Alignment of SuperKEKB Main Ring Magnet System

Mika Masuzawa (KEK)

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  - Tight schedule, everyone wants to do lots of things at the same time.
  - Tunnel keeps moving.
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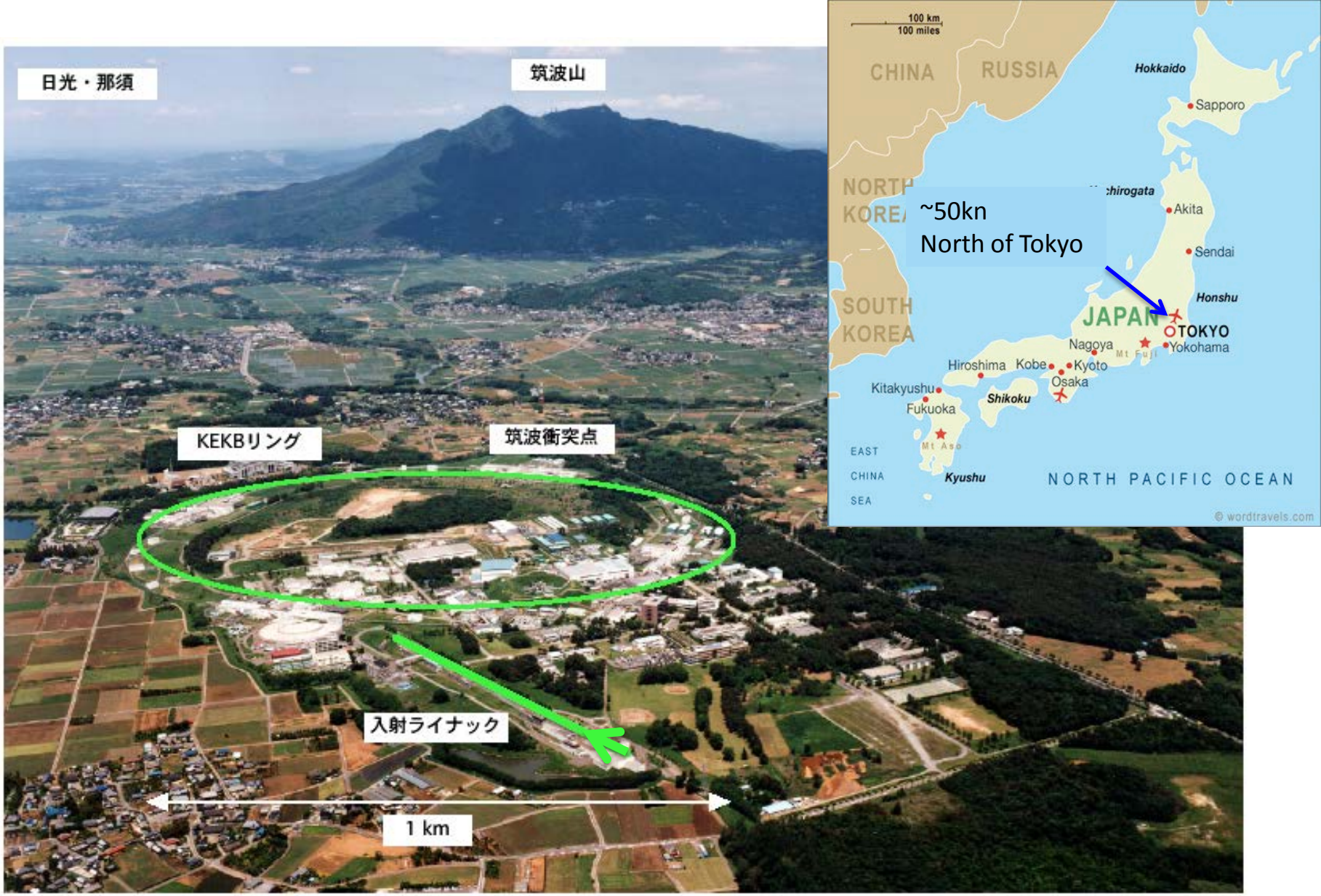
- Strategy
  - Smoothing
- Results
  - Well done!
- Summary

- Introduction
  - SuperKEKB

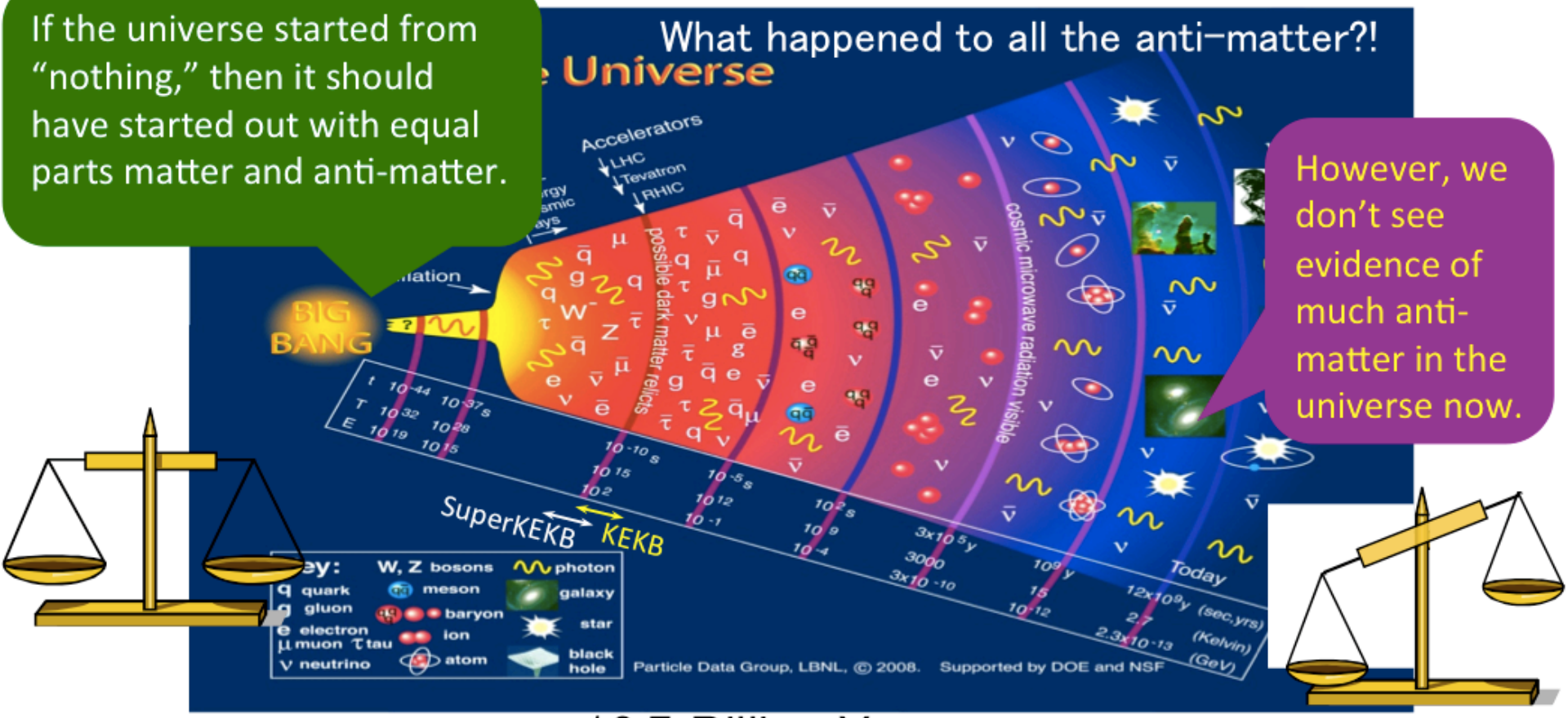


3 km in circumference, 11m below the ground level

3rd largest circular machine alive in the world

SuperKEKB Project

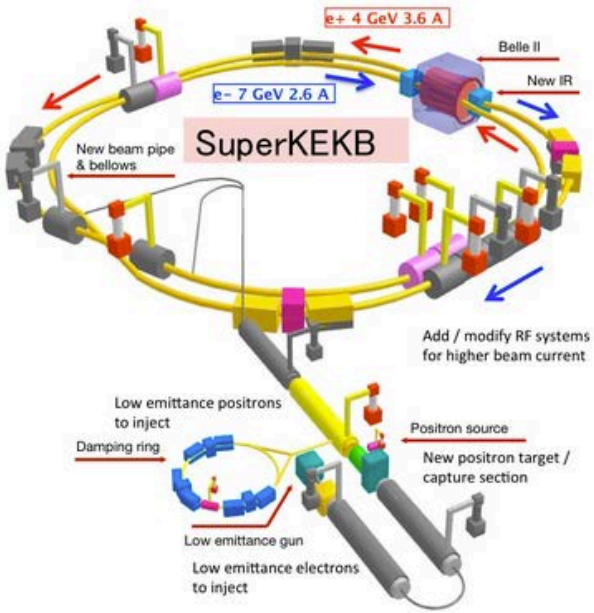
If the universe started from "nothing," then it should have started out with equal parts matter and anti-matter.

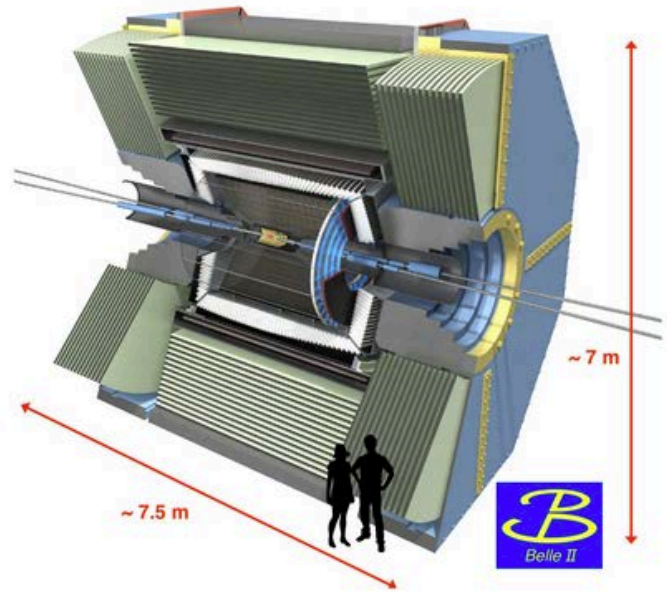


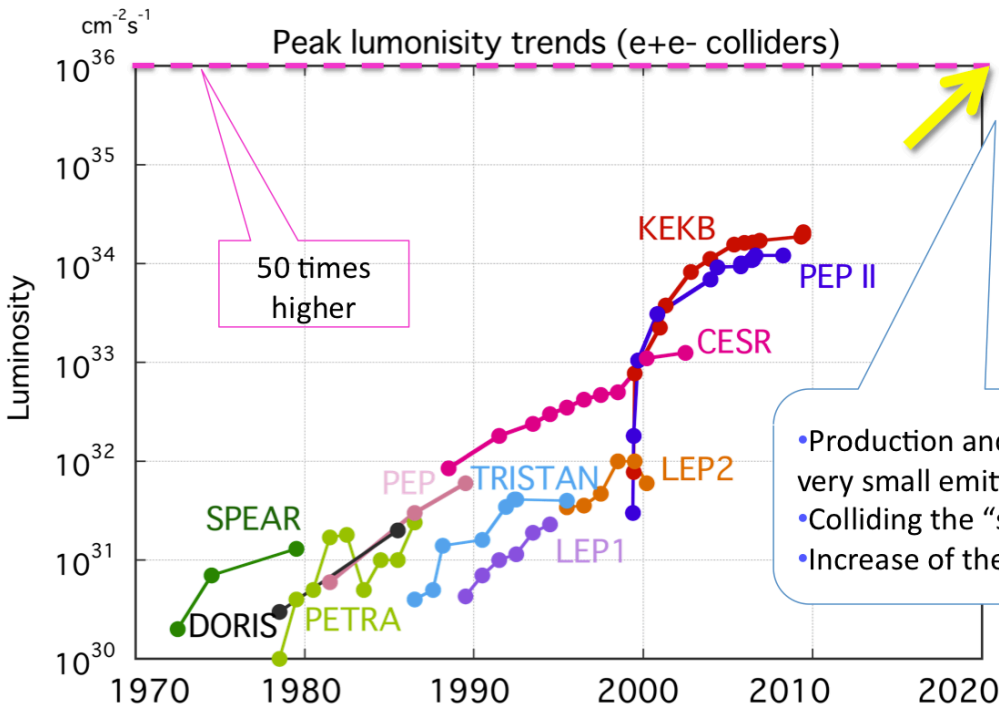
However, we don't see evidence of much anti-matter in the universe now.

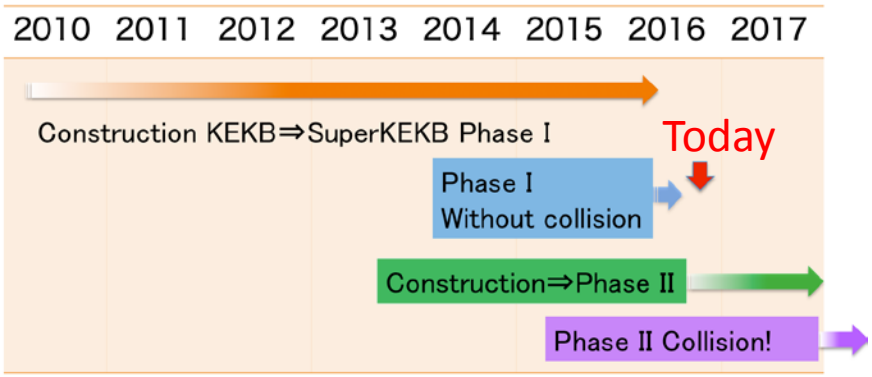
13.7 Billion Years

To discover new physics, we need a high-luminosity collider, and a detector capable of taking large amounts of data.







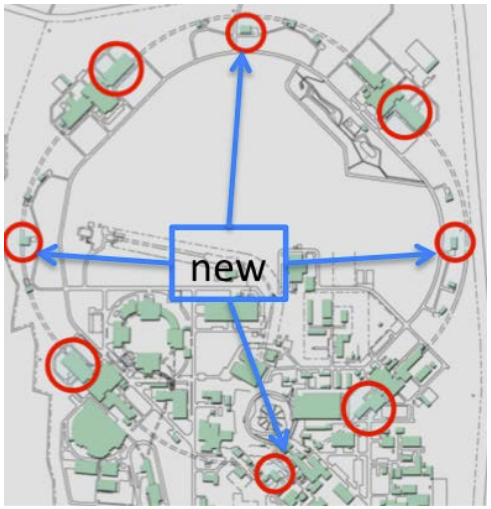


- Production and circulation of the very small emittance beams.
- Colliding the "spot-size" beams
- Increase of the beam currents.

Luminosity frontier machine
Collision of nano-beams!

- Challenges
  - Tight schedule, everyone wants to do lots of things at the same time.
  - Tunnel keeps moving.
  - KEKB alignment network was destroyed by the earthquake in 2011.

Tight schedule, everyone wants to do lots of things at the same time

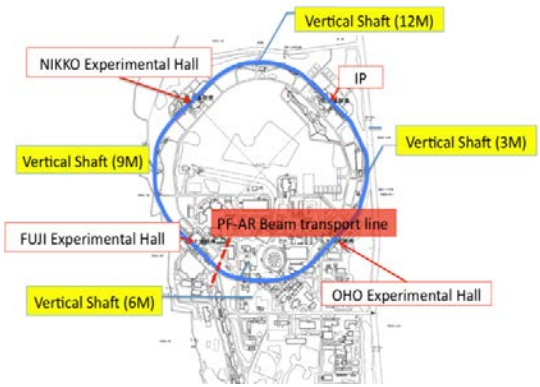


KEKB➔SuperKEKB

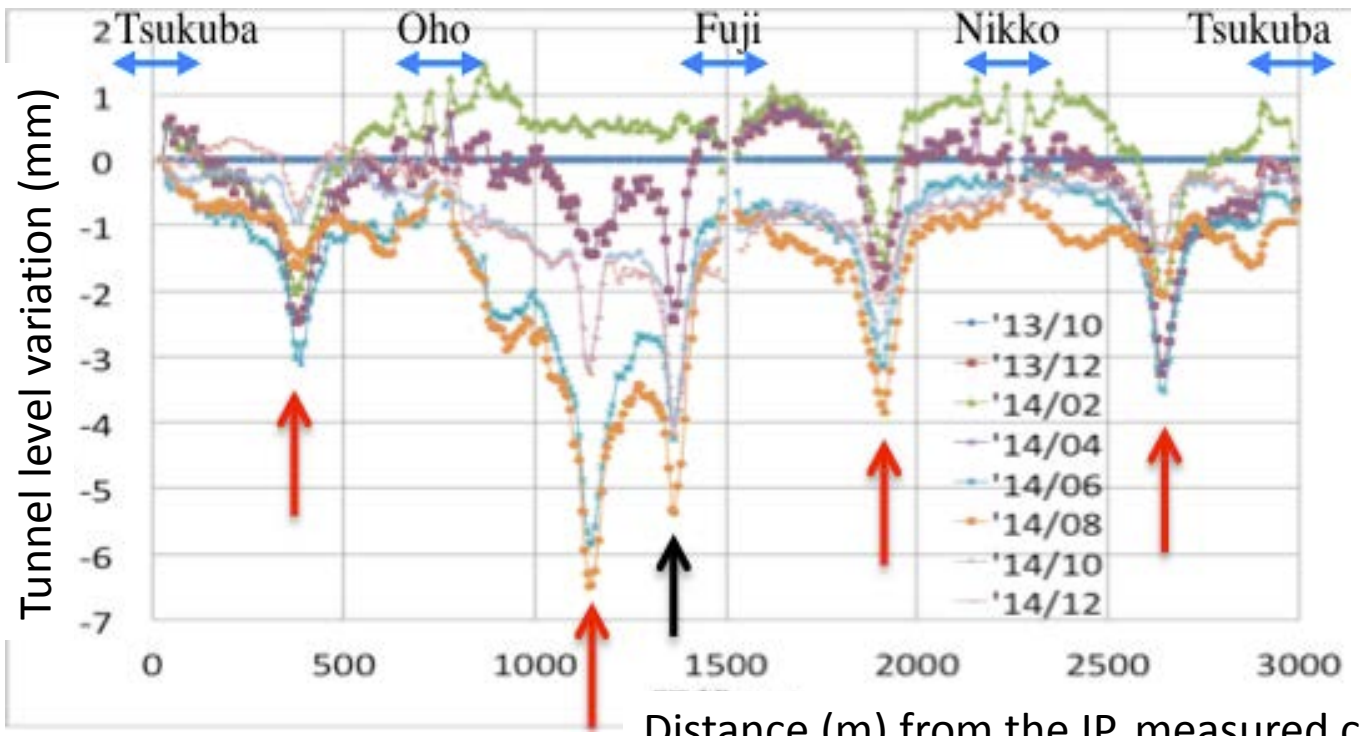
- More magnets & power supplies
- New utility buildings were built.
- Excavation of the vertical shafts, right above the tunnel.
- Rich in ground water…

Tunnel keeps moving (excavation)

- We had to wait until the last minute(~ half a year before the startup) before carrying out 2nd round of alignment because
  - Effect of the construction of new facility buildings along the tunnel was large.
  - Tunnel temperature was not stable at all (varied more than 10 degrees)

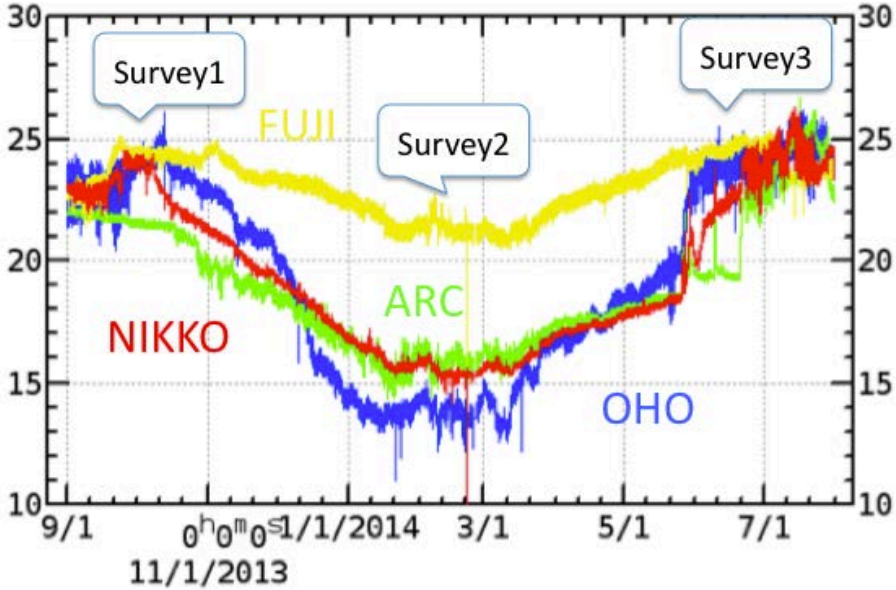


Tunnel monument height variation since October 2013 surveyed with Digital level.



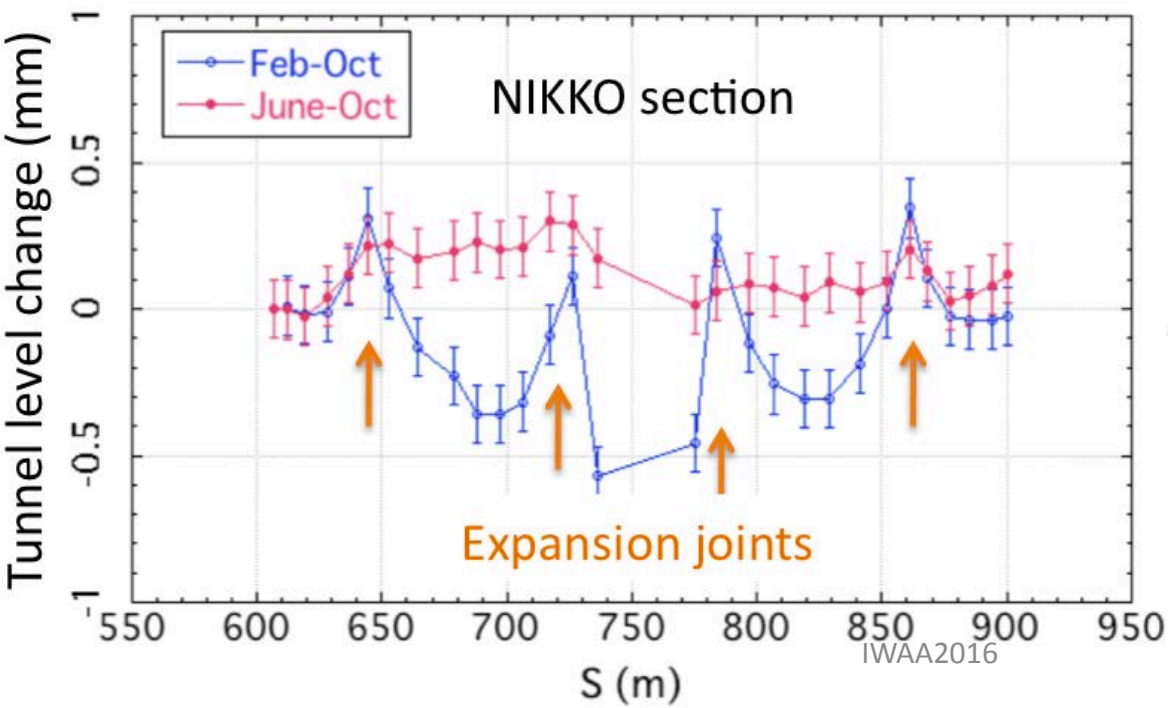
Distance (m) from the IP, measured clock-wise

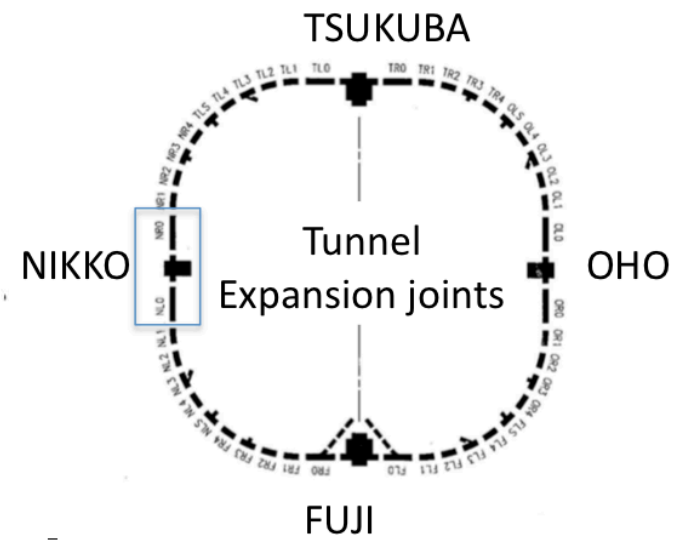
Tunnel keeps moving (temperature)



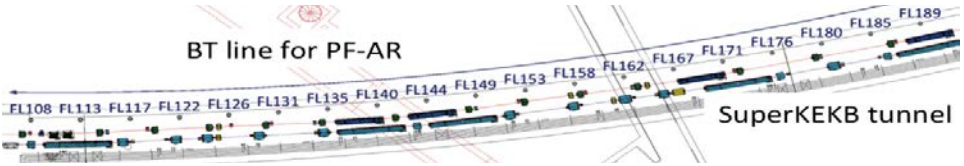
No AC in the tunnel
(to save electricity)

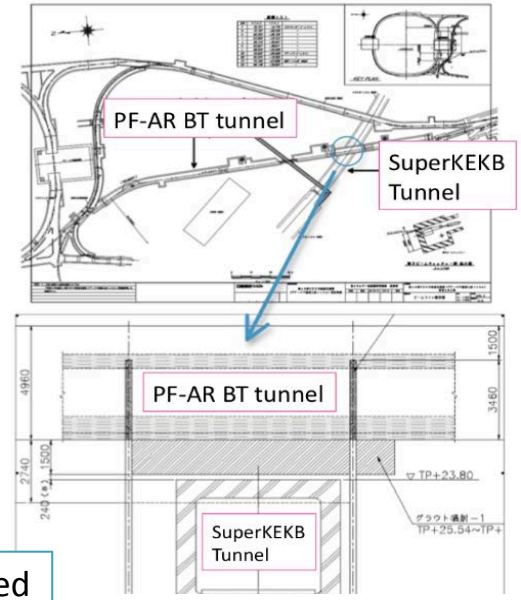
Level changes of up to 0.5 mm are seen at the expansion joints between summer and winter.



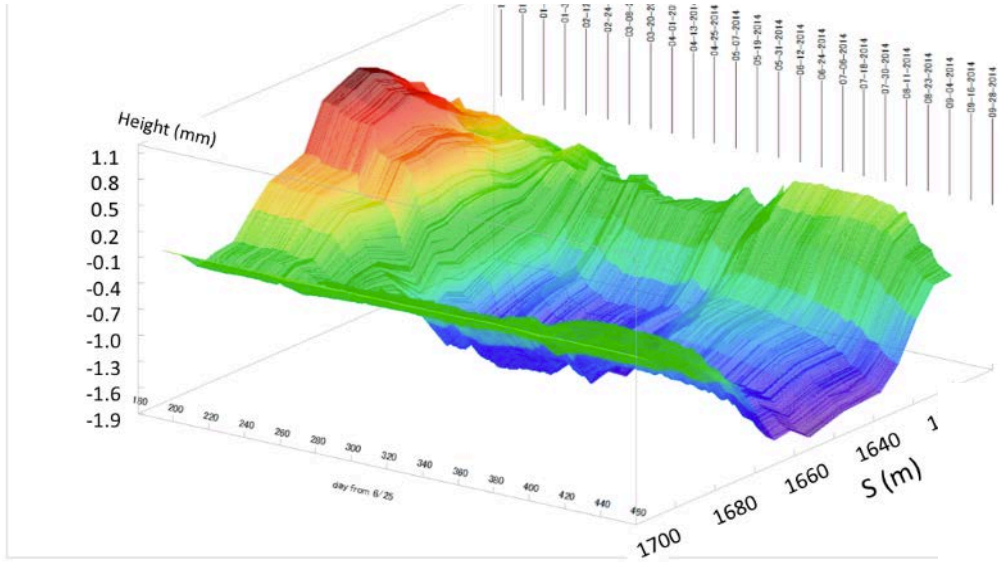


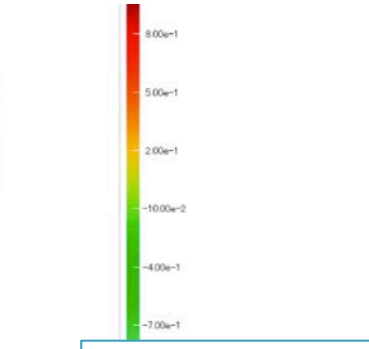
Tunnel keeps moving (new BT to PF-AR)





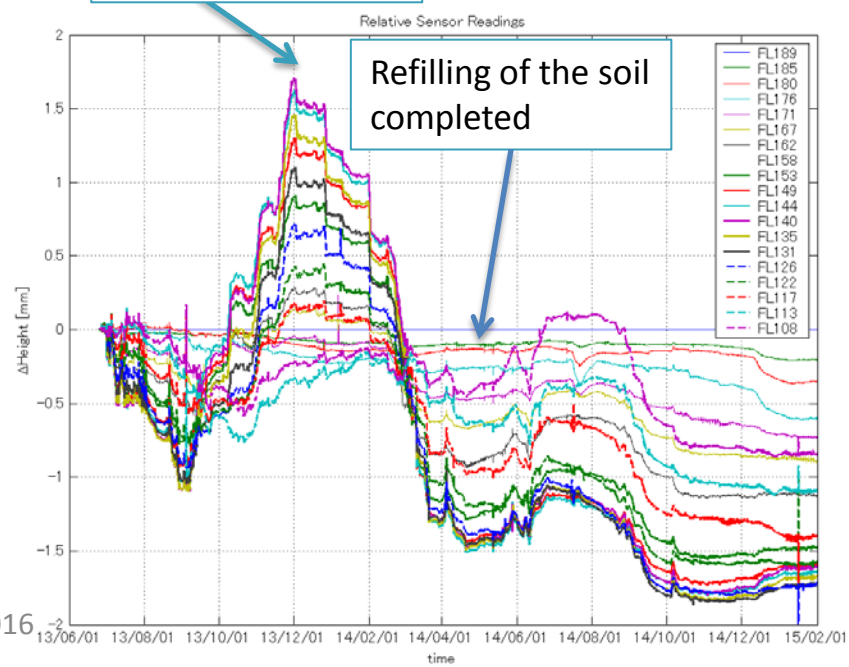
Effect of construction of new PF-AR BT line as monitored by HLS





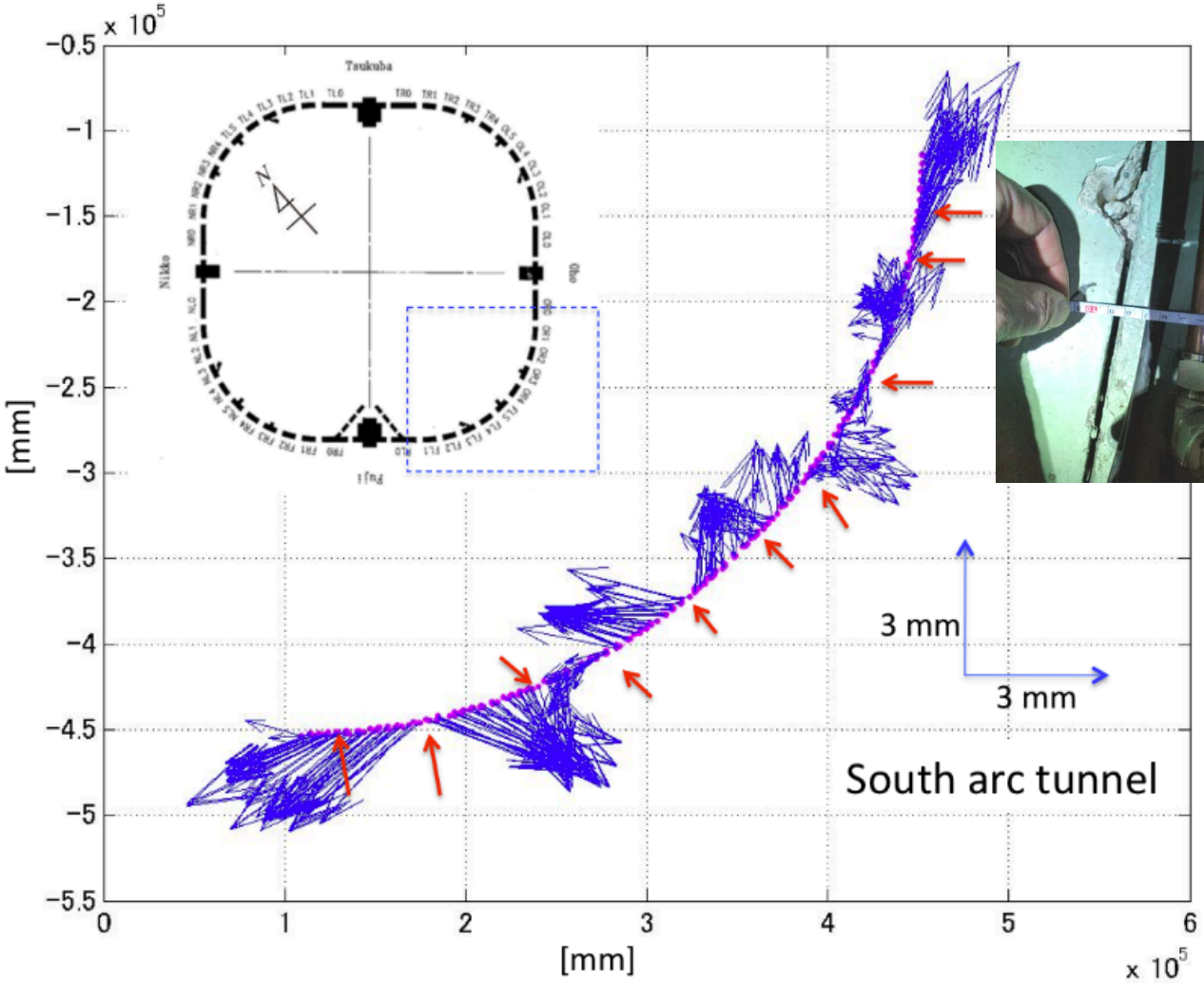
Excavation finished

Refilling of the soil completed



The tunnel level does not seem to go back to where it was before the construction.

KEKB alignment network was destroyed by the earthquake in 2011



Goals of Phase I commissioning

1) to achieve smooth beam circulation
2) to confirm that the circumferences of the LER and HER match within a few mili-meters
3) to do debugging of various hardware and software systems
4) to understand the basic features of the machine and to learn about low-emittance tuning methods.

- Strategy
  - To wait until the summer 2015 for the 2nd round of surveying, which left us with little time for aligning the magnets for Phase I.
  - Smoothing, based on the network analysis

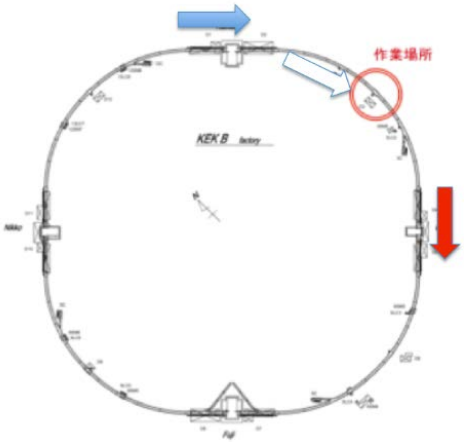
SEXTUPOLE MAGNETS WITH VARIABLE TILT ANGLES FOR SUPERKEKB
By R. Ueki (R. Sugahara) at the Thursday poster session

2nd round survey campaign in the summer

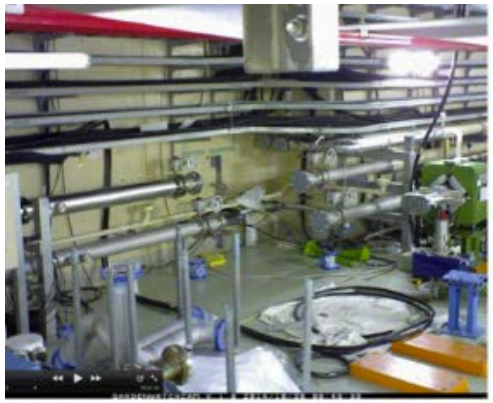
June and July 2015

Survey was carried out by 3 teams. Calibration of the laser trackers was done carefully.

Special attention was paid to systematic errors, as even very small systematic errors can result in a large error at the end over hundreds of measurement sets.



Magnet alignment



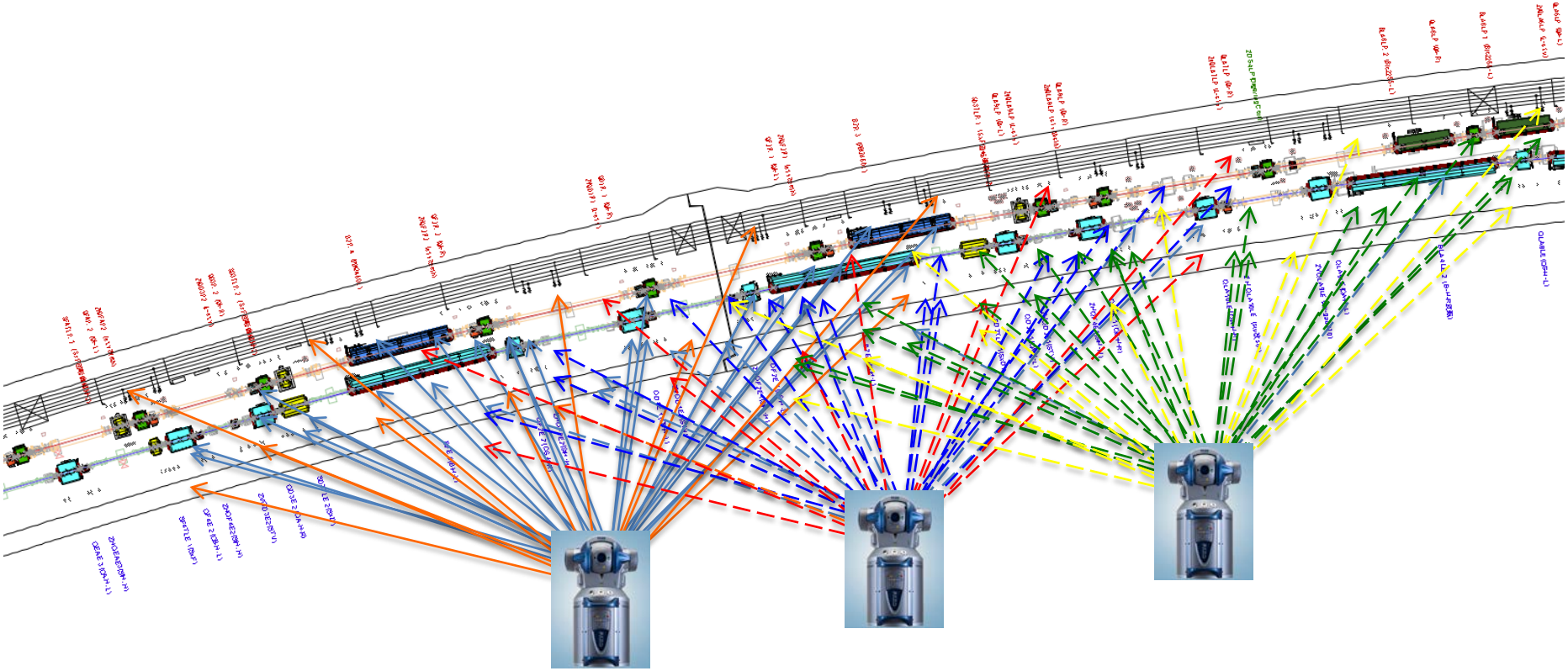
Magnets newly installed in the tunnel were aligned to nearby magnets using a laser tracker.

Aligned new magnets:

- HER quadrupoles
  - In mid-arc section
- IR magnets
  - In Tsukuba straight section and part of the north and east tunnel.

2nd round survey campaign in the summer

June and July 2015



Constraints on the working area/time

Alignment can not coexist with PS test, PS test can not coexist with water flow check, none can coexist with RF high power test (if in the same area)…,civil engineering can not coexist with survey/alignment…

More than 1200 network control points in the tunnel

More than 4000 reference points for the magnets

More than 5000 points to be surveyed and analyzed.

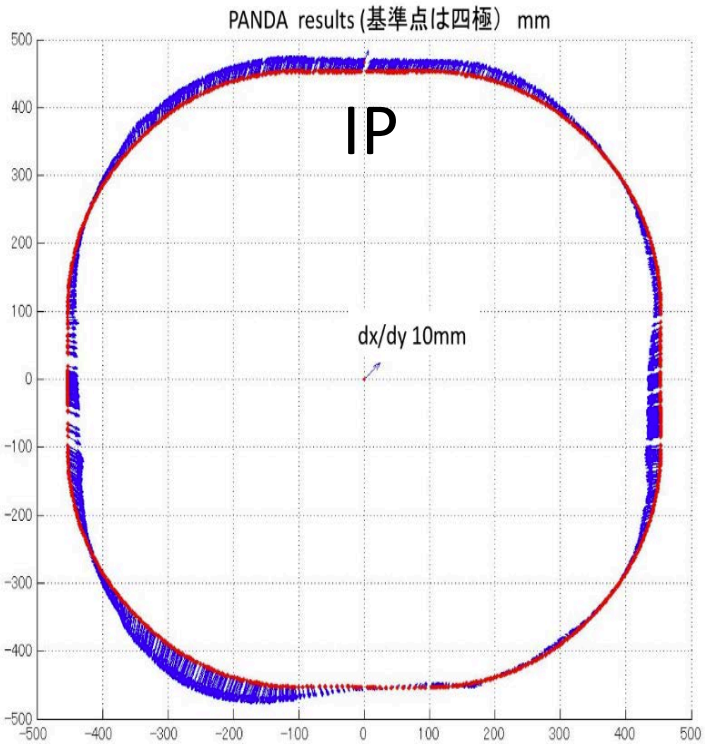
More than 400 LT settings, with overlaps

Survey results ➔ Adjustments of the misaligned magnets

Smoothing, based on the network average calculation

We got hundreds of data points each day from 3 teams,
which were analyzed and cross-checked by us independently everyday. If we found something funny, we requested the survey team to go back before they moved a long distance down the tunnel.

Survey Data and analysis results



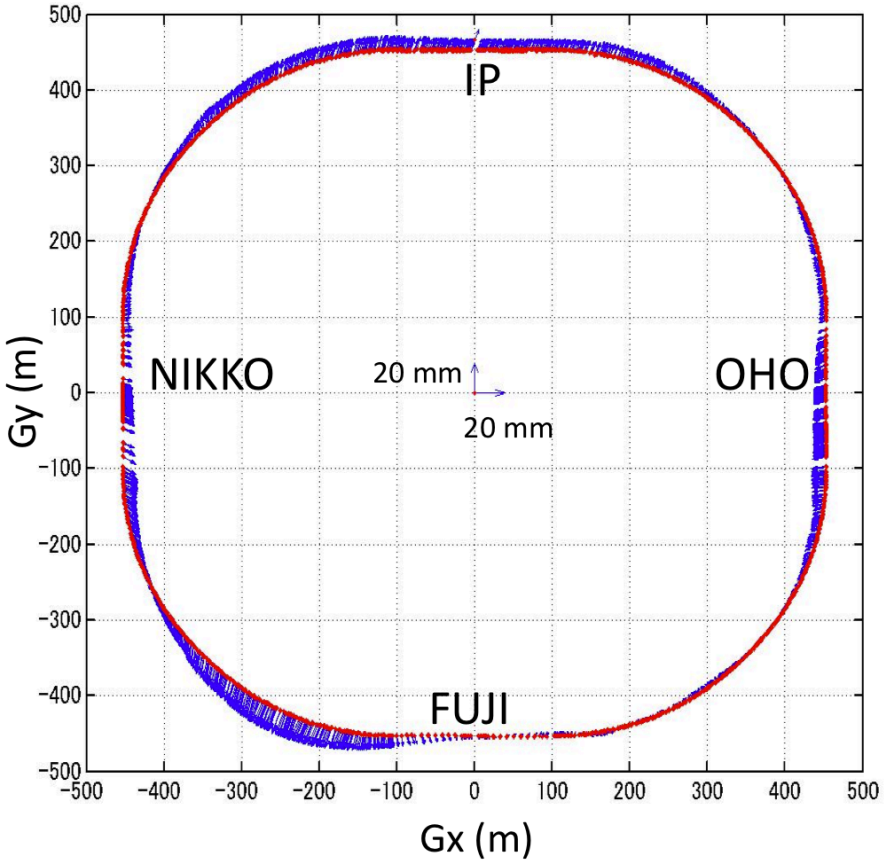
The north and west parts expand outward more than 10 mm. This probably happened when the TRISTAN monuments were first built.

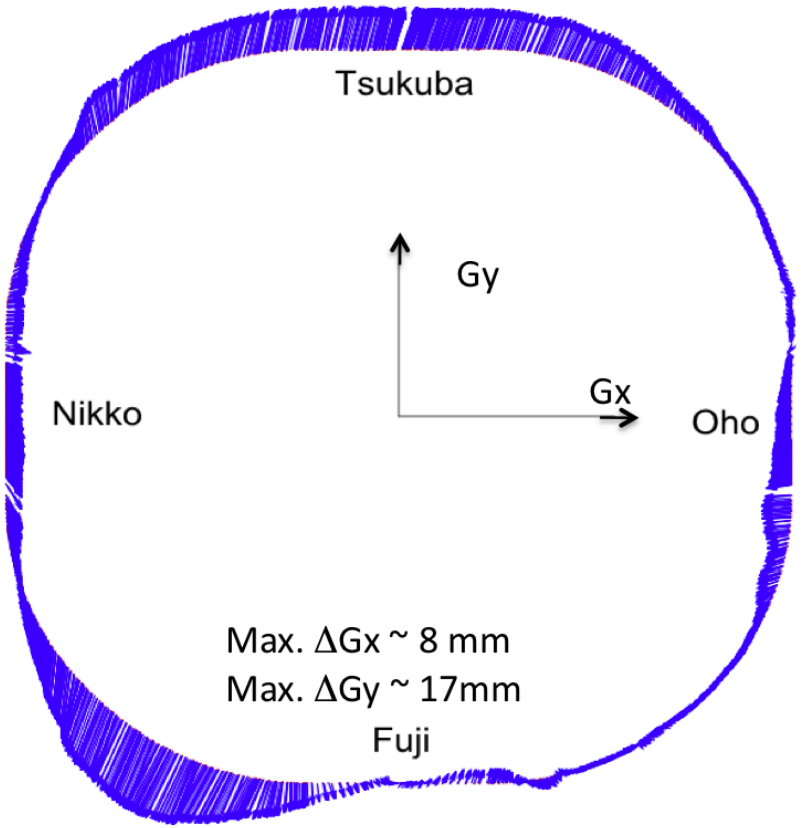
Does this matter?
➔No. Deformation of low order does not matter.

Constraints:
The rings have to close.
➔Smooth periodic curves will do.

Our choice was a Fourier series (n=60). We tried FS with n=30, but the # of magnets to be adjusted increased, and the amount of adjustment became larger…
(of course we can do it but it would have affected other accelerator components such as vacuum chamber and rf…)

Analysis results, comparison



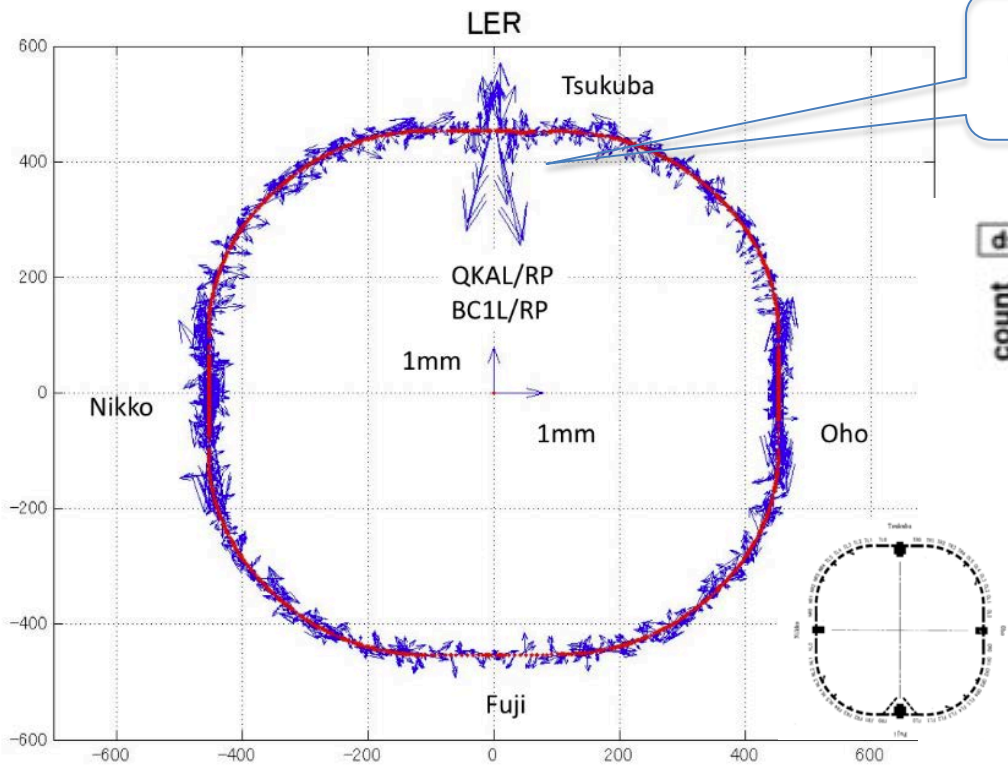


PANDA & PAG-U gave similar results

We are developing our own code from scratch, which also gives similar results but needs some more work.

Survey Data and analysis results

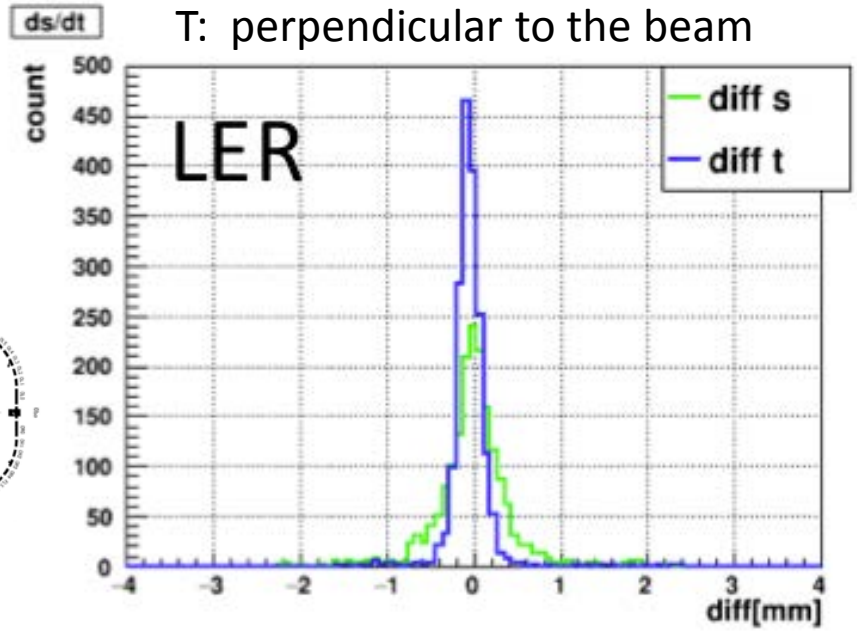
Deviation from smooth curves (LER)



We used the old lattice (oops)

S: Beam direction

T: perpendicular to the beam



The spread in “s” (beam direction) is larger.

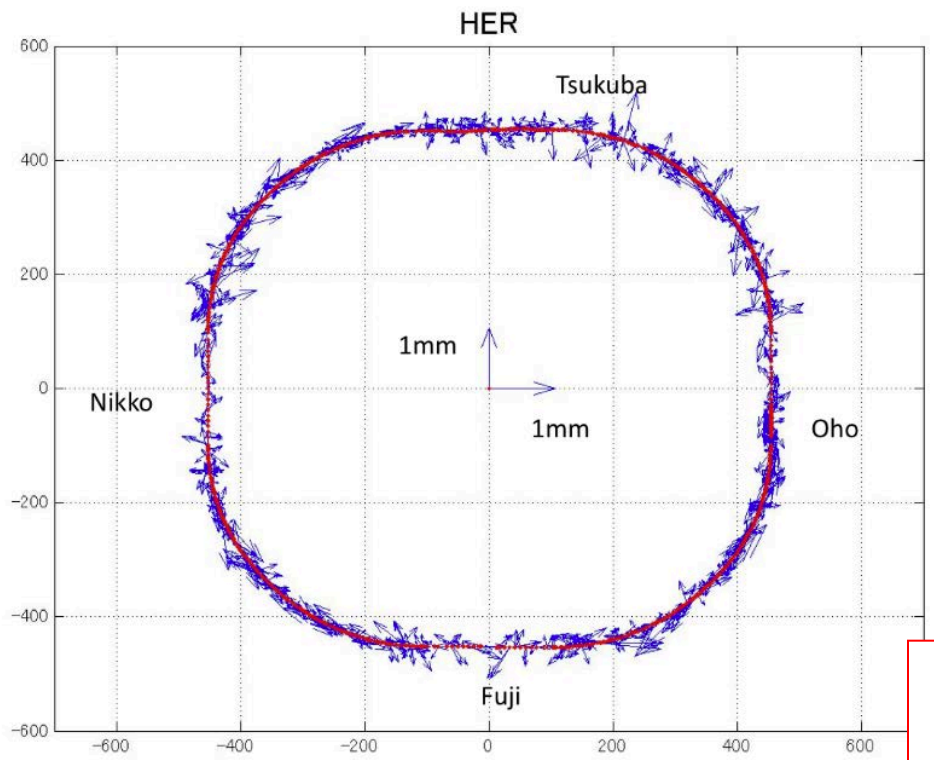
This is due to the expansion joints.

The temperature was NOT controlled during SuperKEKB construction.

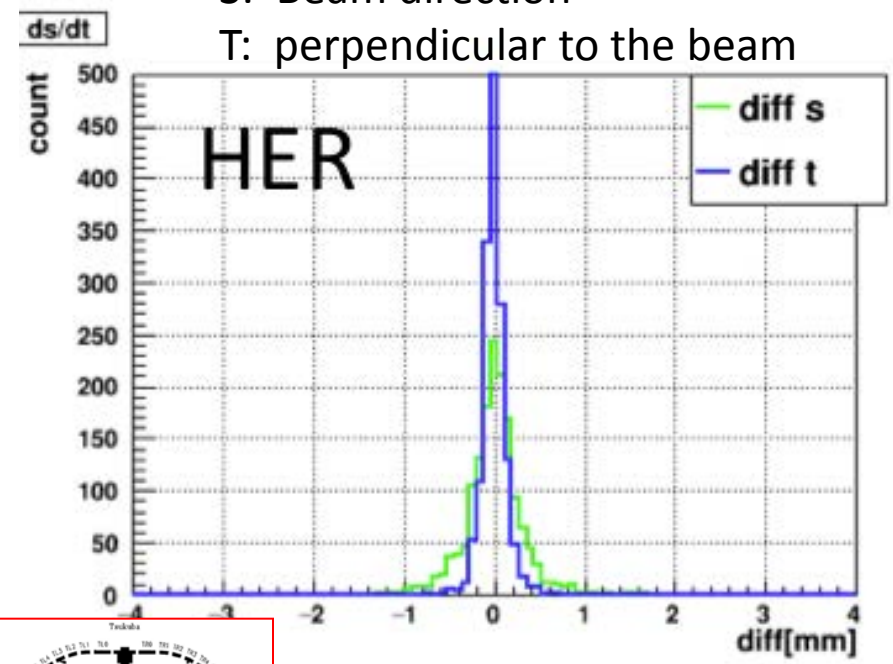
The temperature was different between the 1st rough alignment and the 2nd survey.

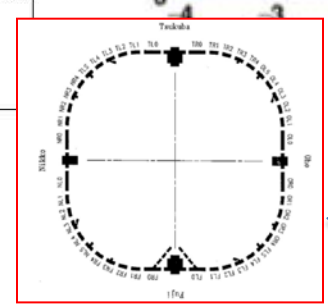
Survey Data and analysis results

Deviation <u>from smooth curves (HER)</u>



S: Beam direction
T: perpendicular to the beam





Expansion joints to absorb the thermal expansion & contraction.

The spread in “s” (beam direction) is larger.
This is due to the expansion joints.
The temperature was NOT controlled during the SuperKEKB construction.
The temperature was different between the 1st rough alignment and the 2nd survey.

Alignment strategy

Discussion with the optics group, prioritize issues for “good-enough” for Phase I

Time (schedule), man power (cost) ,impact to the other groups, against machine performance (good enough for Phase I) was discussed with the Optics G.

	Tolerance (Δt)	Tolerance (Δs)
Dipole	0.4mm	0.8mm
Wiggler	0.4mm	0.8mm
Quadrupole	0.2mm	0.4mm
Sextupole	0.2mm	0.4mm
LER Dipole(3 ref. pts)	0.4mm	0.8mm

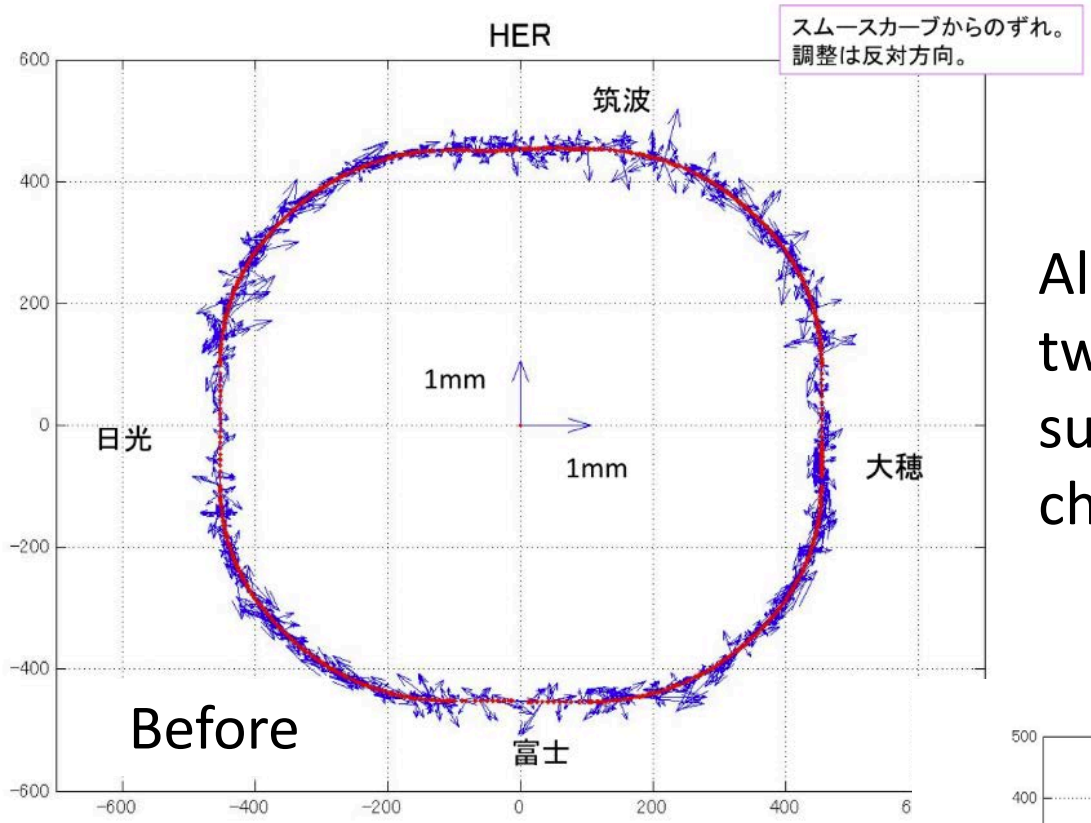
Tough work in the tight space.

Not our tunnel

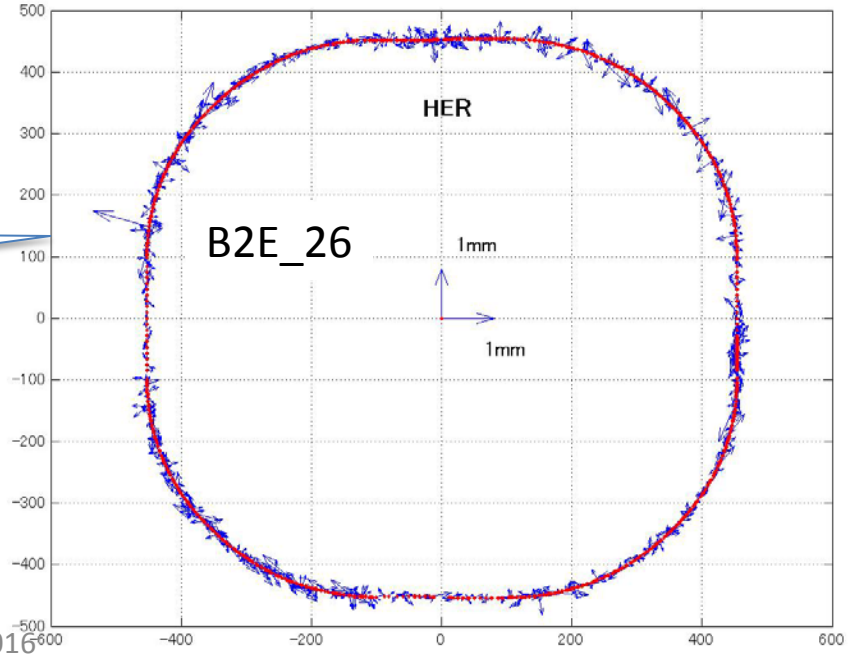
The magnet pitch and roll angles were measured using digital inclinometer.

Alignment strategy

Alignment was carried out by two teams, followed by a survey team dedicated to checking the alignment.



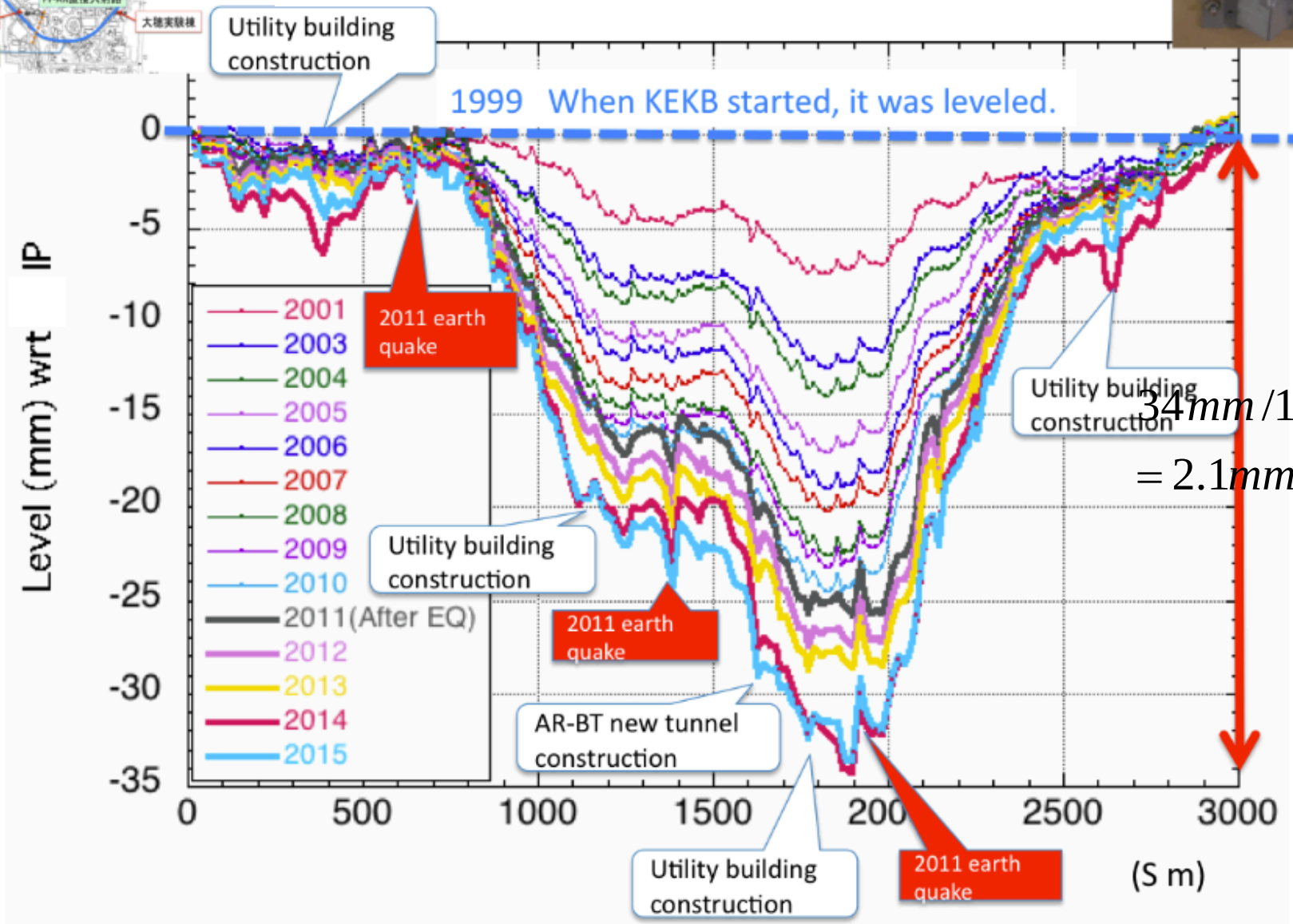
Found a misalignment, which was fixed right away.



Survey Results

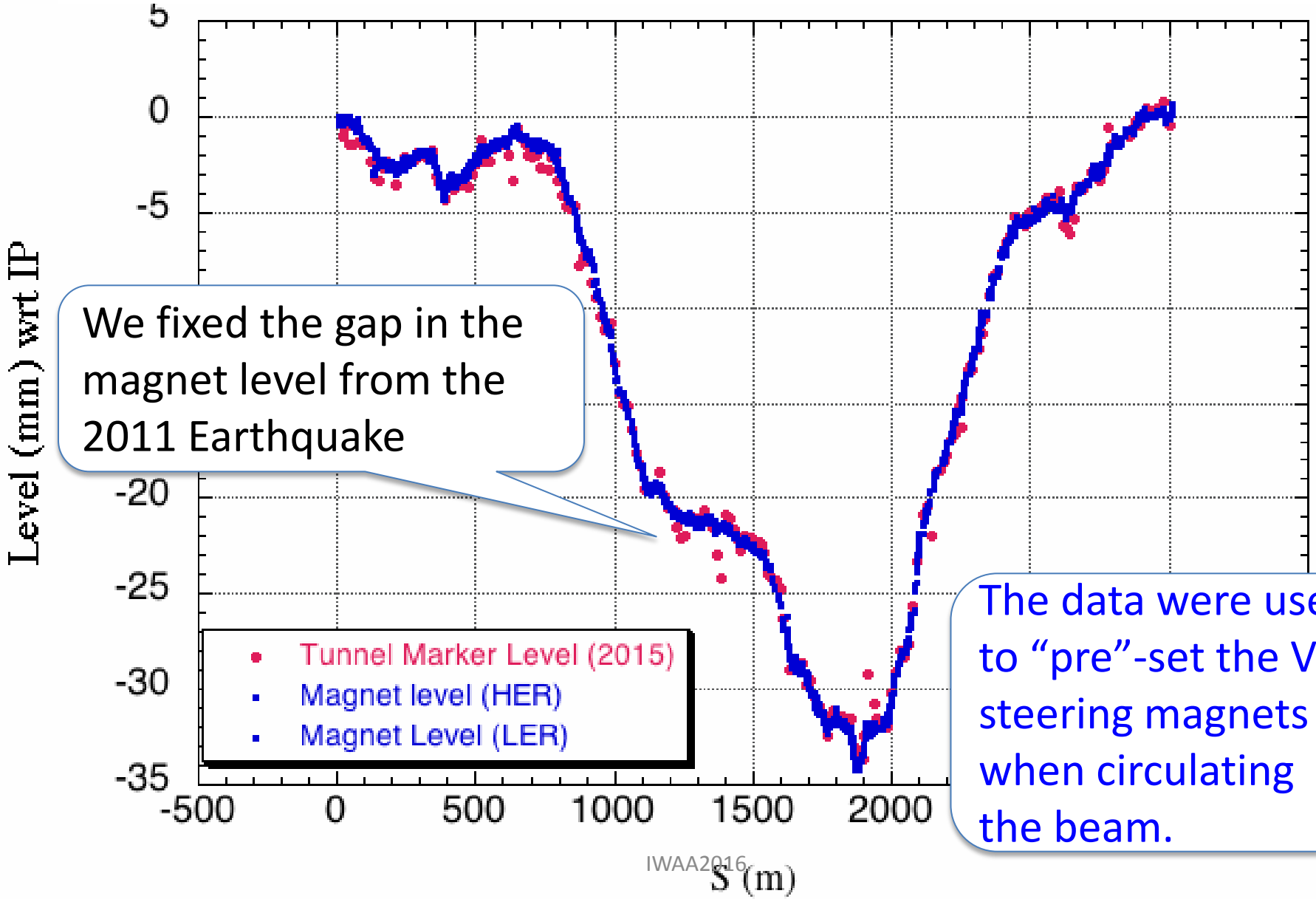
VERTICAL (LEVEL)

Tunnel sinking continues



$$34mm/16years = 2.1mm/year$$

Survey Data and analysis results



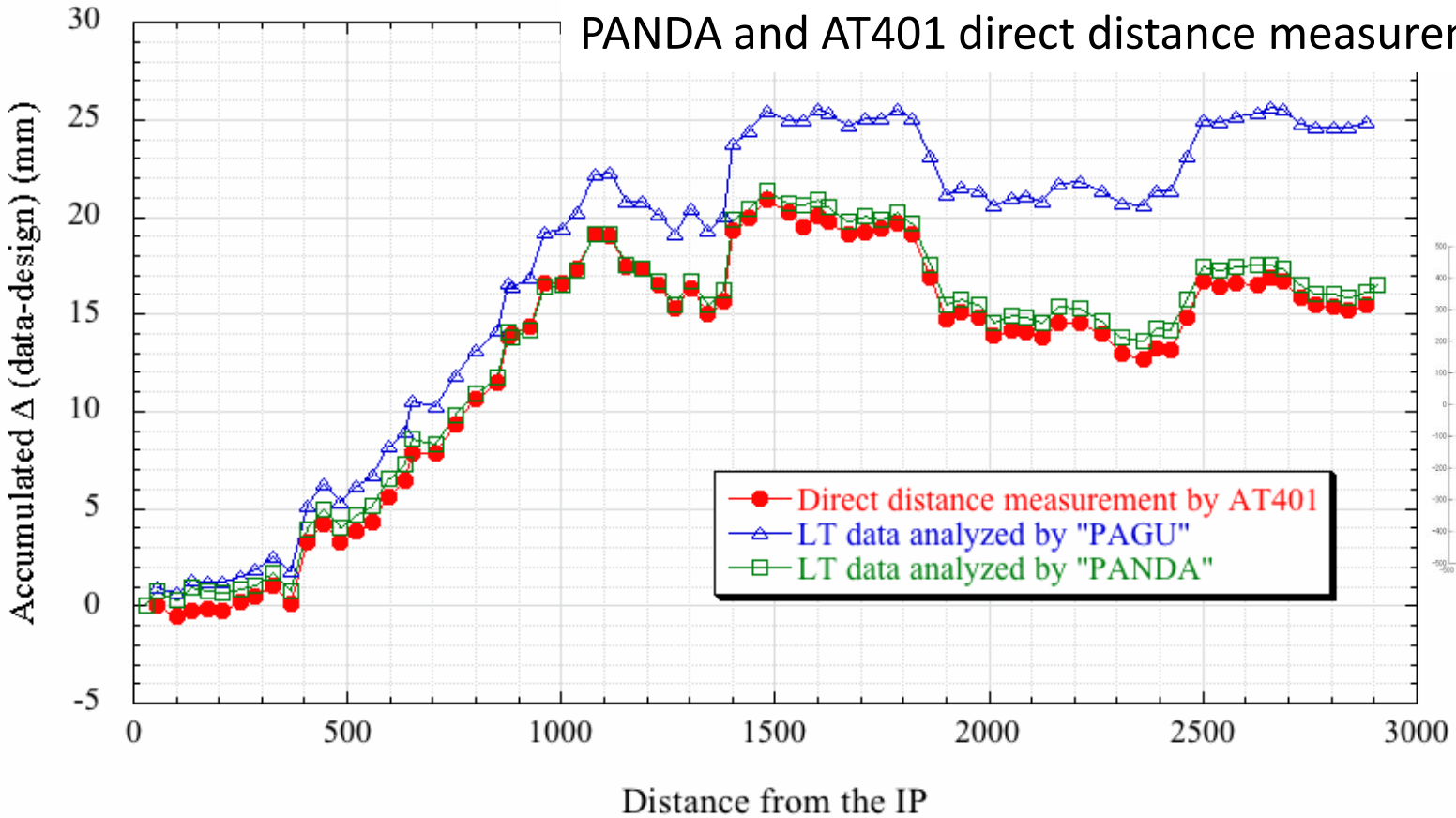
We fixed the gap in the magnet level from the 2011 Earthquake

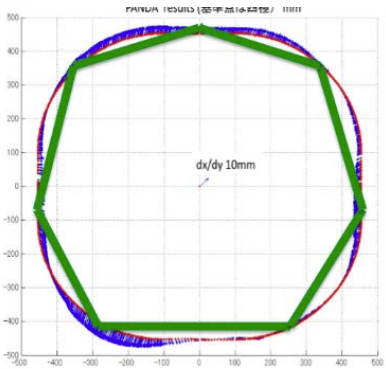
The data were used to "pre"-set the V-steering magnets when circulating the beam.

- Results
  - Well done!

Circumference estimate

PANDA and AT401 direct distance measurement agree

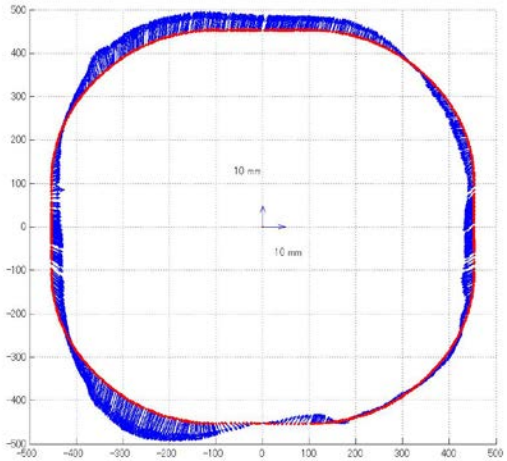




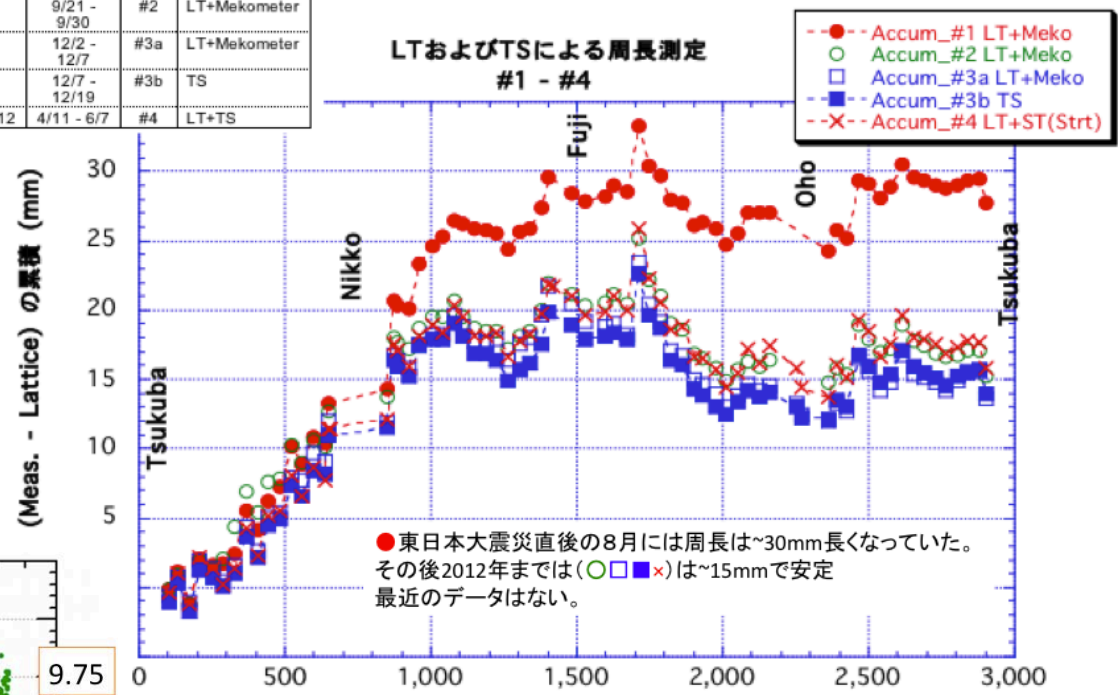
Our best guess from the survey and analysis (PANDA) was that the circumference is about 16.4 mm longer than the SuperKEKB design. This information was used when injecting the LER beam to the ring on Feb.9, 2016 and the beam said Yes!

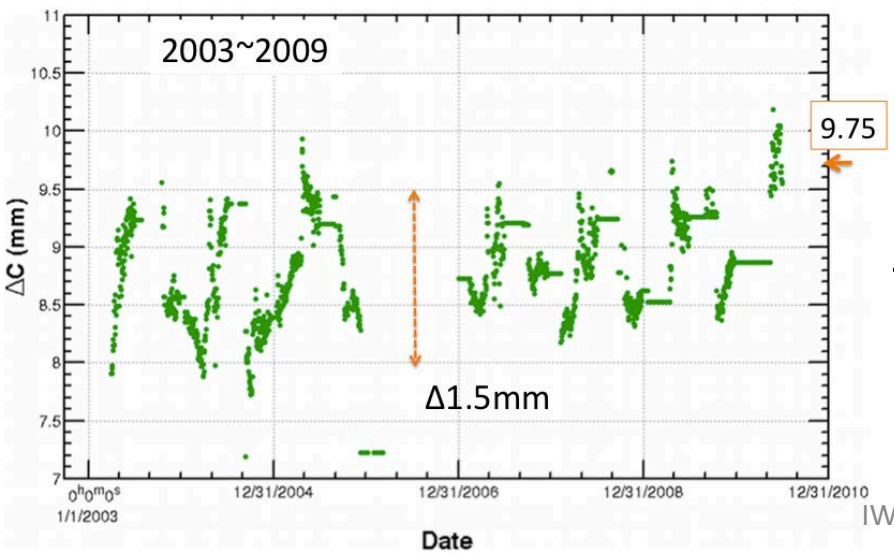
Our rings look like this

(Our rings have been always larger than the design)



2011	7/28 - 8/24	#1	LT+Mekometer
	9/21 - 9/30	#2	LT+Mekometer
	12/2 - 12/7	#3a	LT+Mekometer
	12/7 - 12/19	#3b	TS
2012	4/11 - 6/7	#4	LT+TS



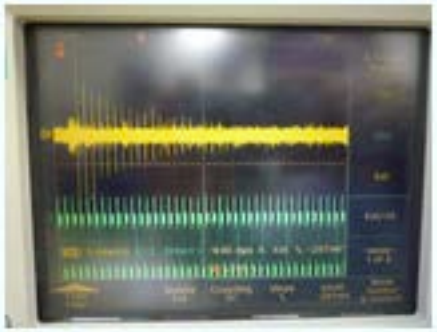


Our rings were the largest right after the Great East Japan Earthquake in 2011. They started shrinking but not back to the level of KEKB.

First beam to the SuperKEKB MR LER…

18:35:14

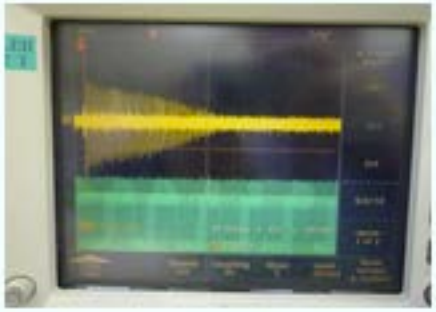
20ターン目が見えた



19:53:52

ZHQF4P24 調整

100ターン



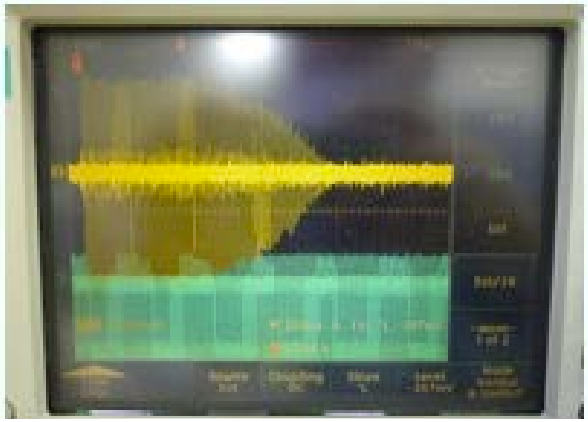
Each spike corresponds to 1 turn.

20:03:44

ZVQDWNP1調整

130ターン

130 turns!



Storage was achieved the next day when we turned on the RF

Difference between LER and HER

LER was commissioned first, then HER.

RF said that the difference between two rings in circumference is ONLY 0.2 mm!

I know, we were just lucky but.

We came a long way

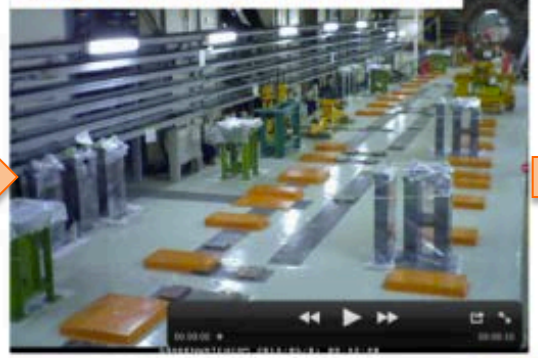
The last days of KEKB

Dismantling of the KEKB magnet

2011 Earthquake

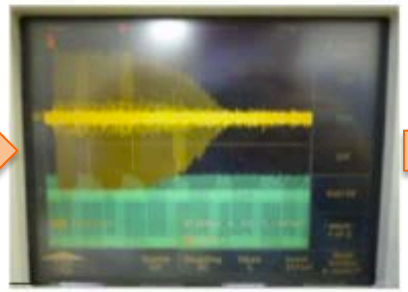
Magnets cables removed

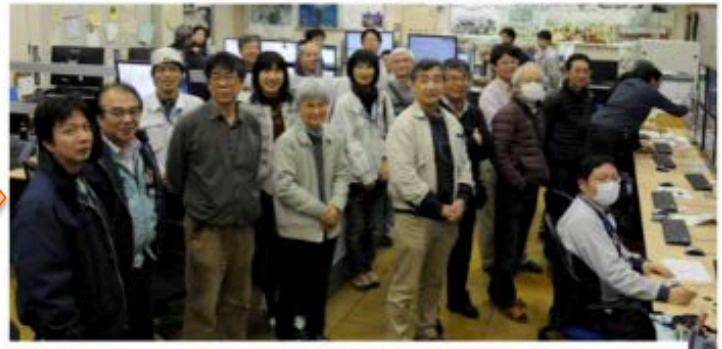
SuperKEKB Beam line



Magnets being installed

SuperKEKB layout





KEKB Review 2016

A big milestone for us 2/9/2016

- Summary

Summary

- The SuperKEKB MR magnet system was completed in time for Phase I commissioning.
- The prediction for the circumference agreed with the actual circumference within 0.3 ppm accuracy and the difference in the circumference in both rings was found to be 0.2 mm (!), which contributed to the smooth start-up of the MR.
- We would like to add more HLS sensors to monitor the tunnel level changes, especially at the IP & LCC sections (T. Kawamoto's poster on Thursday).

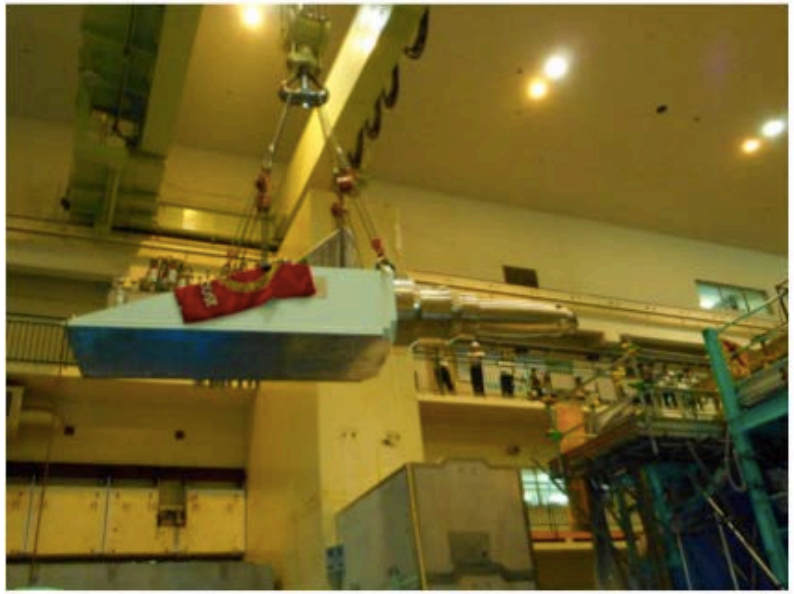
No time to rest

We are preparing for Phase II, with the final focus superconducting magnet systems.

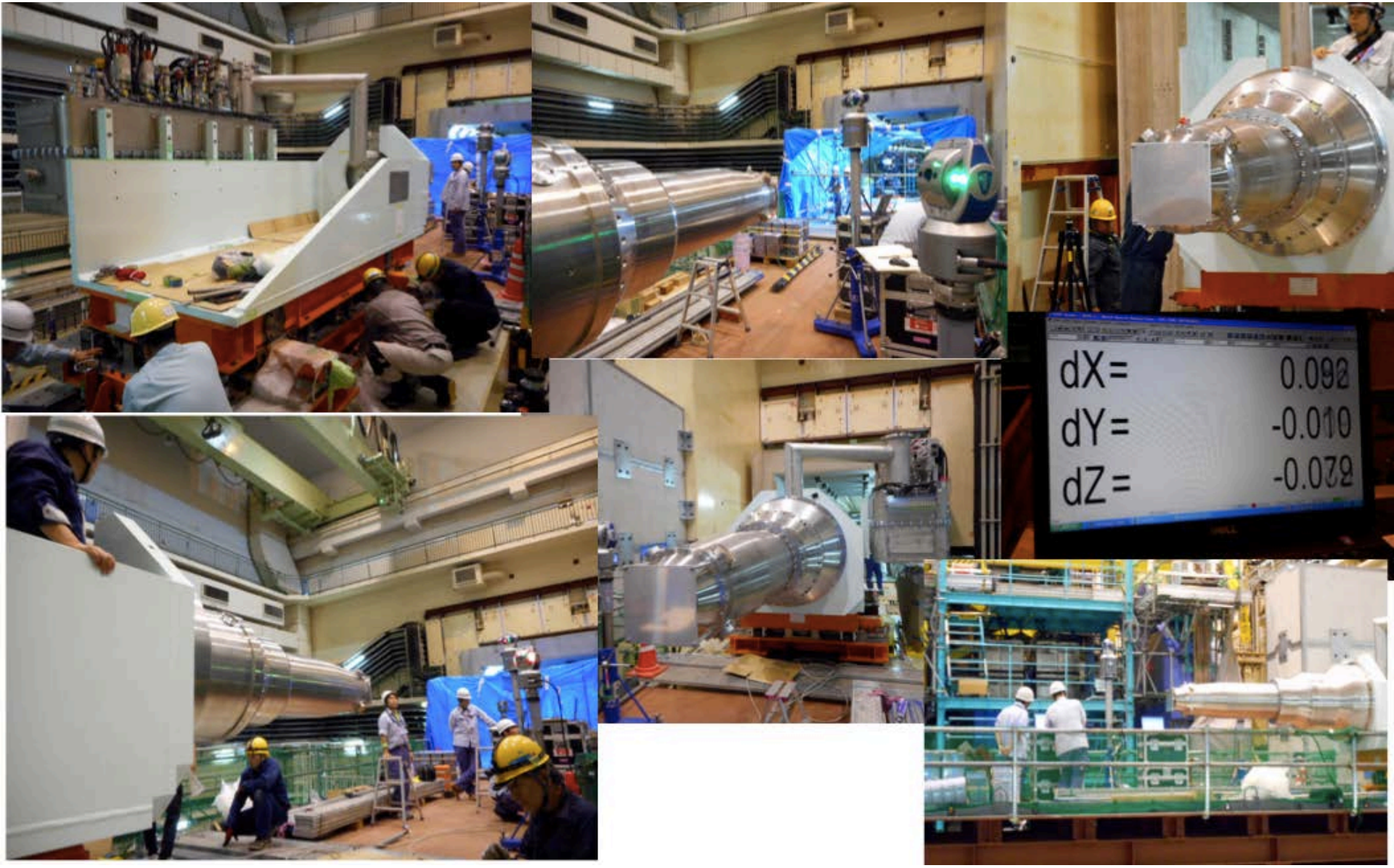
One cryostat was installed in August, 2016.

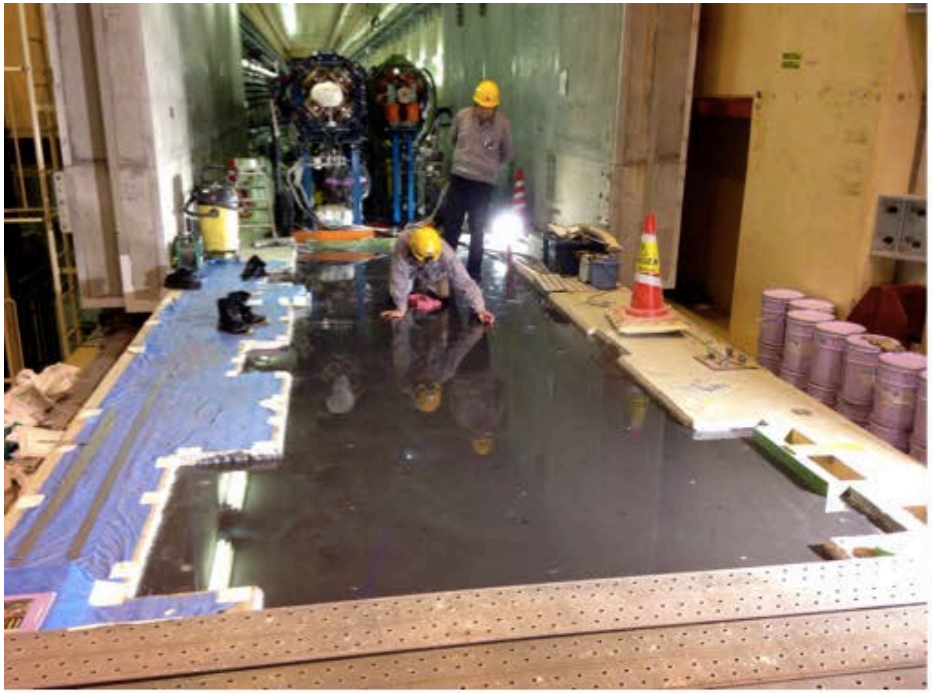
The floor was leveled nicely by “self-leveling” method.

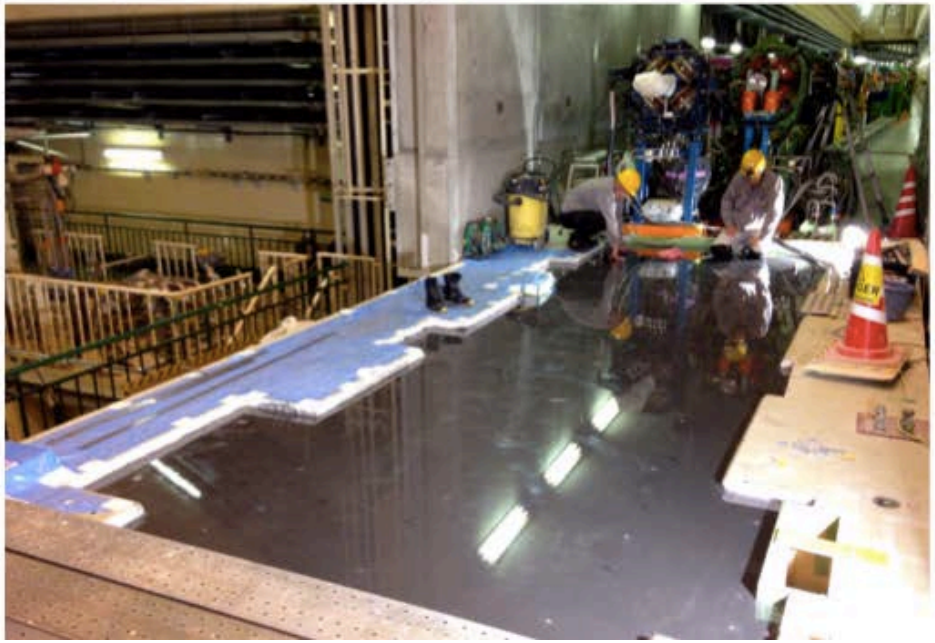
QCSL cryostat installation Aug. 2016



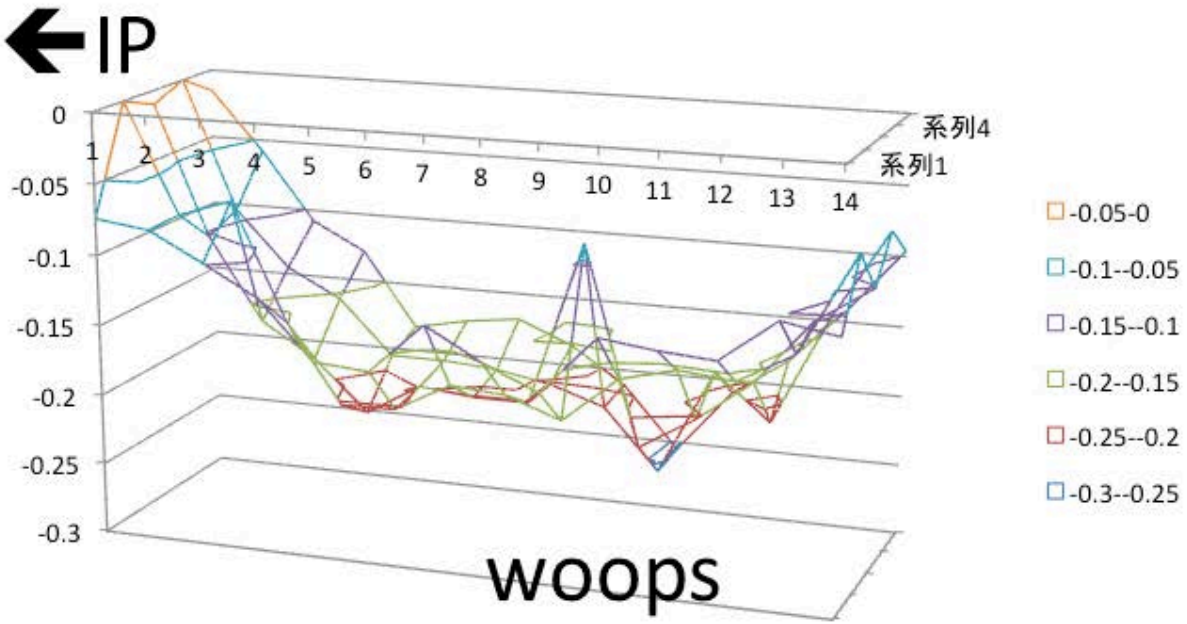
Alignment



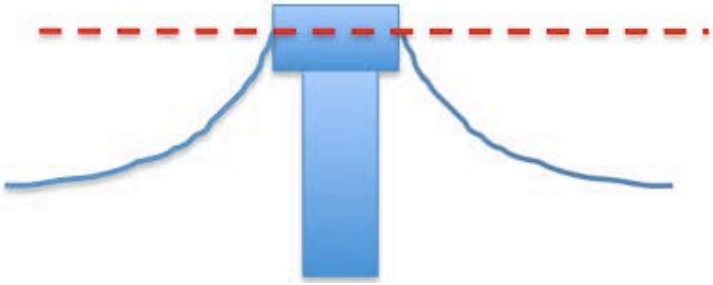




self-leveling


IP
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
1
2
3
4
5
6
7
8
9
10
11
12
13
14
系列4
系列1
-0.05-0
-0.1--0.05
-0.15--0.1
-0.2--0.15
-0.25--0.2
-0.3--0.25
woops


43



Merci