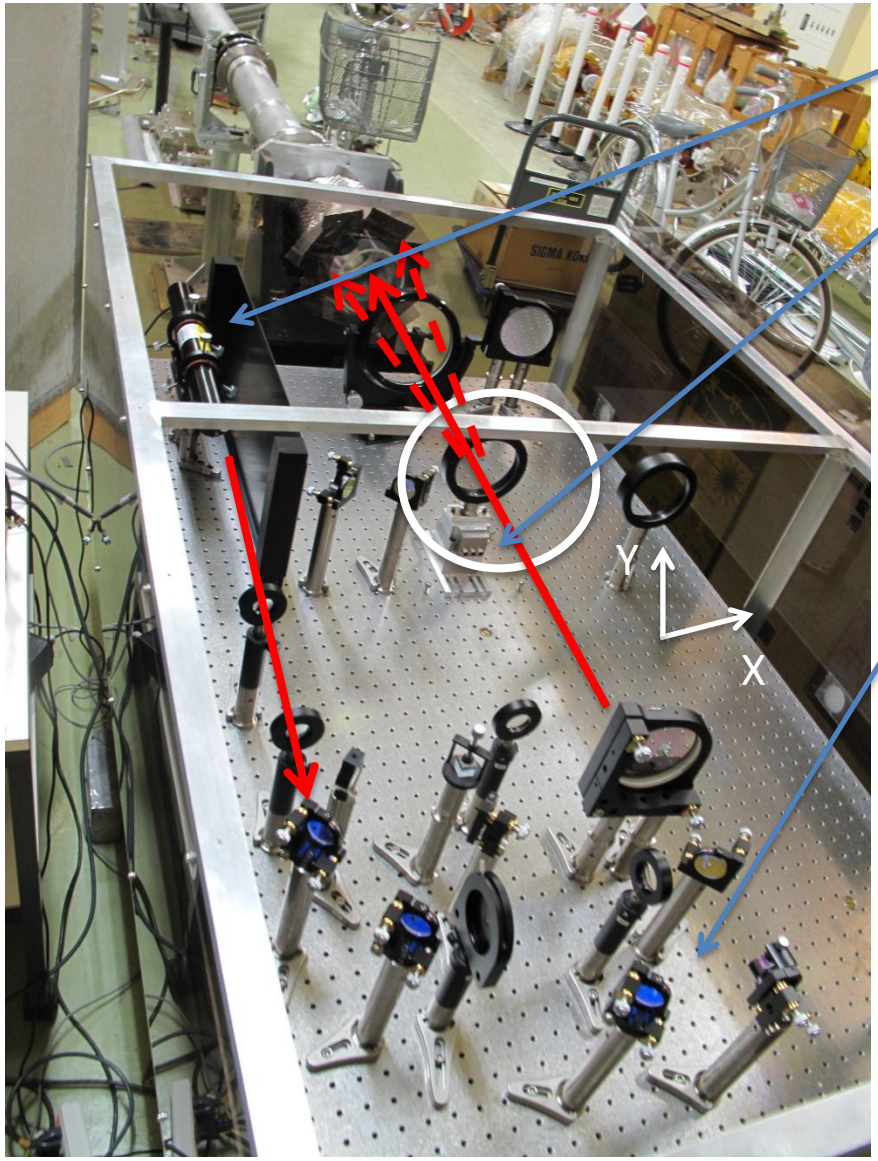
1. Laser PD system for straight reference line

2. Leica AT401
Laser tracker for general use
+ alignment on unit girder

Establishment of laser PD method

- Technology developed for KEKB
  - Not used routinely → Re-established and improved
- Round and narrow laser beam
  - Newly developed laser optics in collaboration with AIST (Advanced Industrial Science and Technology)
- Refurbishing PD
  - Select the PD's used for KEKB without gain deterioration
    - Minimize mounting error
    - Replacement of cable with flat cable
  - Estimate the accuracy +-0.3mm in mind
- Now initial alignment was started with laser PD
  - AB sector 120m → Alignment done once
  - C5 sector 500m → Laser profile proven

Laser system



He Ne laser (for C5) 9mW

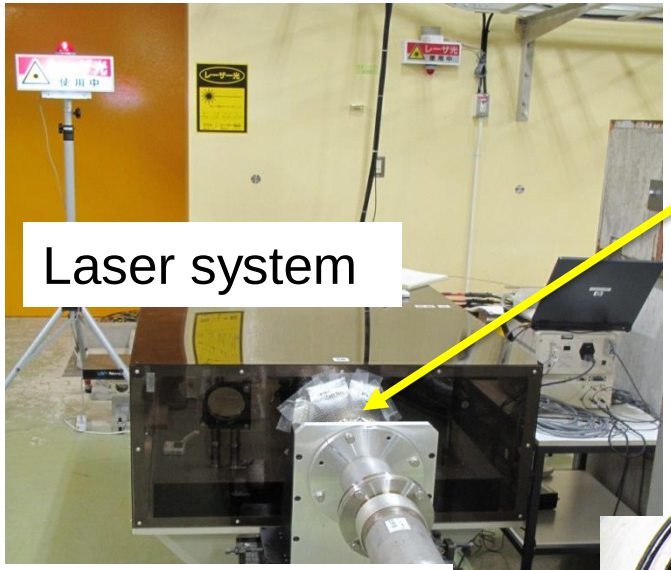
Picomotor (NewPort):
- Dynamic range = 13mm
- Resolution
  - 1.8 nrad / H step (30 nm)
  - 0.7 nrad / V step (30 nm)

Beam expander

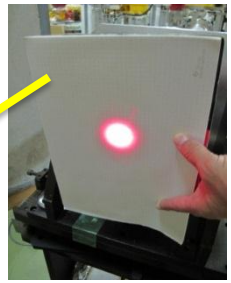
Gaussian beam less than 40mm size was transmitted through 500m line.

Pointing stability established by feedback by monitoring at the end.

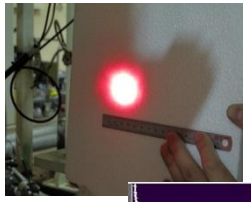
Passage of He-Ne Laser over 500m

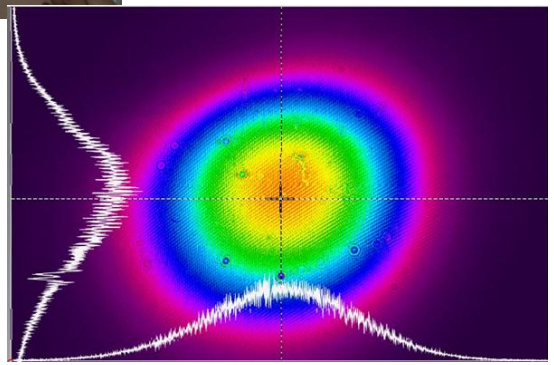


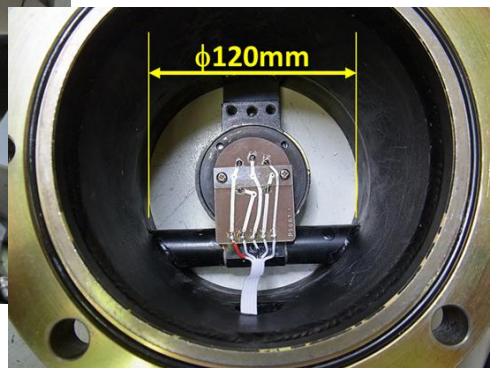
40mm by eye at the injection point



40mm by eye at the 500m-long linac end



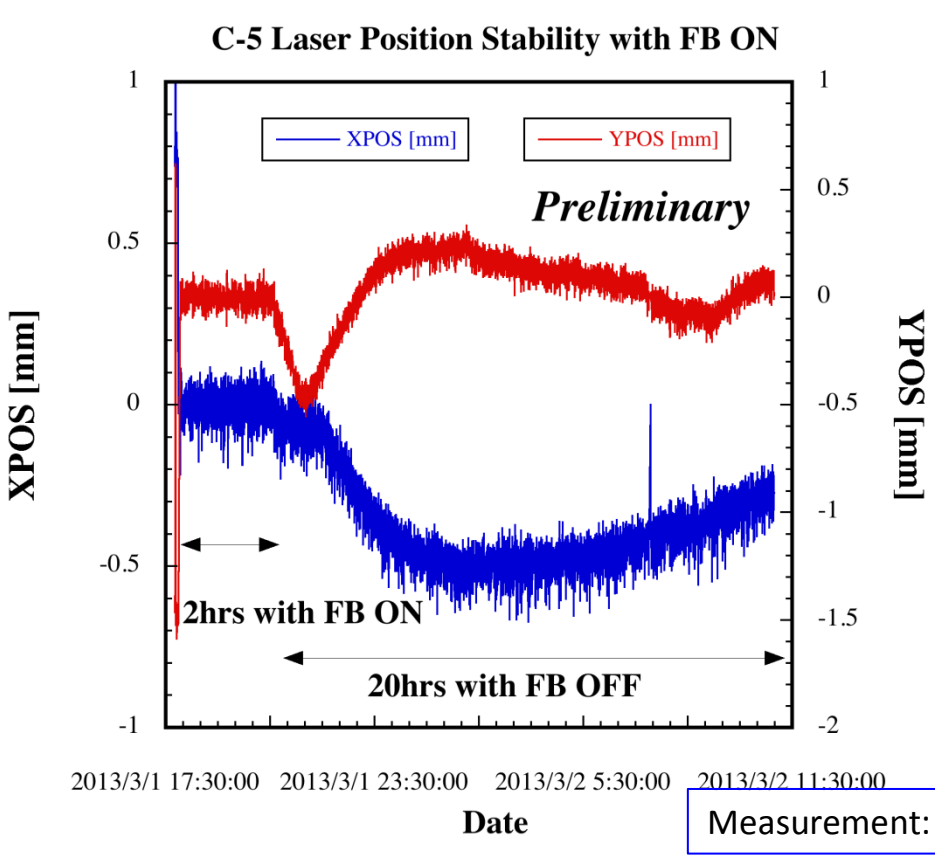


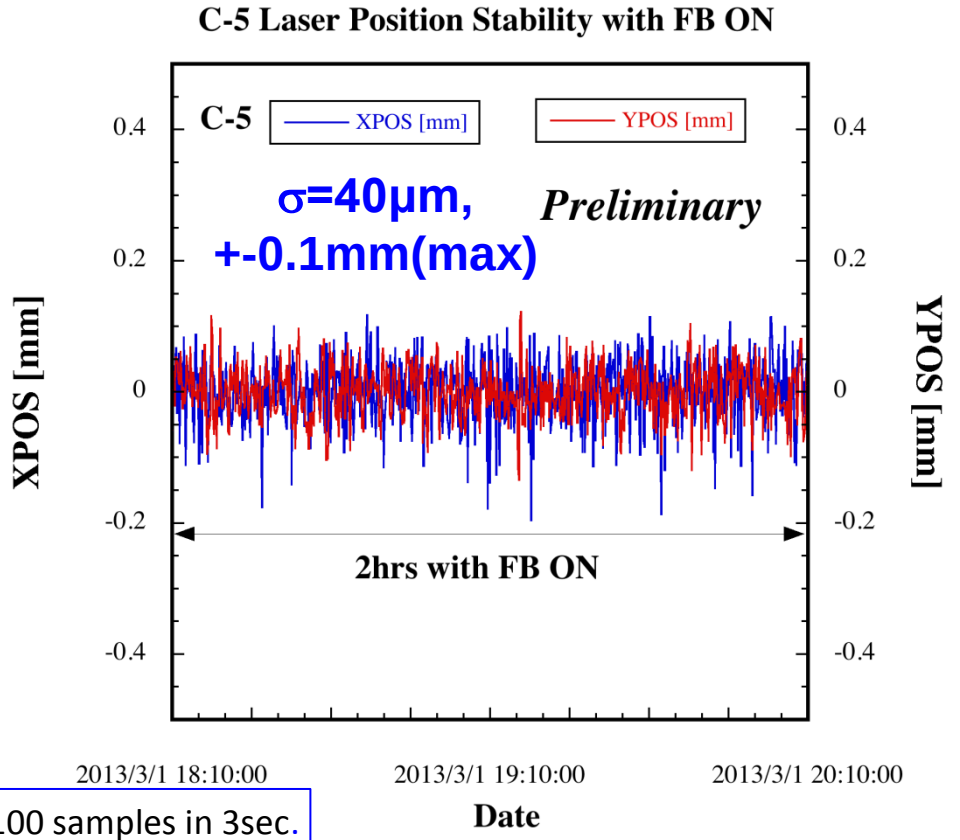


Spot size
on 1 March 2013
Round beam with
4σx～21mm
4σy～18mm

Small enough for 10mm PD sensor.

Laser pointing stability
C-5 line (500m) with FB control





Measurement: 100 samples in 3sec.

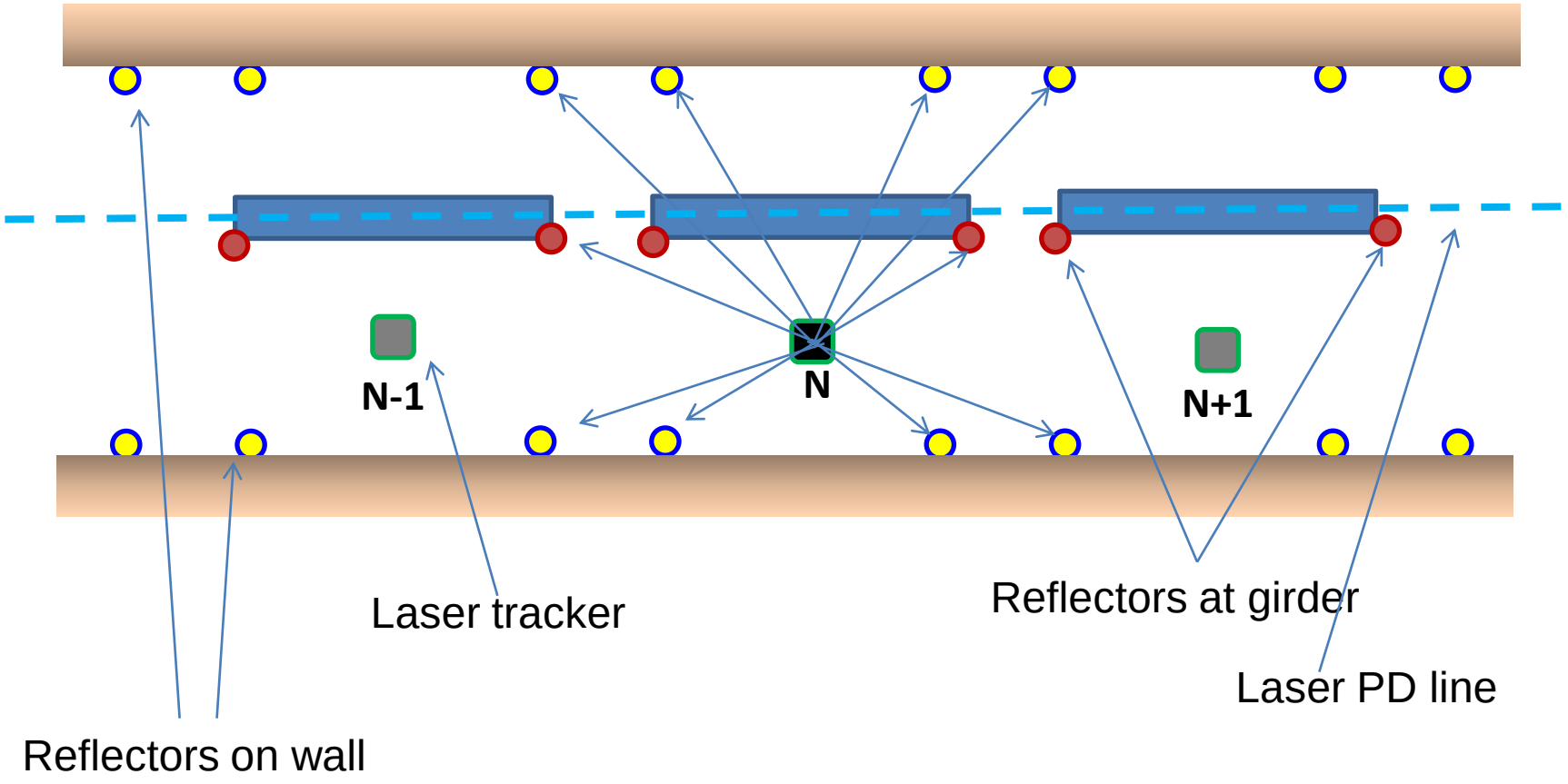
The system <0.1mm was proven with feedback on laser pointing.

Initial alignment of girders in progress using laser PD

- Laser beam set with feedback.
- PD sensitivity measured as needed
- Adjust girders to zero PD output
- Each girder is assumed to be aligned within +-0.3mm
  - This error estimated from the gain balance of four sensors.

Long-distance alignment measurement by successive laser tracker measurements

One of the way to cross check

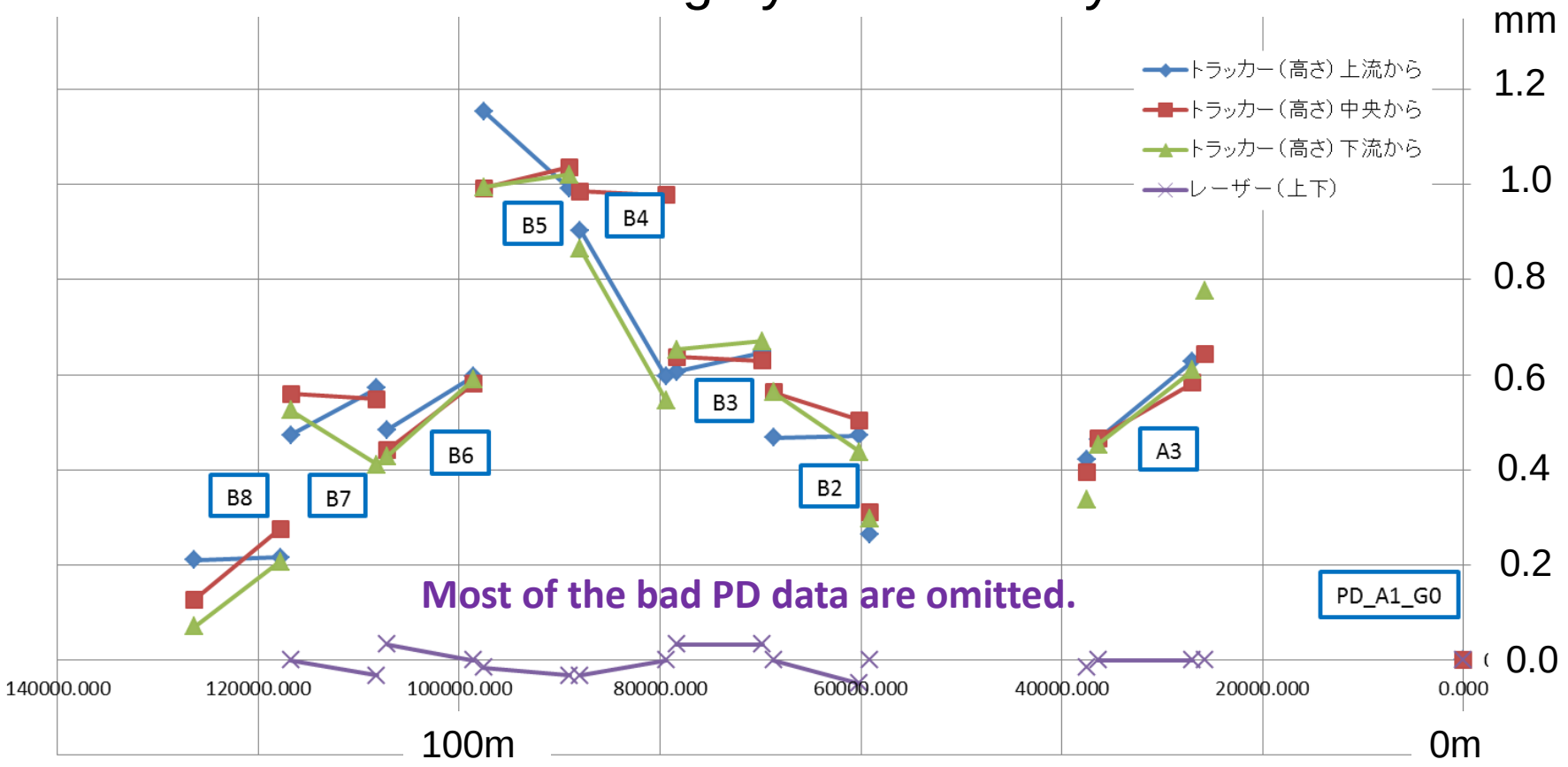


Comparison in long-distance alignment

Unit girder vertical position along AB sector

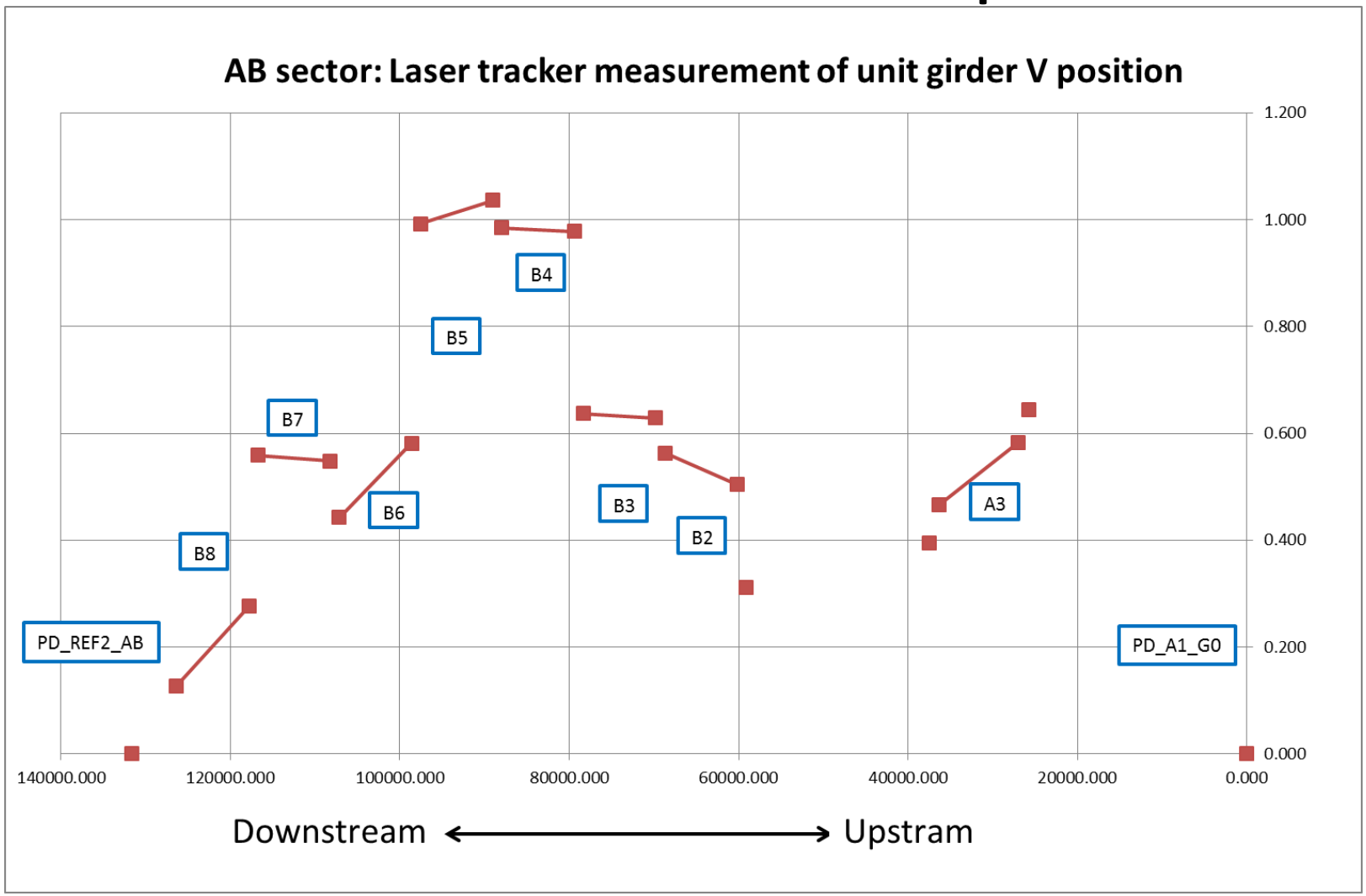
▲ ◆ ■ Meas. By laser tracker

-X- Reading by Laser PD system

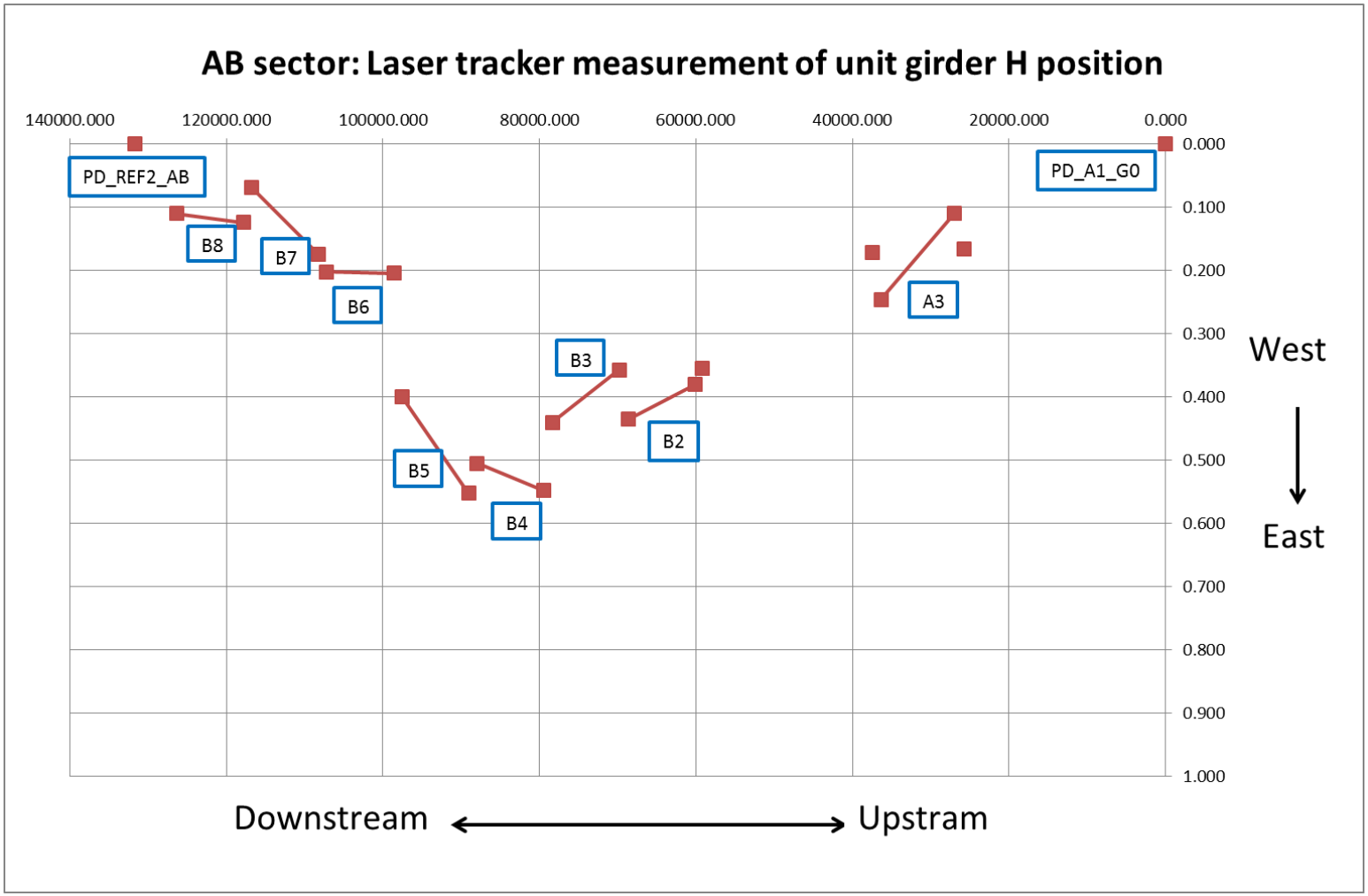


Downstream ←----------→ Upstream

Vertical
Laser tracker nominal points



Horizontal
Laser tracker nominal data points



Cross checking in a long-distance

- Alignment with laser PD along 120m line done.
- Cross checking is on-going
  - Between 1. Laser PD & 2. Successive laser tracker
  - These agree within as large as 1mm.
- The origin of this large error is under study.
- The same studies are underway in
  - C-2 (250m), C-5 (500m), and AB (120m) again
- Our target of this cross checking
  - being consistent within 0.3mm rms

Thinking from laser tracker precision spec.

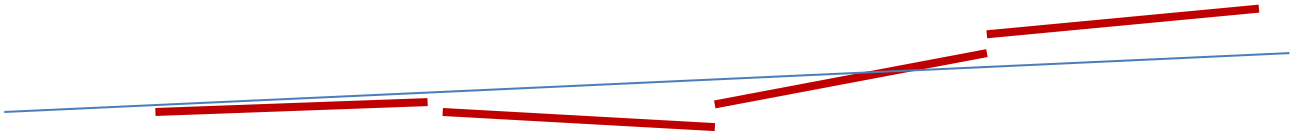
Leica AT401 precision spec

Measurement in 10m scale: σ～4μr

Local alignment between two adjacent girders

Relative precision

Precision of components ～ 80μm



Successive 500m alignment use

L＝unit length～10m, C5 sector 8×6＝48 units

Error propagation over 500m in random walk

$\sqrt{48} \times \sigma \times L \sim 7 \times 4\mu r \times 10m \rightarrow 280\mu m$

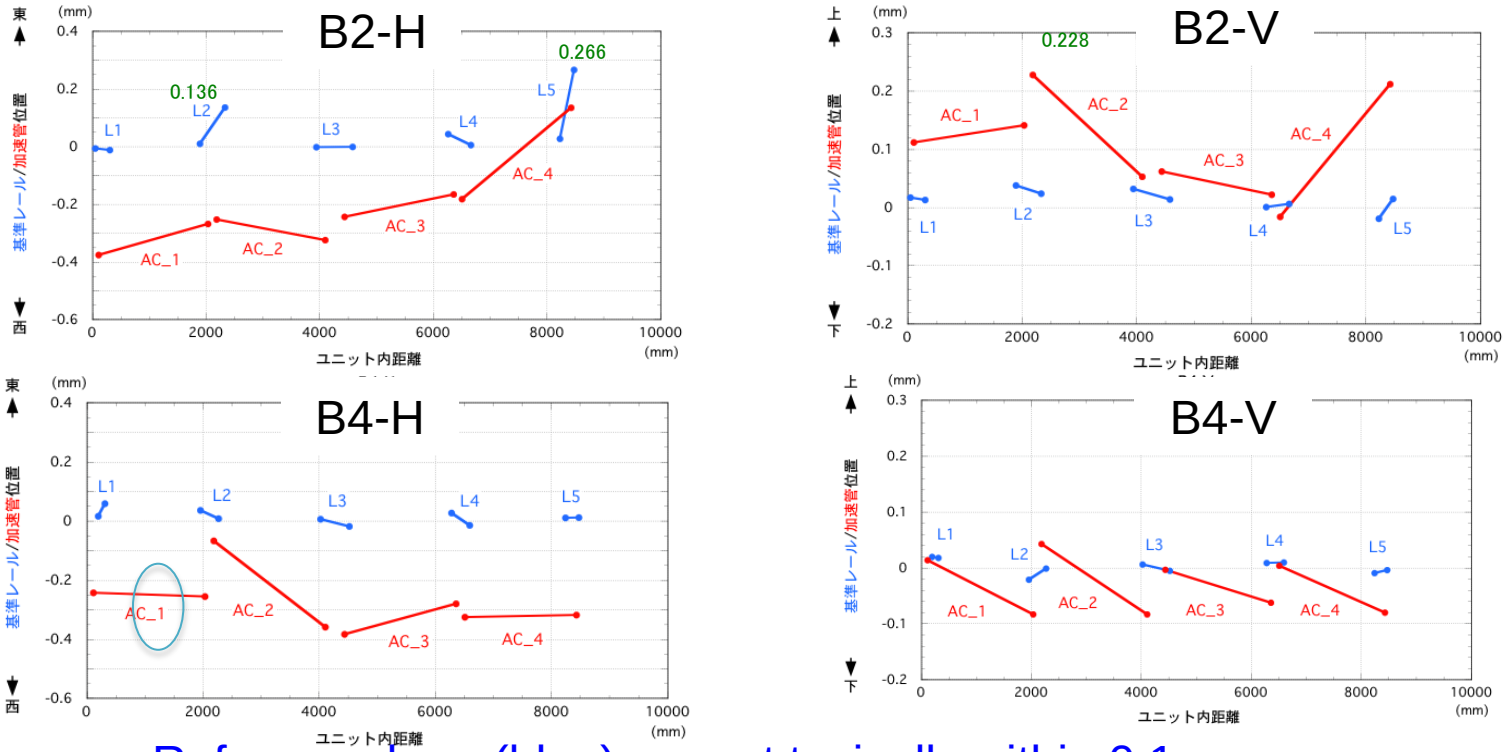
Seems feasible for long scale but needs to be practically confirmed by comparing to the laser PD.

Hard ware alignment on girder
Short-distance local alignment

- Mechanical setting of beam-line components
- Support frame is pressed to mechanical reference on the girder
  - Structure support geometry error +-0.05mm
- Then hard wares are supposed to sit aligned within 0.1mm

Present situation on short-distance (local) alignment

Hard ware alignment on a 10m girder



Reference bars (blue) are set typically within 0.1mm.

Hor. up to 0.5mm slope

Ver < 0.2mm

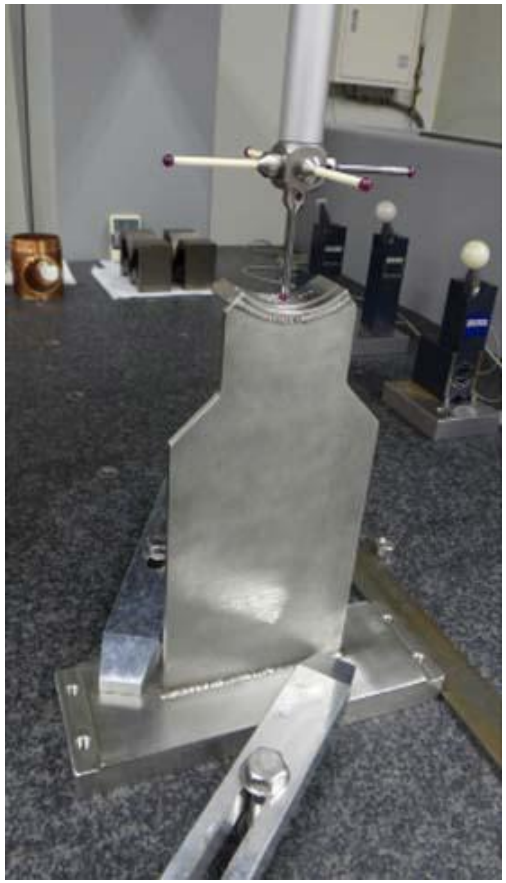
Systematic error may exists in H by 0.5mm, while V stays 0.2mm from reference bar.

K. Kakihara, 22 Nov. 2012

Hard ware alignment on girder

- The end two points are referred for alignment of hard wares on the girder.
- Reference plane (V) and reference bar (H) are defined w.r.t. these reference points, established by laser tracker.
- Hard ware supports are mechanically pushed along these references
- Hard wares are supposed to be within 0.1mm.
- Confirmation of this method by laser tracker is underway. Error amounts to 0.5mm!
- **Need to identify the error source and improve down to 0.1mm max.**

CMM evaluation of ACC structure support



Errors seem within tolerance of +- 0.05mm.
(This result is under re-evaluation.)

H misalignment of 0.5mm can not be explained.

Due to earthquake?
To be studied.

K. Kakihara, 17 Jan. 2013

Long-distance alignment tool for long-term

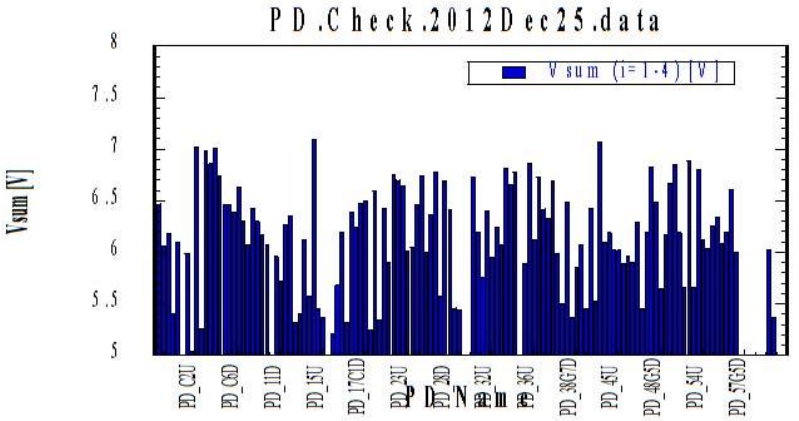
- Present laser PD system
  - Present method should be good for initial alignment
  - But not assured for long-term usage under beam radiation
  - Beam radiation is suspected to be the most probable reason
- Apply other methods?
  - Fresnel (Study suspended)
    - Need to smooth all the laser PD ducts to confirm 500m Fresnel system.
  - Wire and HLS (not proceeded)
    - need someone to establish
  - DESY small ball (just thinking)
  - Need additional manpower to introduce any one
    - → should be suspended unless critical.
- Improve PD system
  - Practically feasible and we focus to this now

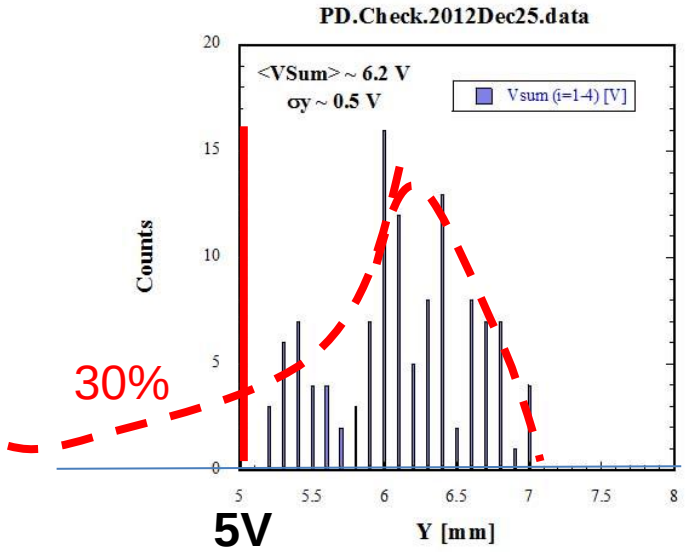
PD gain reduction

After operation for KEKB in several years, 30% of PD's suffer from gain reduction.

The origin is not yet identified, but we suspect the beam radiation as one of the relevant reasons. We hope the low emittance will help reduce beam loss.

We need to evaluate PD radiation resistivity, improve PD and/or reduce beam loss affect on PD's.



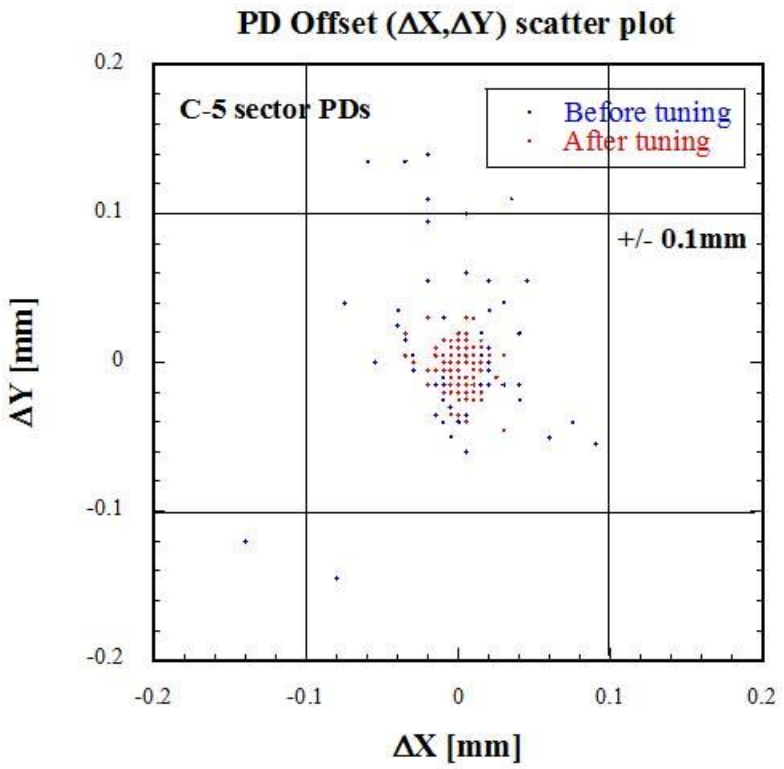


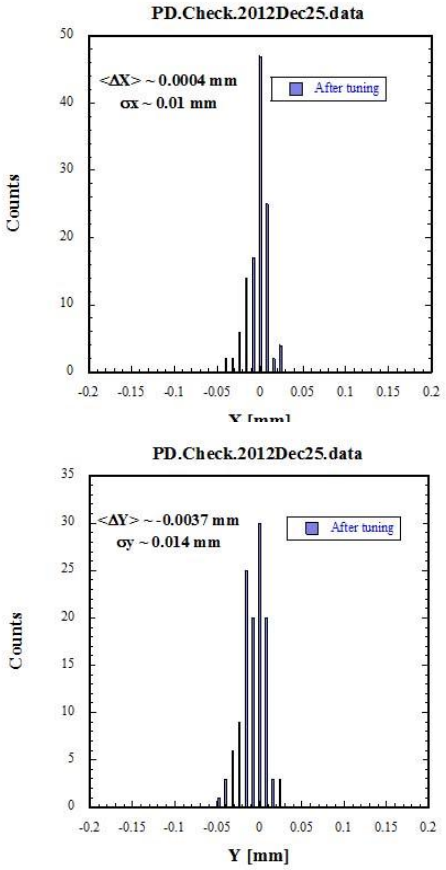
T. Suwada, 17 Jan. 2013

Evaluation and developments on PD

- PD material
  - Radiation-resistive PD?
- Evaluation of deterioration
  - Test at B8 end under consideration
- Improvement
  - Set PD's aside during heavy beam operation →possible
  - Introduce radiation resistive PD → will study
  - Radiation shield from beam loss → impractical
  - If abandon PD → laser tracker or beam

PD sensor re-aligned in the holder





Alignment of PD sensor in a holder.

Adjustment done. Then

$\sigma x = 10 \mu m$
$\sigma y = 14 \mu m$

Misalignment of PD sensor in the holder is small enough.
Other error sources are to be fully studied.

Other possible way in hand
Rely on laser tracker

- From labor for 500m measurement point of view
- Laser PD with removing and restoring PD's
  - Each sector ends
    - 12 pts for 6 sectors / 2 person X day → during long-term maintenance
  - Each girder ends
    - Remove/restore 96 points for 48 units → 17 person X day → impractical
- Laser tracker with successive unit-wise measurement
  - 1 unit / 2 person X hour
  - 6 sectors → once a year
    - 48 successive measurements → 2 person X 6days
  - A sector of interest = 8 units as needed → during long-term maintenance
    - 8 successive measurements → 2 person X 1day

Perspective

- Cross check long straight-line alignment of girders by two methods, laser PD and laser tracker.
- Establish the long-term usage of one of the above systems.
- Local alignment of hard wares on the girder will be reduced from 1mm order to 0.1mm.
- Beam-based alignment information is to be added into the present alignment process.

Time frame in summary

- 2013 start beam transmission
  - Initial alignment based on laser PD
  - Compare and confirm the long-distance alignment
- 2014 acquire beam information
  - Imprement beam-based information
- 2015 supply to rings
  - Improve with more beam and better beam
- 2016 toward ultimate goal
  - Introduce other alignment method if required

Conclusion

- We are proceeding initial alignment of girders using laser PD system.
- The long-distance alignment method should be confirmed targeting an error of 0.3mm.
- Hard wares on the girder should mechanically be aligned within 0.1mm.
- Long-term usage of the long-distance alignment tool should be established.