Beam Commissioning of SuperKEKB rings at Phase-1

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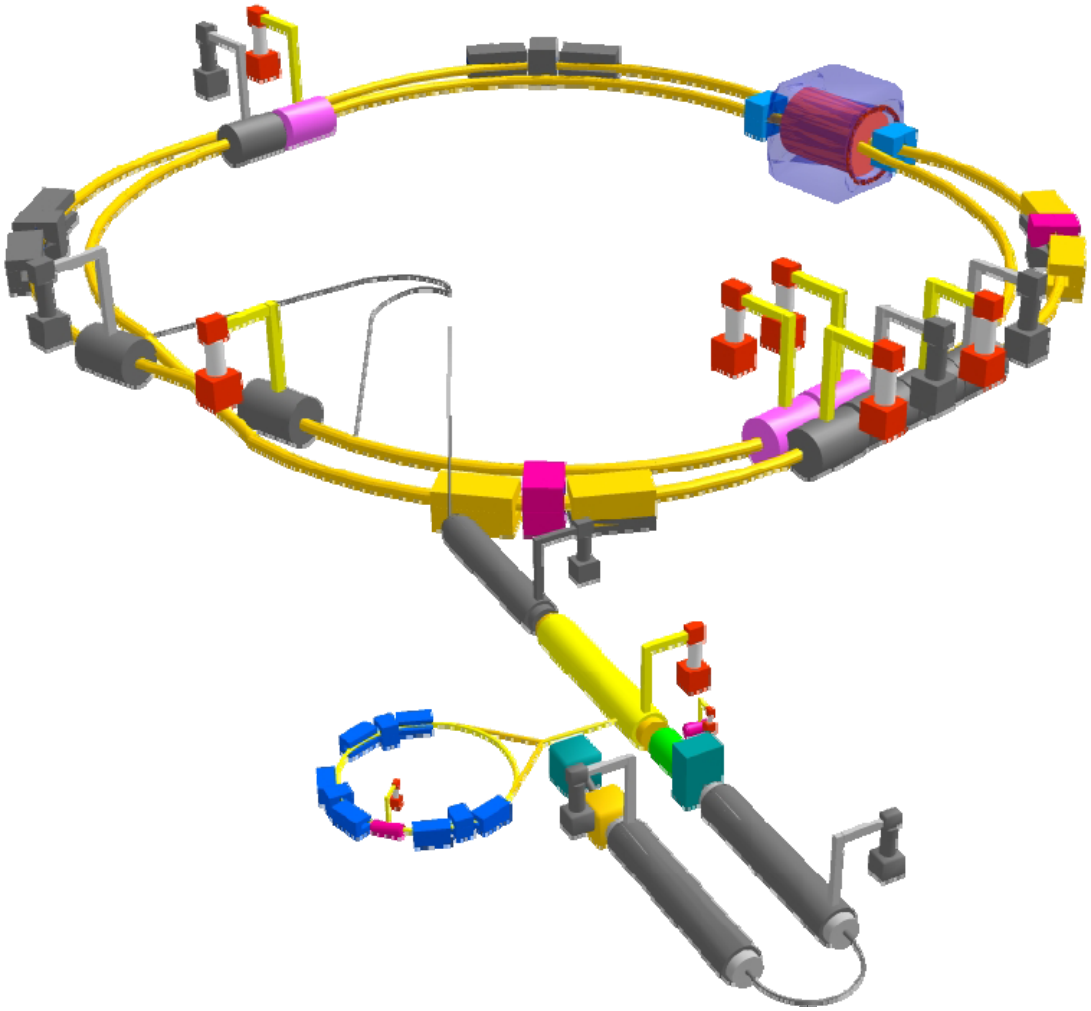
SuperKEKB accelerators



- Circumference 3km
- LER:e^+ 4GeV 3.6A
- HER:e^- 7GeV 2.6A
- f_{RF}=508.886MHz
- h=5120
- Low emittance 3.2/4.6nm with ~0.28% xy-coupling
- Bunch length 6/5 mm @1mA/bunch
- β* at IP H/V 32/0.27mm 25/0.3mm
- Luminosity 80×10^{35}
  - x40 of KEKB

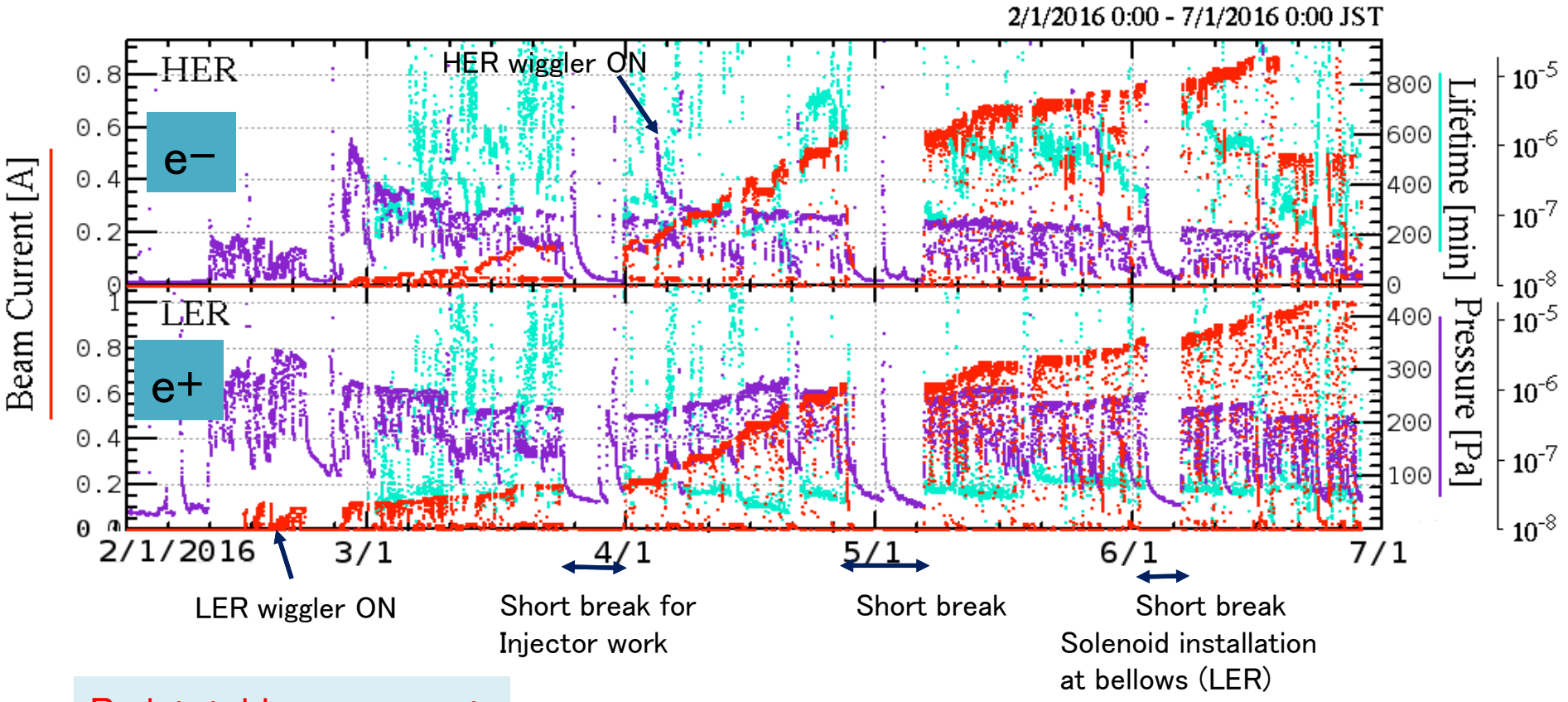
Commissioning stages

- **Phase-1 (Feb 2016-Jun 2016)**
  - Without Belle-II detector (with Beast test detector)
  - Without superconducting final quads
  - Without collision
  - Without positron damping ring
- **Phase 2 (Oct 2017 - Jul 2018)**
  - With Belle-II detector and superconducting final quads.
    - Without innermost detector (Pixel, SVD)
  - With positron damping ring
  - Target luminosity : 1×10^{34}
- **Phase 3 (Jan 2019---)**
  - Full set Belle2 detector
  - Physics run with target luminosity of 8×10^{35}

Target of Phase-1 operation

- **Startup of each hardware system**
- **Establish beam operation software tools**
- **Preparation for installation of Belle-II detector**
  - Enough vacuum scrubbing (ex. 360-720 Ah)
- **High beam current operation**
  - Find and solve difficulties associated with high beam current operation
- **Optics tuning without IR (nor detector solenoid)**
  - Low emittance, low x-y coupling tunig
- **Various machine developments**

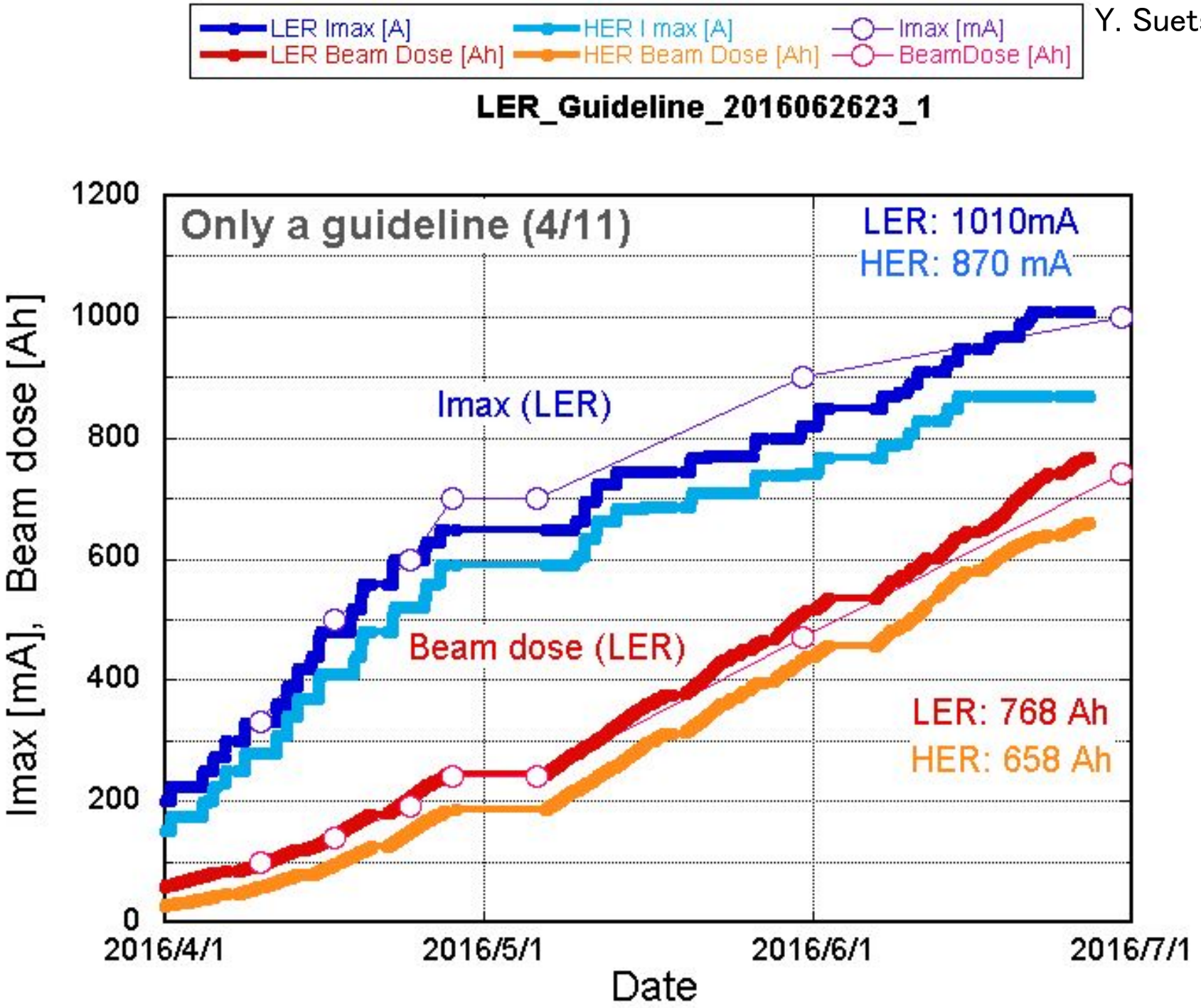
History of Phase 1 operation



Red: total beam current
Purple: vacuum pressure
Cyan: beam lifetime

HER:
870 mA, 5.7x10^{-8} Pa, ~200 min. (6/17)
LER:
1010mA, 4.7x10^{-7} Pa, ~60 min. (6/22)

Y. Suetsugu


LER Imax [A]
HER I max [A]
Imax [mA]
LER Beam Dose [Ah]
HER Beam Dose [Ah]
BeamDose [Ah]
LER_Guideline_2016062623_1
Only a guideline (4/11)
LER: 1010mA
HER: 870 mA
Imax (LER)
Beam dose (LER)
LER: 768 Ah
HER: 658 Ah
Imax [mA], Beam dose [Ah]
Date
0
200
400
600
800
1000
1200
2016/4/1
2016/5/1
2016/6/1
2016/7/1

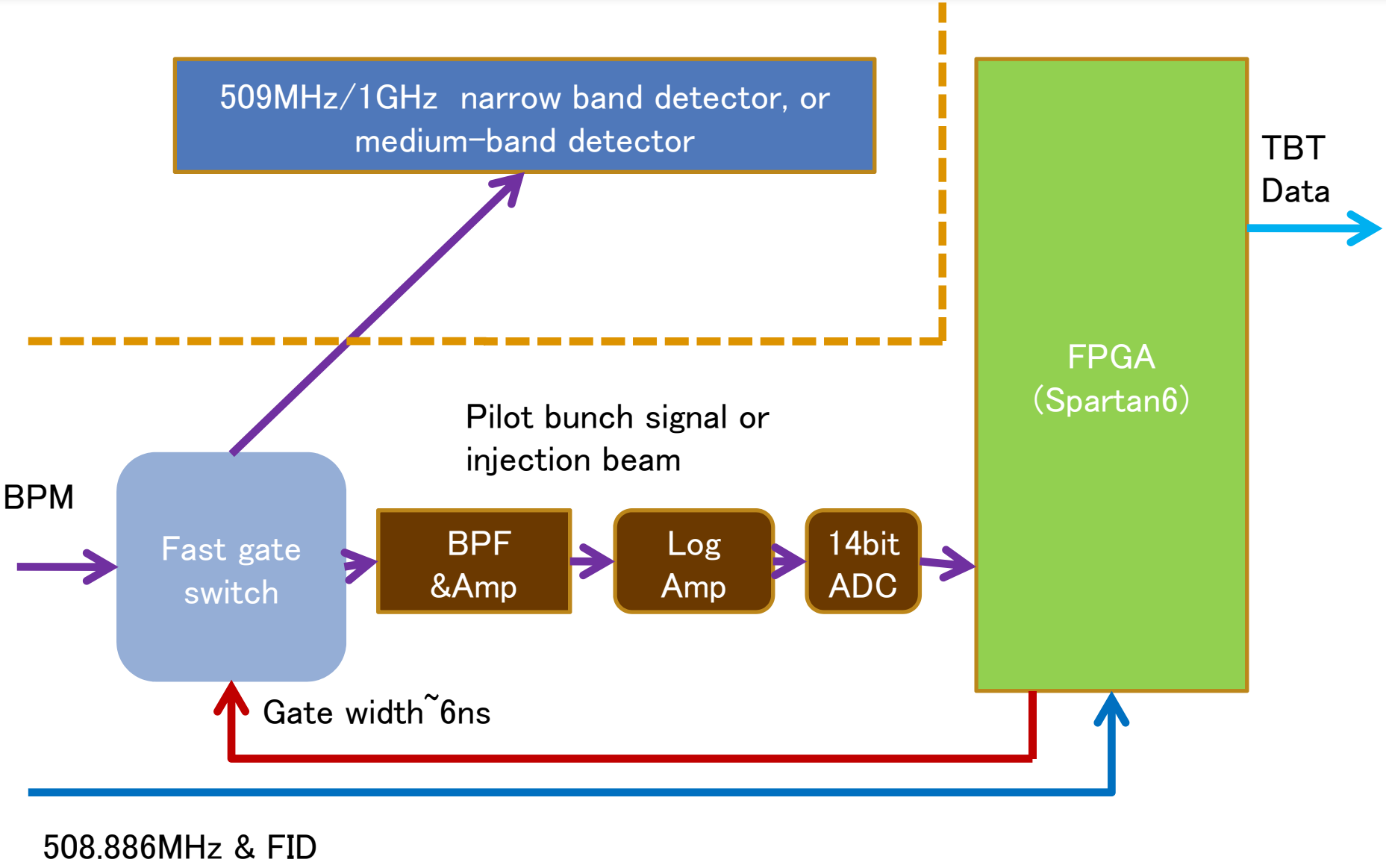
Beam instrumentations

System	Quantity		
	HER	LER	DR
Beam position monitor (BPM)	466	444	83
Gated turn-by-turn monitor (GTBT)	58	59	0
Transverse bunch feedback system	2	2	1
Longitudinal bunch feedback system	0(1)	1	0
Visible SR size monitor	1	1	1
X-ray size monitor	1	1	0
Beamstrahlung monitor	1	1	0
Betatron tune monitor	2	2	1
Beam loss monitor	200		34
DCCT	1	1	1
CT	1	1	0
Bunch current monitor	1	1	1

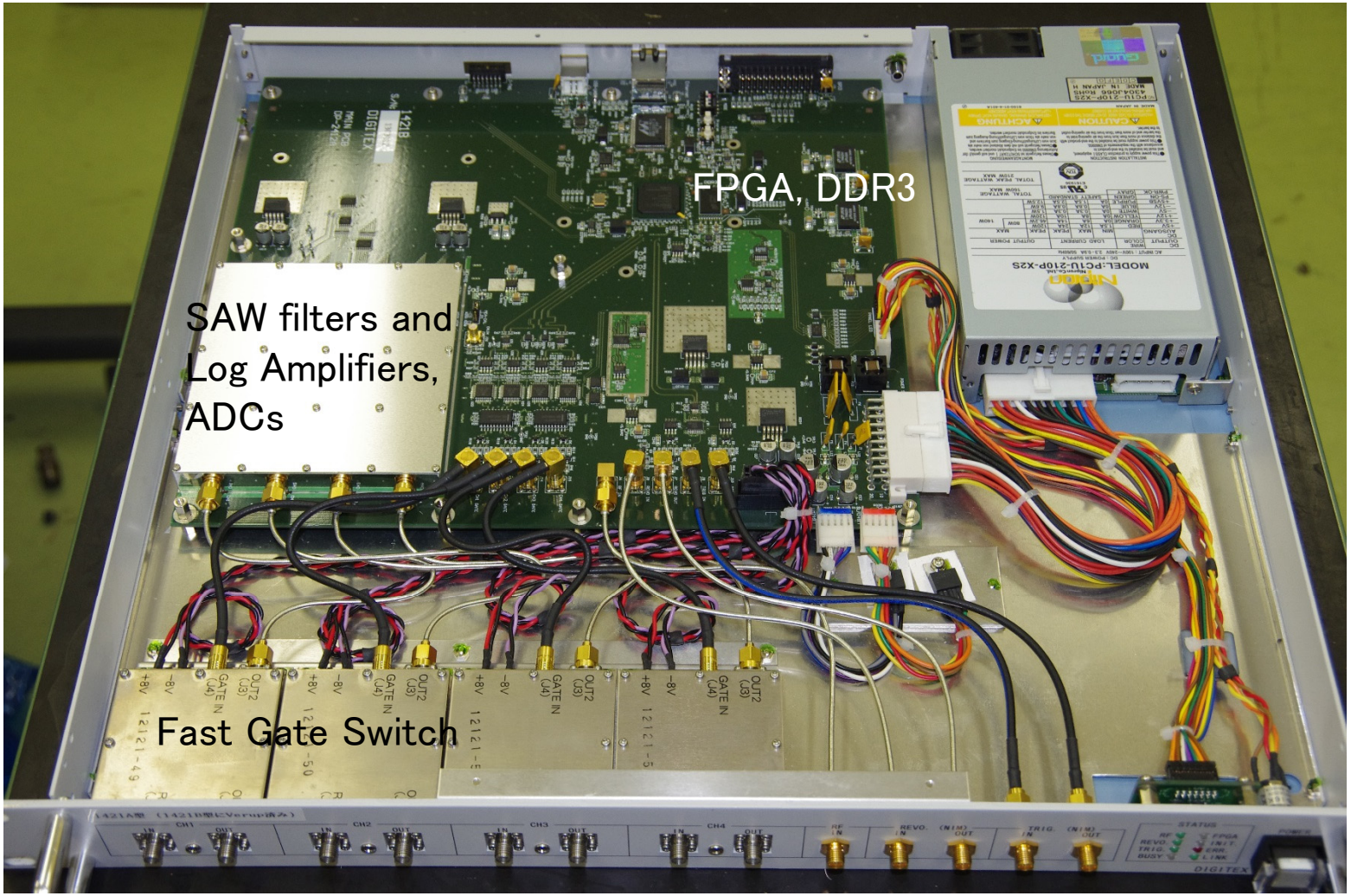
Injection Tuning

- **Gated Turn-by-turn monitor : Timing adjustment is needed before use!**
  - 50/450 BPM, even placement : NO GTBT around important point such as beam collimeters, injection section...
  - Needed to bring oscilloscope and observe BPM single directory.

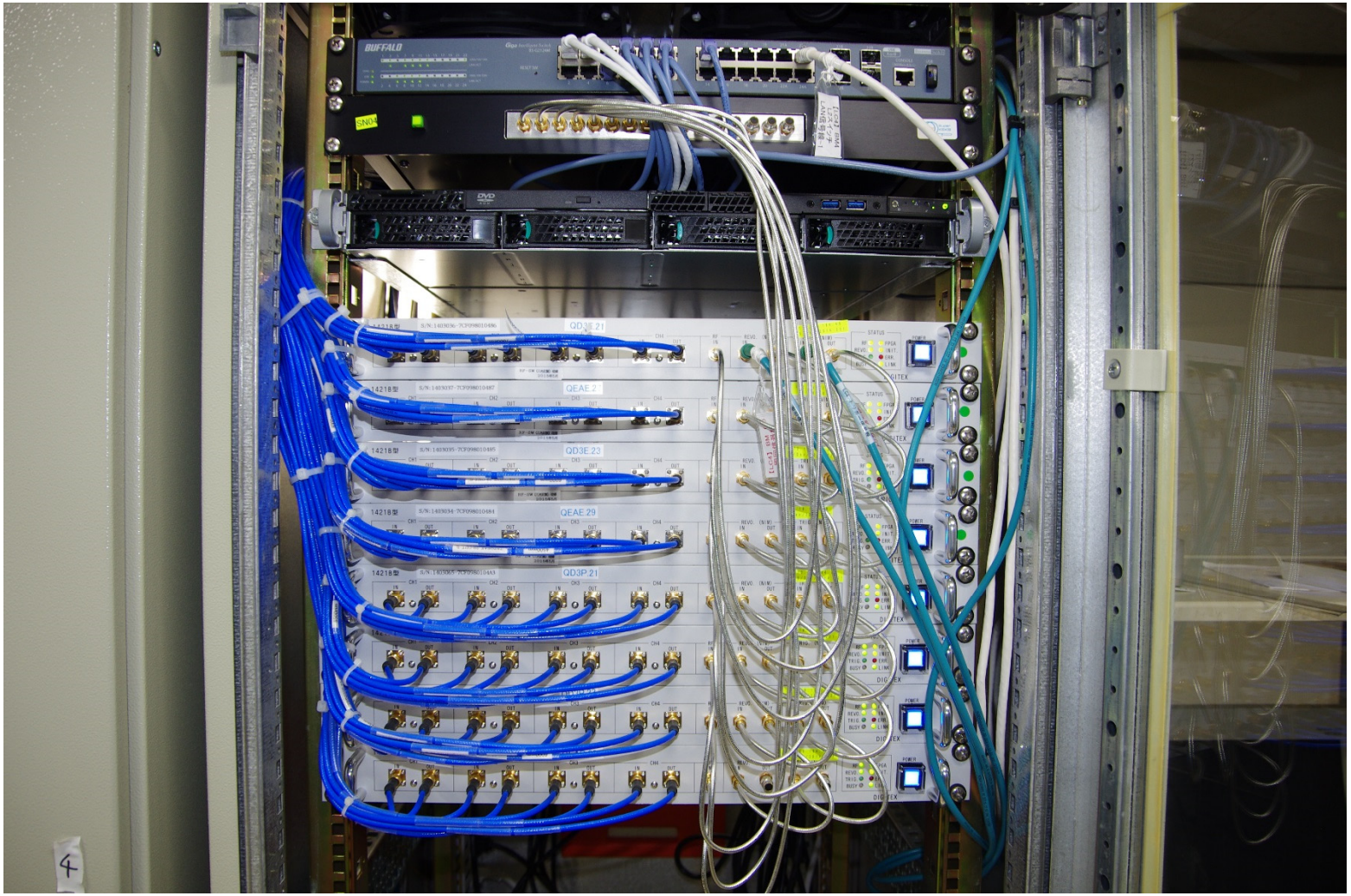
Gated turn-by-turn monitor



1421B Gated turn-by-turn monitor

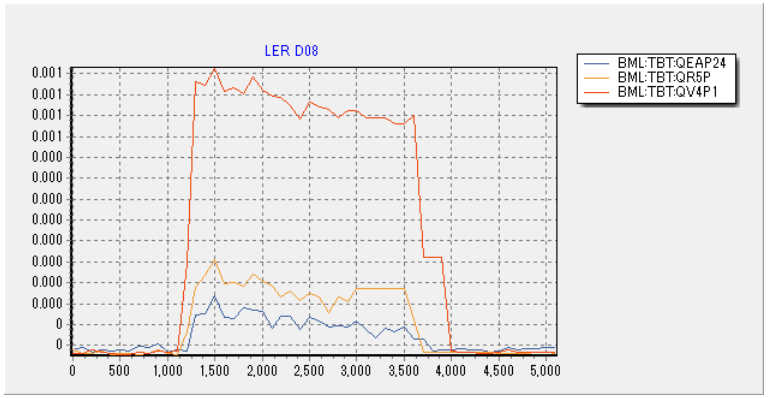


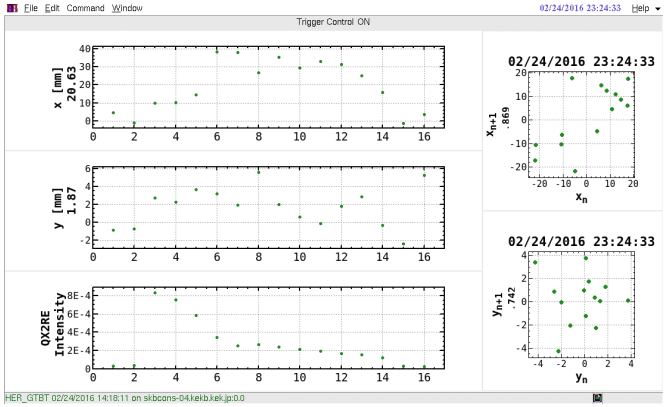
117 units have been distributed around 20 local control rooms



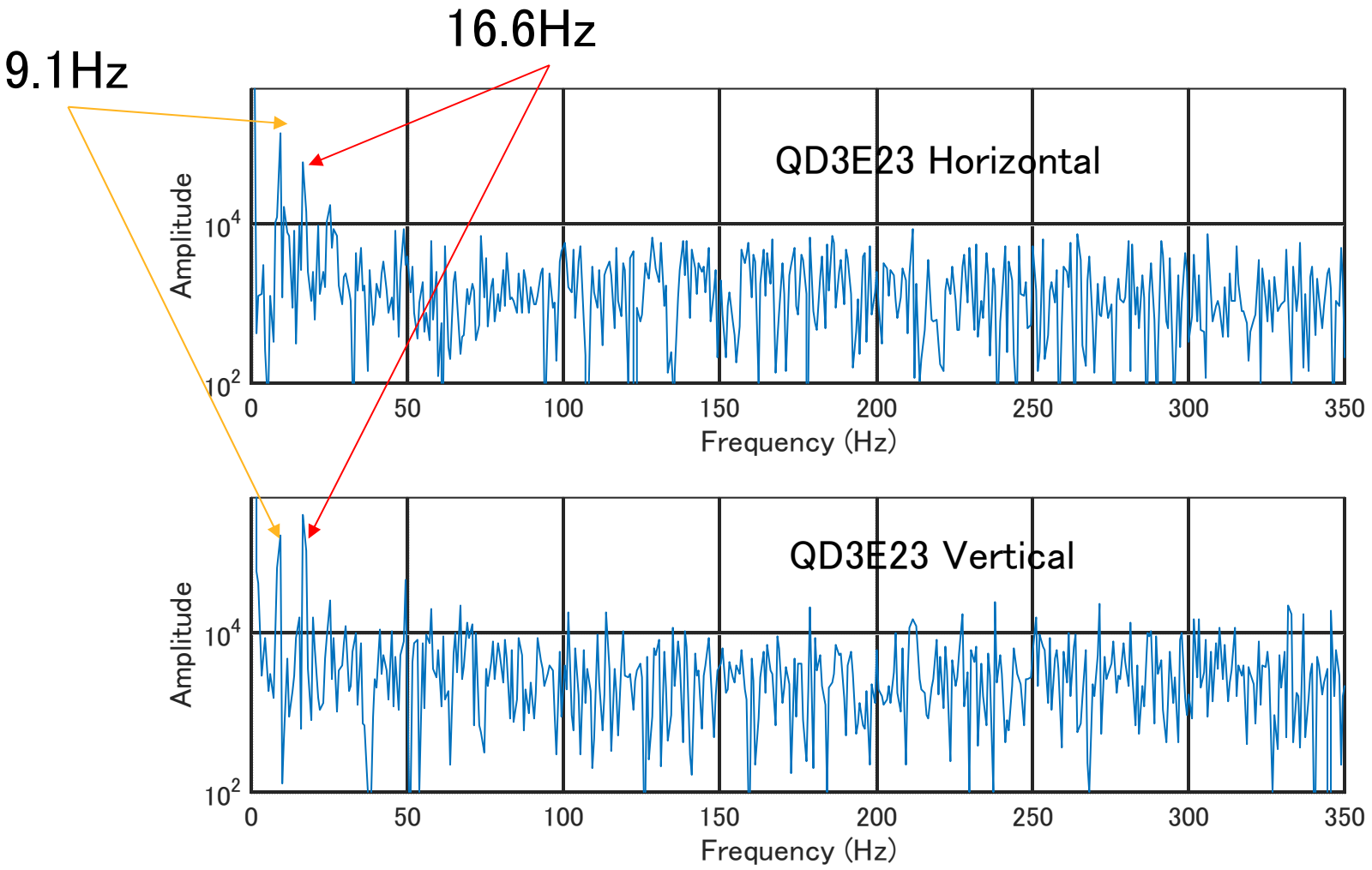
Commissioning of GTBT

- **Roughly adjusted ADC timing using injection beam**
  - Contributed injection/storage tuning
- **Fine timing adjustments**
  - Single bunched beam
  - Using pilot(non-FB) bunch
- **Rough and fine timing adjustment of fast gates using pilot bunch during scrubbing run.**





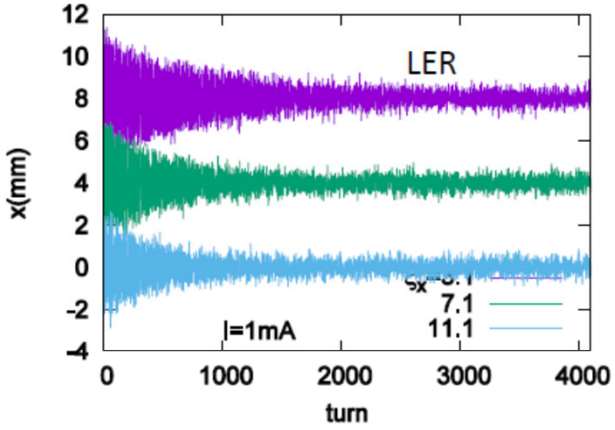
Orbit vibration (1.3s=131k turns)

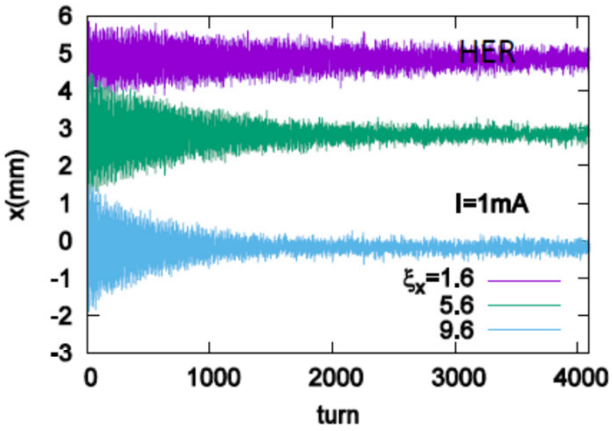


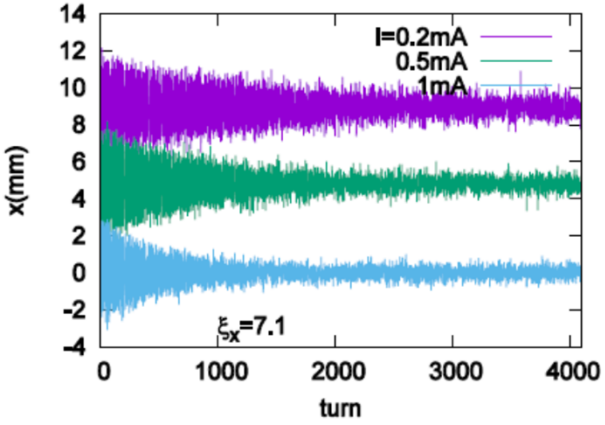
Amplitude of 16.6Hz Vertical ~ 5μm

Accelerator study

Head-tail damping- transverse decoherence

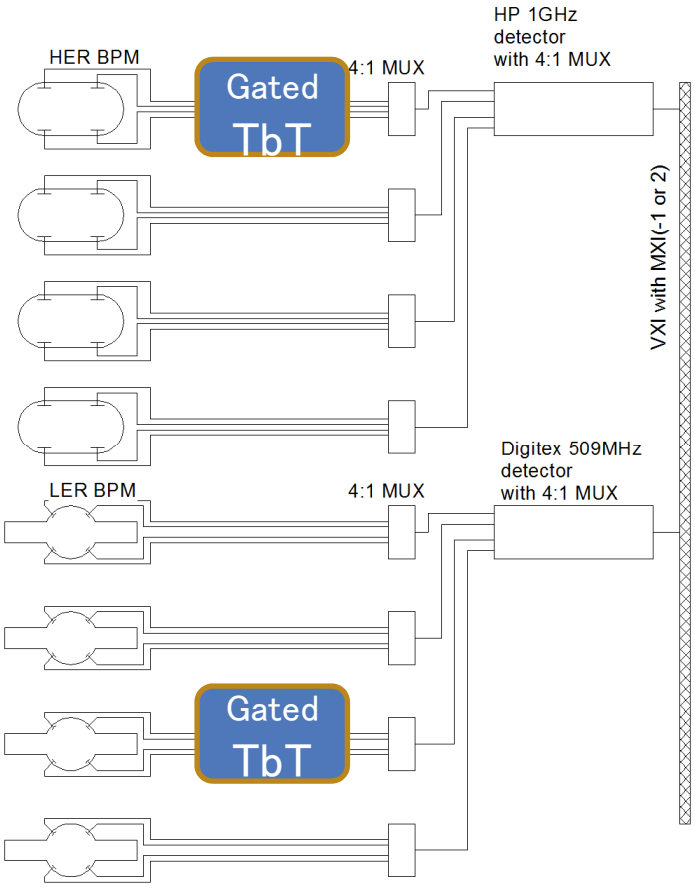






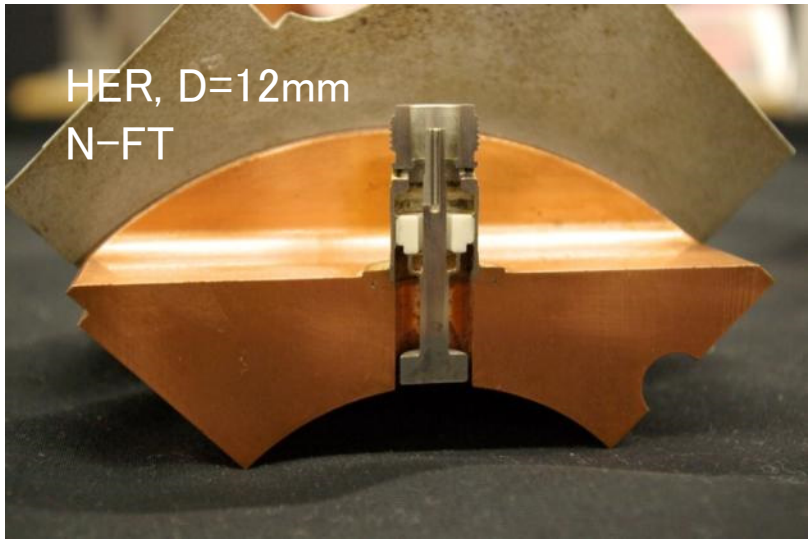
- Detailed analysis will be done by N. Kuroo.

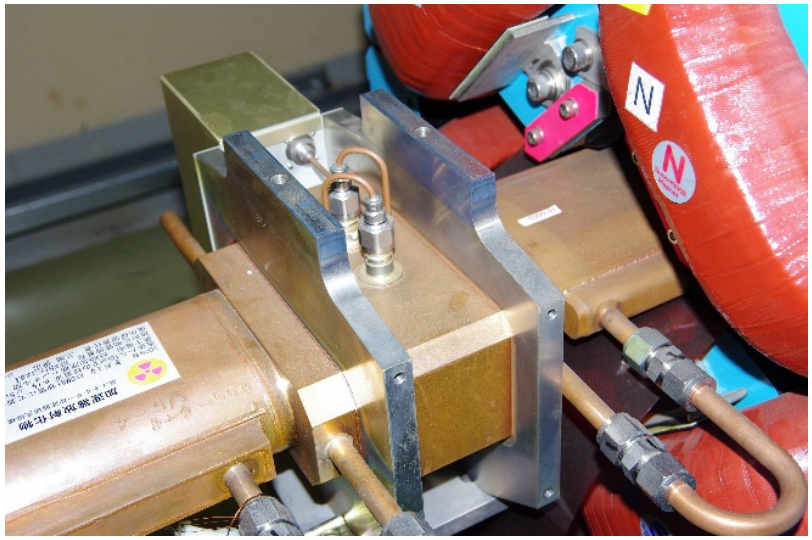
Main BPM system (narrowband)

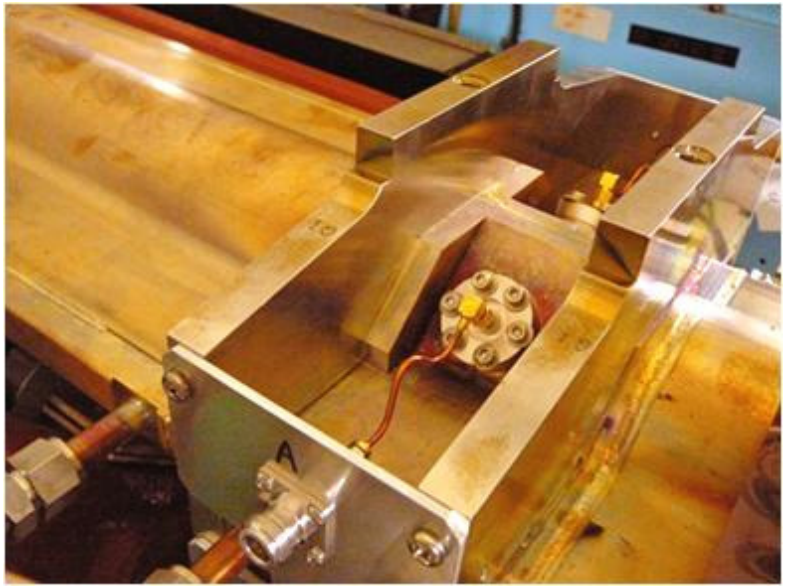


- HER : 1GHz (old) detector used at KEKB.
- LER : 509MHz new detectors.
- All VXI main frames were replaced with new ones.
- Rotation angle of BPM was measured prior to operation for position-correction.
- Gain calibration, beam based alignment and in situ survey of bad BPM have been applied.
  Instead of BPM mapping at bench.
- Movements of BPM blocks relative to adjacent sextupoles are monitored by displacement sensors to correct the beam positions.
- Data acquisition software of KEKB is modified to fit the new arrangement of the detectors.

Button heads, BPM blocks

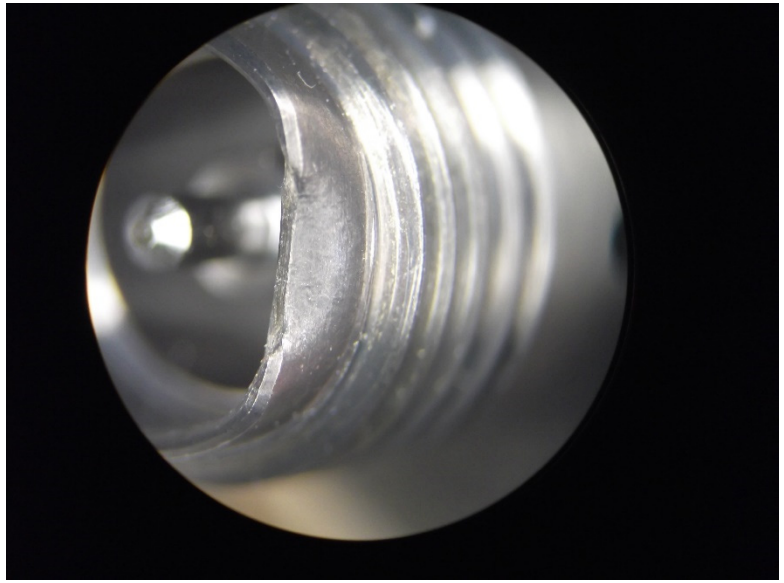






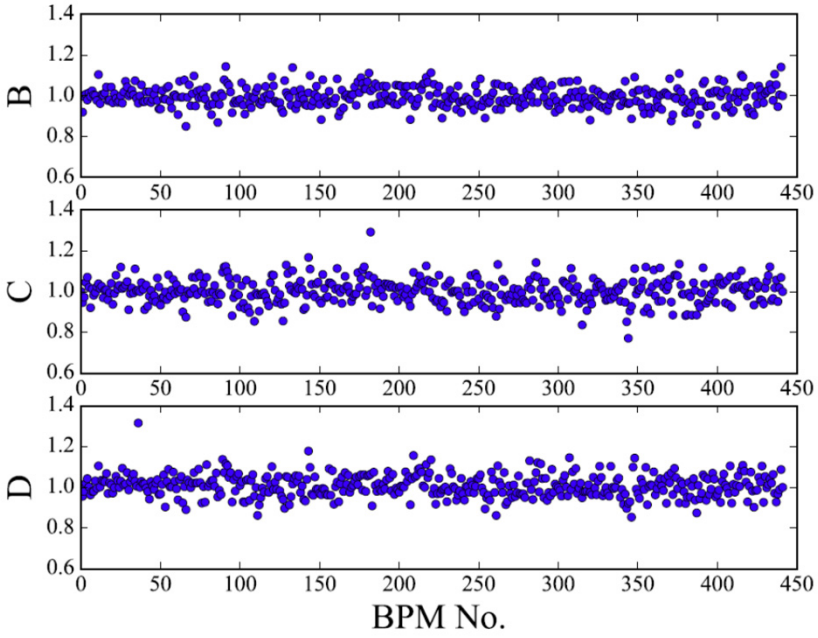
Cabling check

- **Cabling check**
  - Cabling was checked by beam because final cabling check was not done to reduce the cost.
  - Wrong cable connections were found at 25 BPMs, then corrected.
  - One damaged FT (SMA connector)

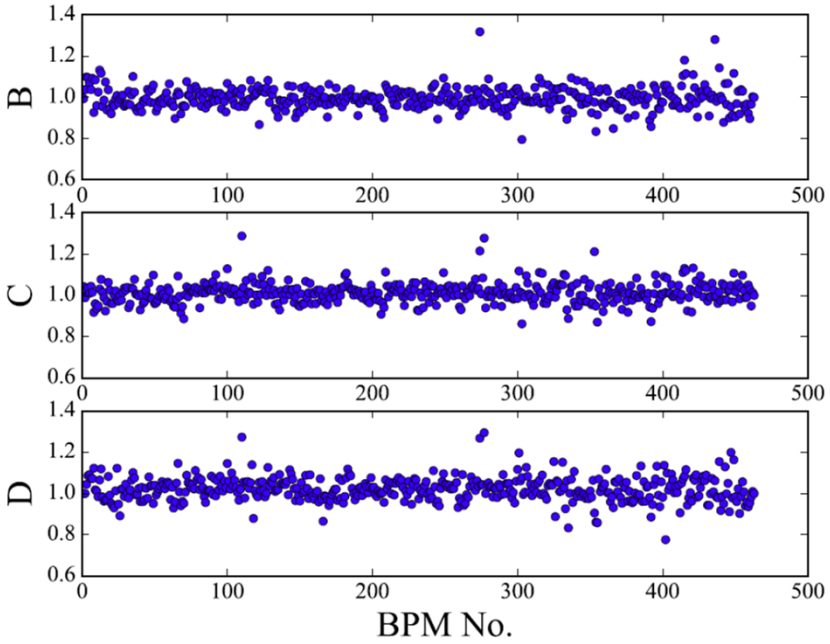


Gain Mapping

- LER

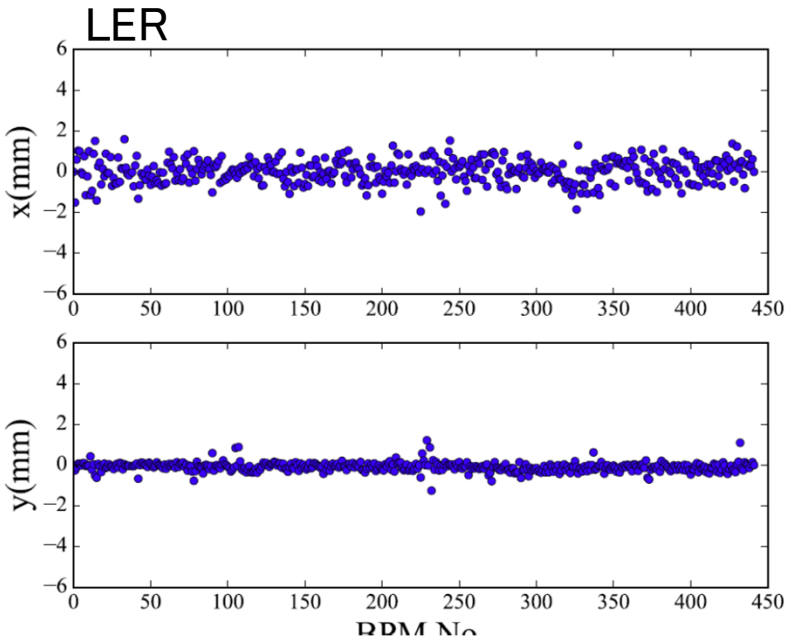


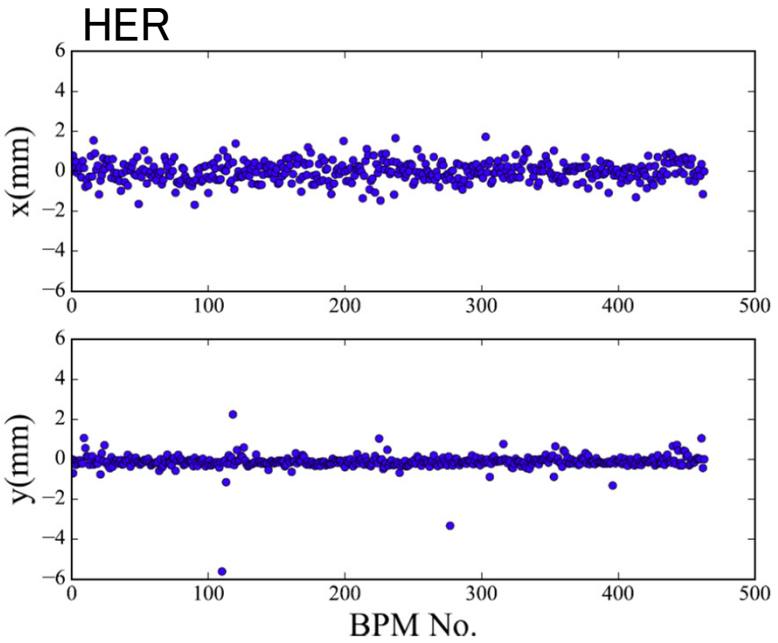
- HER



- **Dispersion of LER-gain shows a little bit worse than that of HER**
  - Flange-type connection(LER) vs. Brazing (HER)
- **Drift of gain with time**
  - HER BPM seems drift much larger than LER
  - Old N-type connector, old cables

BBA





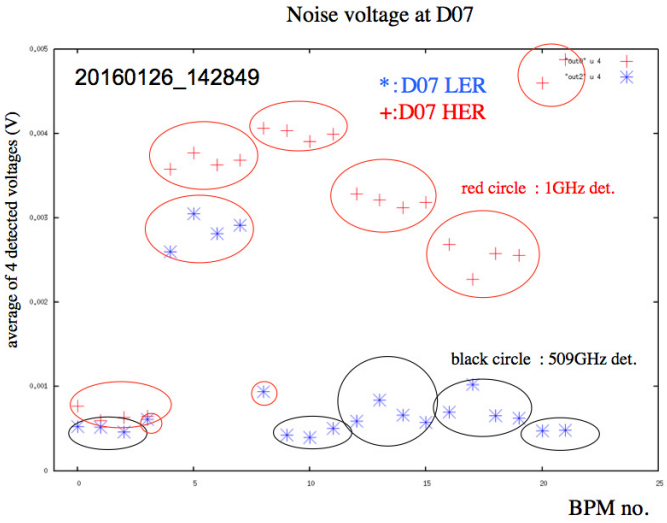
- **RMS values of offset**
  - LER: 0.570 mm (x) 0.222 mm (y)
  - HER: 0.505 mm (x) 0.392 mm (y)

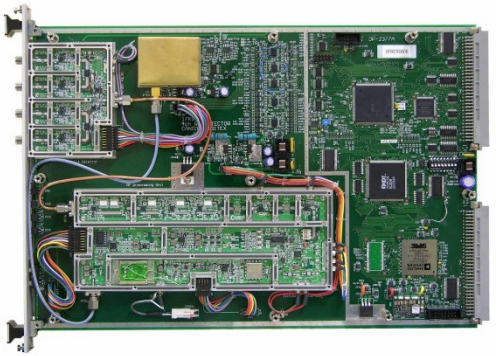
Obtained performance

- **Position resolution**
  - Position resolution was estimated by beam by so called ″three-BPM method″ which measures correlation of the orbit among three BPMs.
  - The result represents upper bound of the resolution because the measurement can be affected by beam movement between switching interval of a multiplexer.
  - The obtained resolution is better than 3μm and 5μm in LER and HER, respectively, for most of BPMs.

Noise in 1GHz (KEKB) detectors

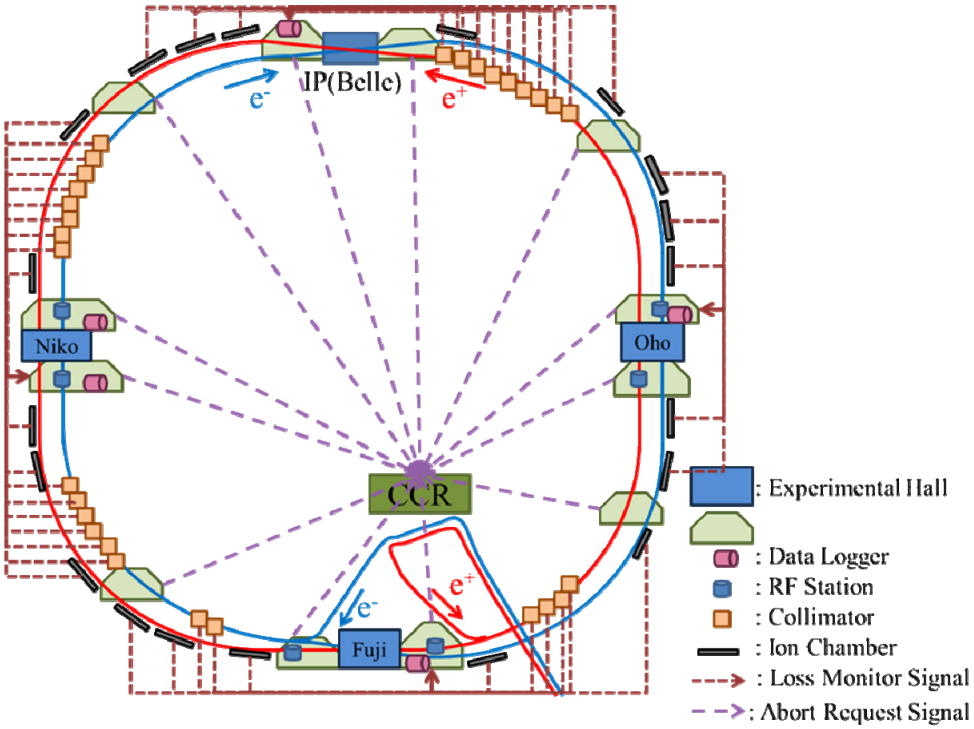
- **Larger noise level was found in the 1GHz detectors in a site building D7 where RF equipment's are located.**
  - BPM resolution at Oho and Nikko straight sections is affected probably by the same cause.
  - Small noise level in the 509MHz detectors is assumed to be due to their better shielding of analogue circuits.
  - Noise source is not identified yet.
  - A measure is to replace the 1GHz detectors with the 509MHz detectors.

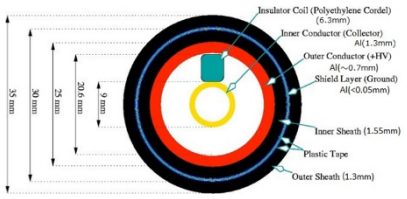


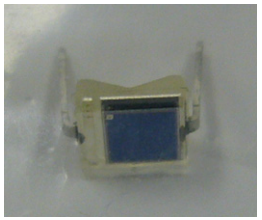


Loss Monitor

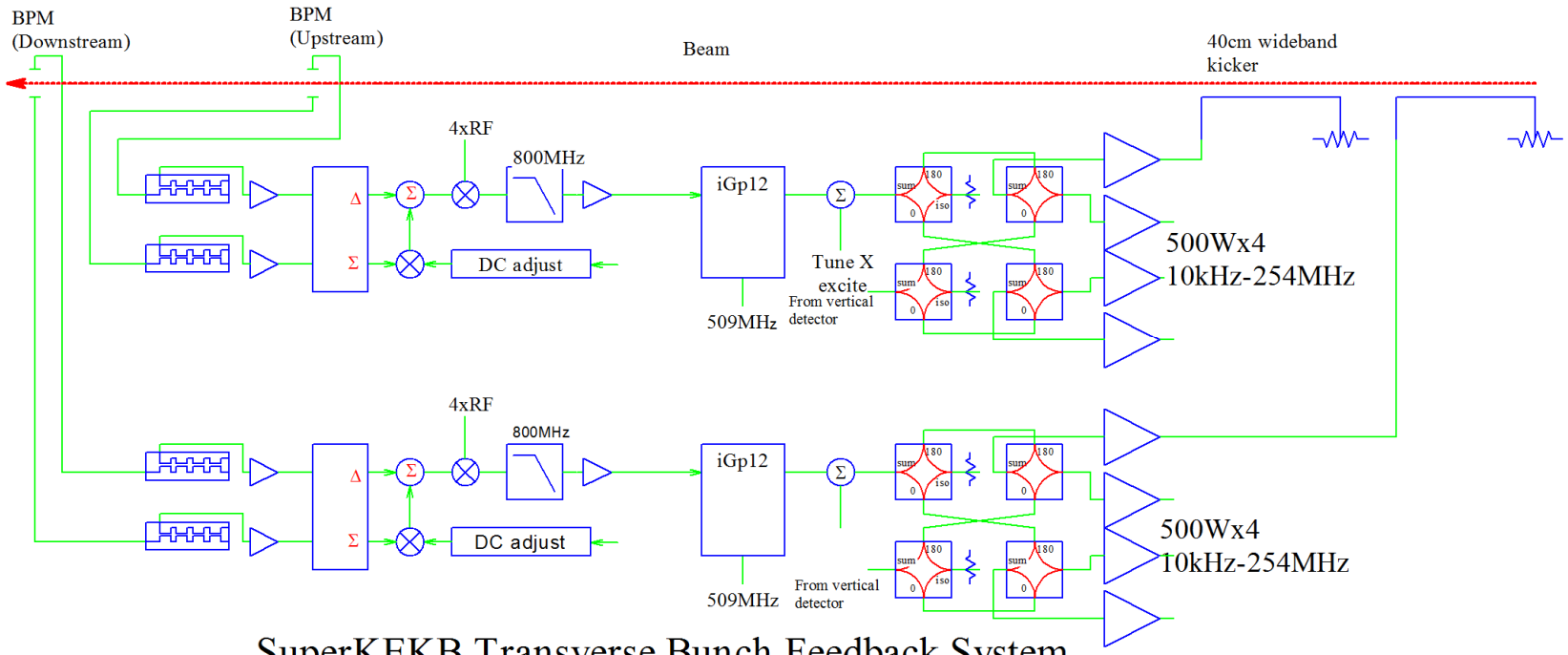
- We use beam loss monitors for protection of the hardware against unexpected sudden beam losses. The loss monitor system provides an trigger to the beam abort system.
- The sensors are ion chambers (32) and PIN photo-diodes (114).
- We optimize the threshold of the abort trigger and the PIN position by checking the beam information at each abort event.
- H. Ikeda will report the details on 13th morning talk “Beam Loss and Abort Diagnostics during SuperKEKB Phase-1” (TUAL03)





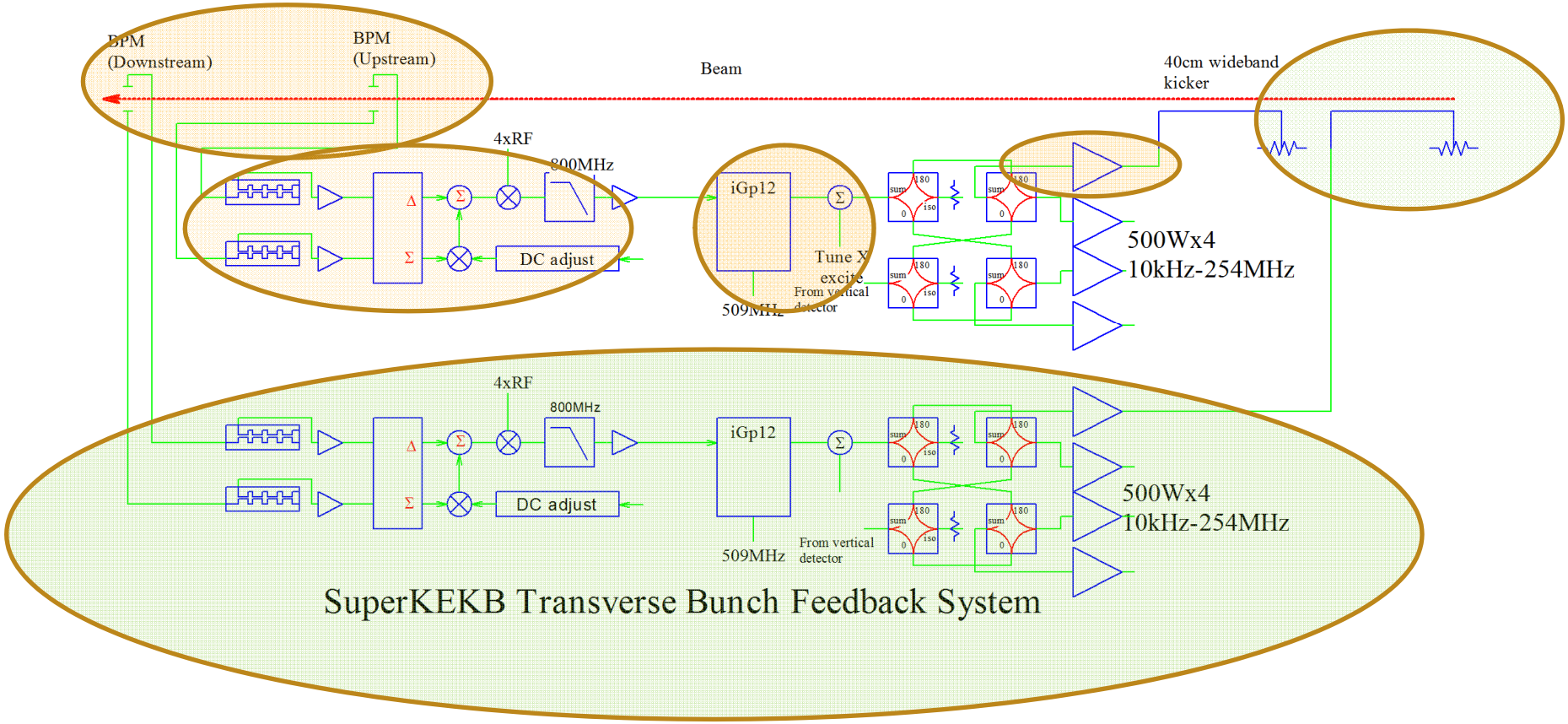


SuperKEKB Transverse FB systems



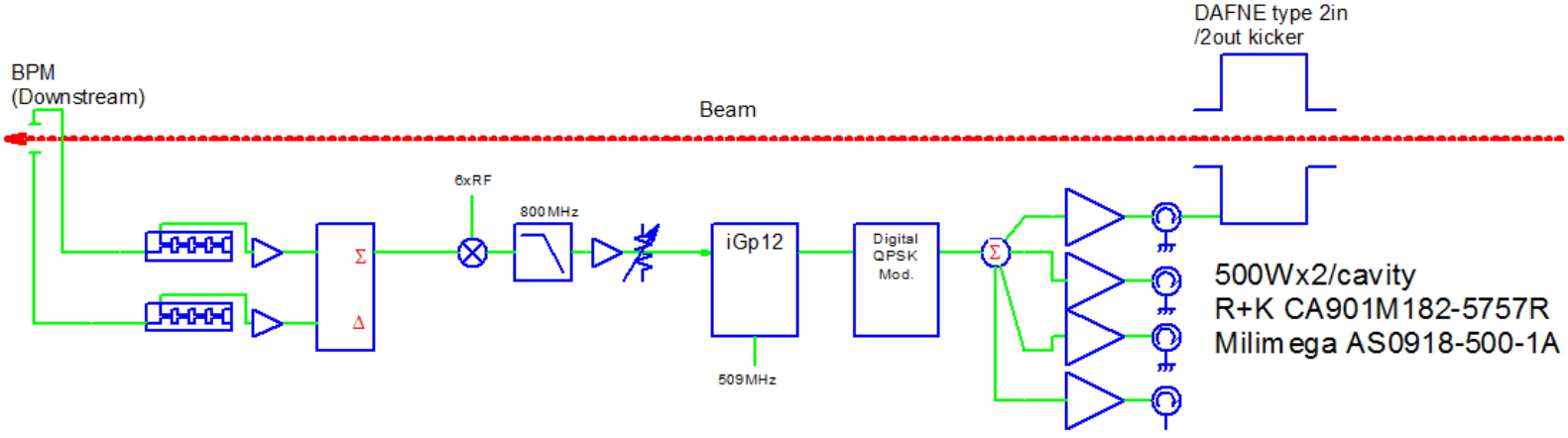
SuperKEKB Transverse Bunch Feedback System

SuperKEKB Transverse FB systems

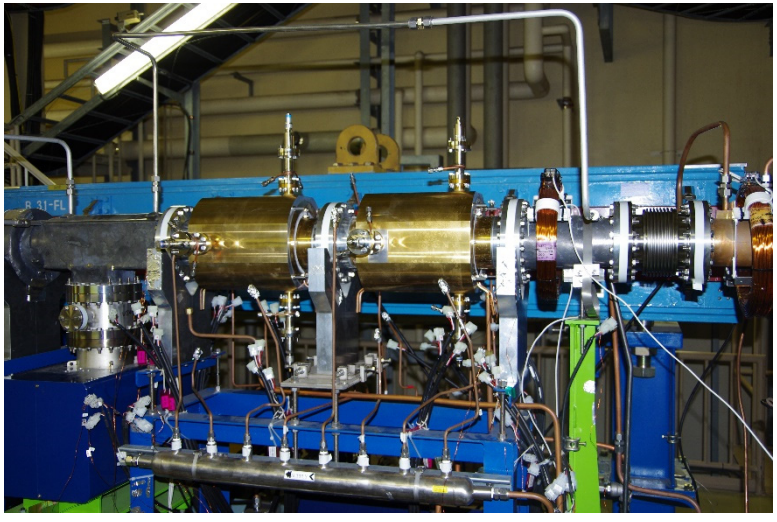


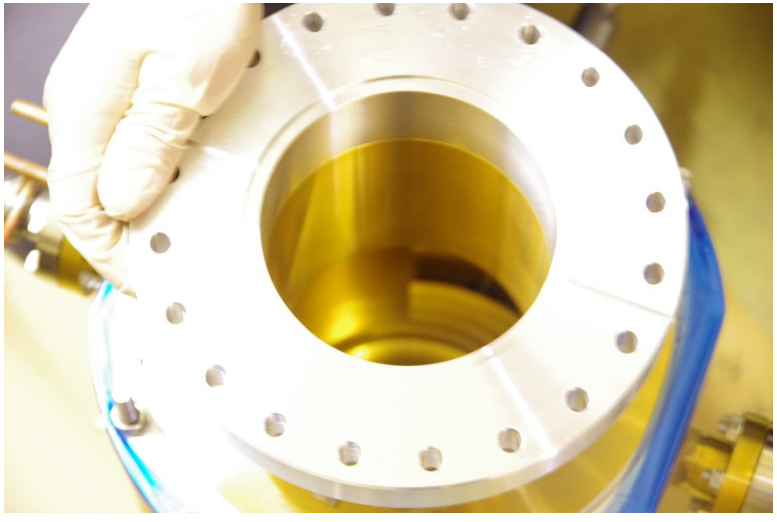
Collaborating SLAC(US-Japan) and INFN-LNF(KEK-LNF)

SuperKEKB Longitudinal FB system

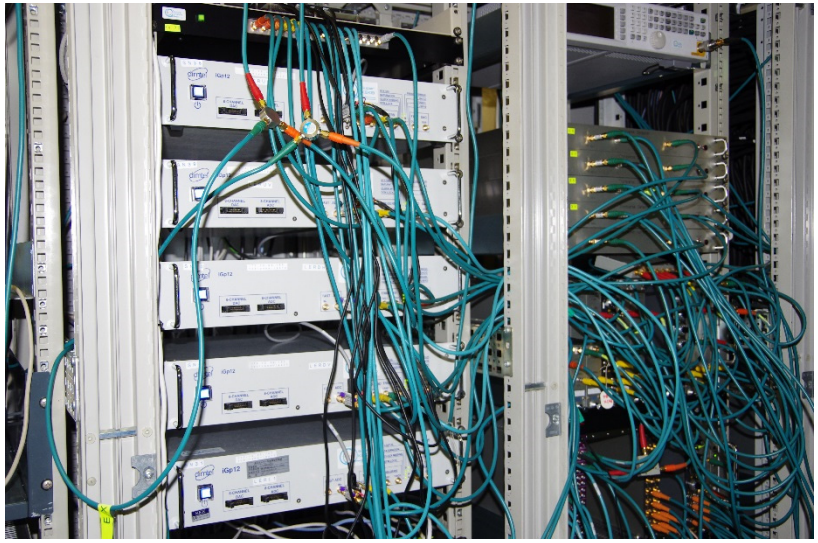


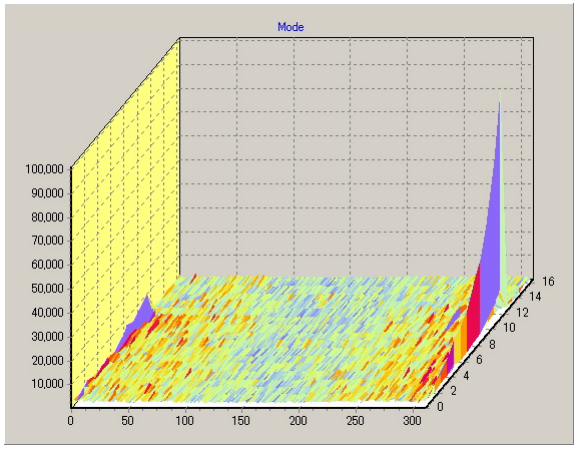
SuperKEKB Longitudinal Bunch Feedback System





iGp12 digital feedback filter



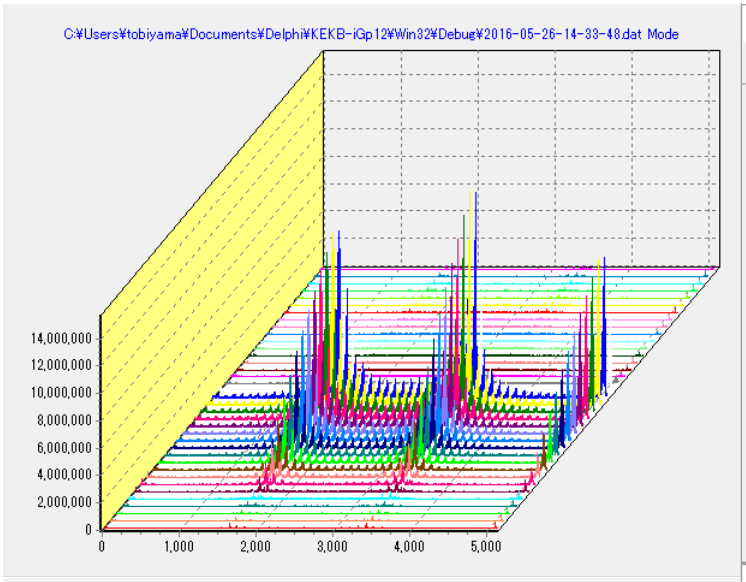


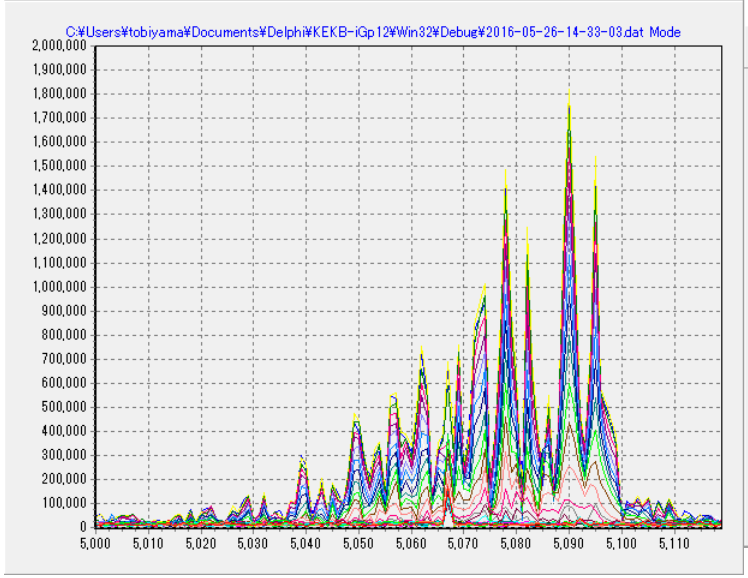
- **Successor of iGp digital filters developed under US-Japan collaboration with SLAC.**
  - 12bit ADC/DAC
  - 10 – 20 tap FIR filter
  - 12MB memory to analyze instabilities
- **10 iGp12s are used**
  - 8 with larger FPGA (VSX95T)
  - 2 with normal FPGA (VSX50T)
- **Single bunch excitation using PLL**

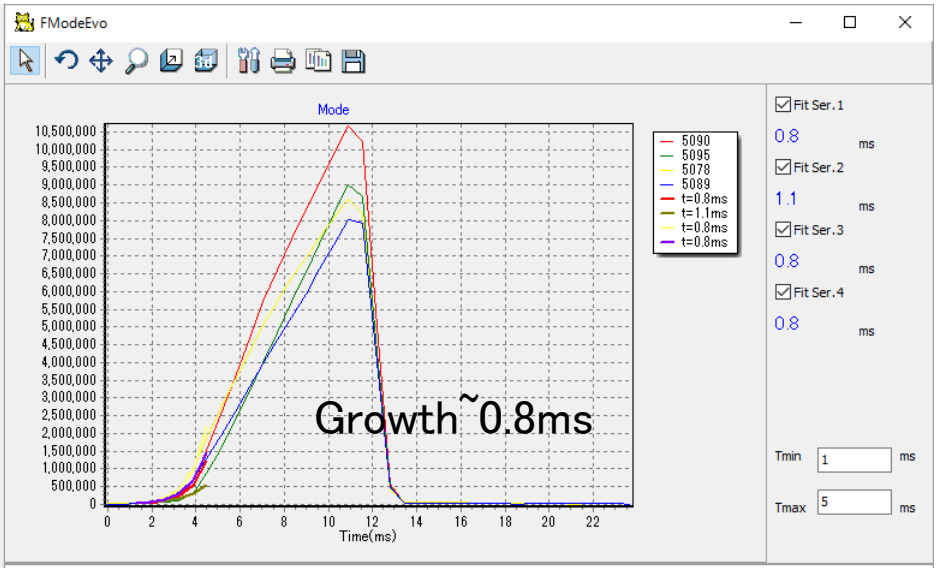
Commissioning

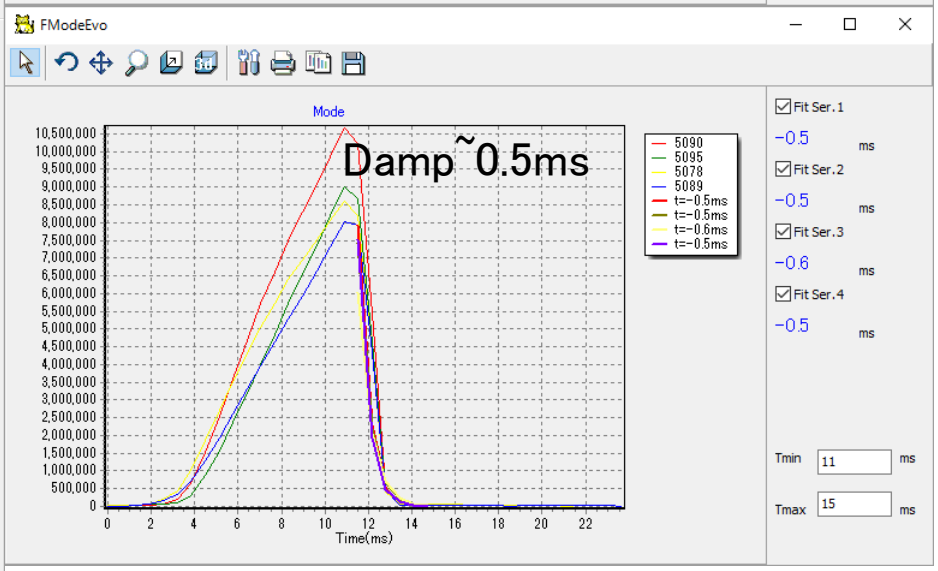
- **Strong transverse coupled-bunch instability has been observed in both rings even with fairly low stored current at very early stage of the commissioning.**
  - LER : Both H and V instability, V was much stronger and limited the stored current in the beginning.
  - HER : Both H and V. Both instability limited the stored current less than 0.5mA (total current with multi-bunch mode) in the beginning.
- **BxB feedback systems have been contributing to the ring commissioning**
  - Vacuum scrubbing
  - Coupled-bunch instability study(EC, Fast Ion)

Example of G-D experiment(HER-H)

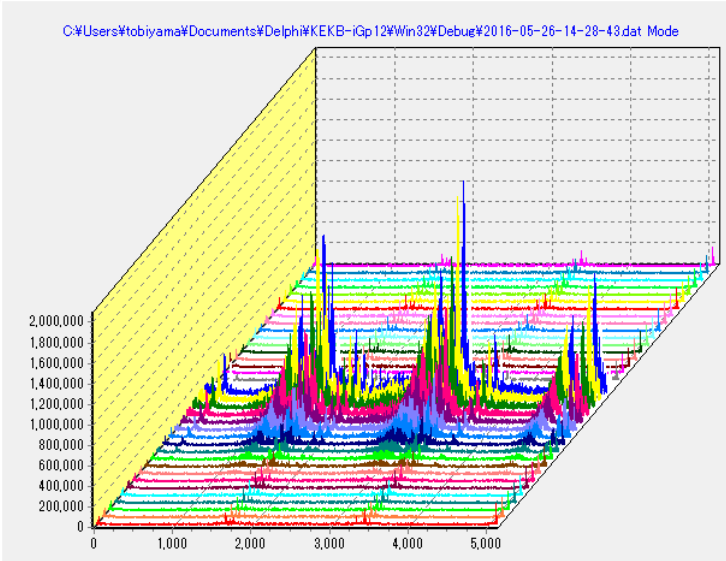


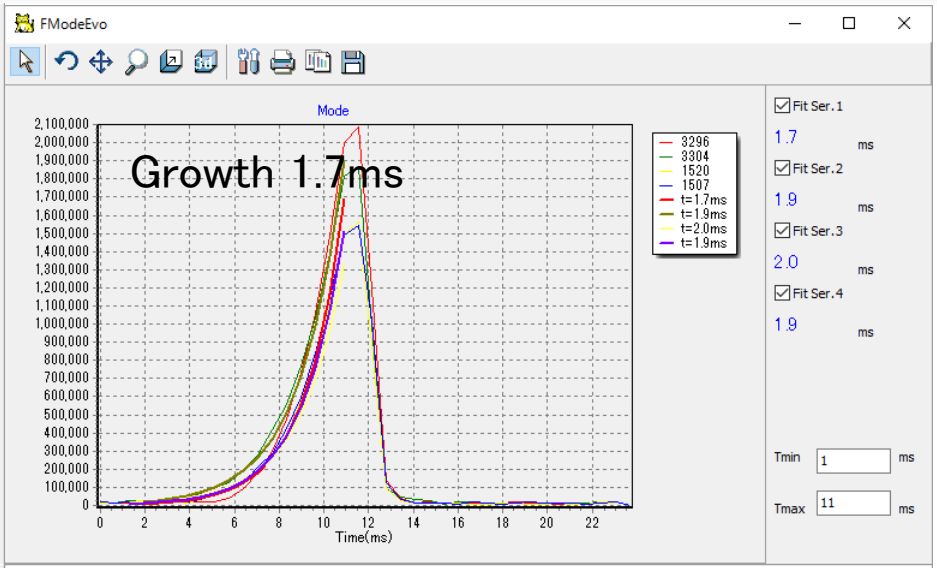


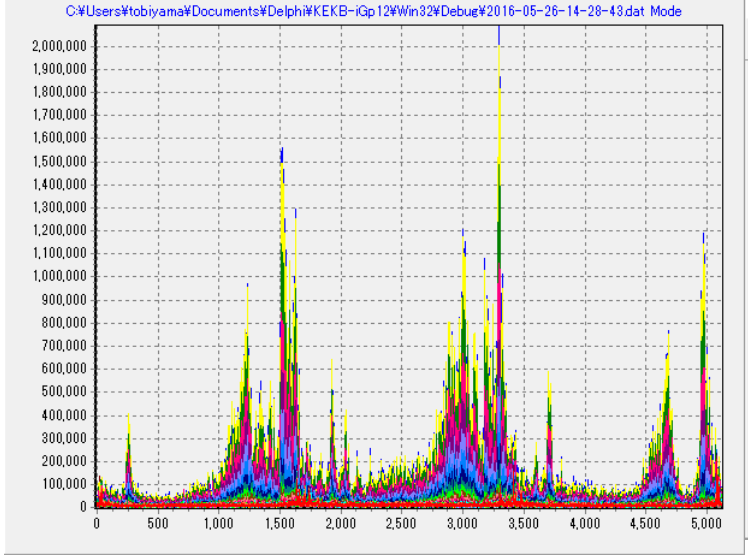




LER-V


C:¥Users¥tobiyama¥Documents¥Delphi¥KEKB-iGp12¥Win32¥Debug¥2016-05-26-14-28-43.dat Mode


FModeEvo
Mode
Growth 1.7ms
3296
3304
1520
1507
t=1.7ms
t=1.9ms
t=2.0ms
t=1.9ms
Time(ms)
Fit Ser.1
1.7 ms
Fit Ser.2
1.9 ms
Fit Ser.3
2.0 ms
Fit Ser.4
1.9 ms
Tmin 1 ms
Tmax 11 ms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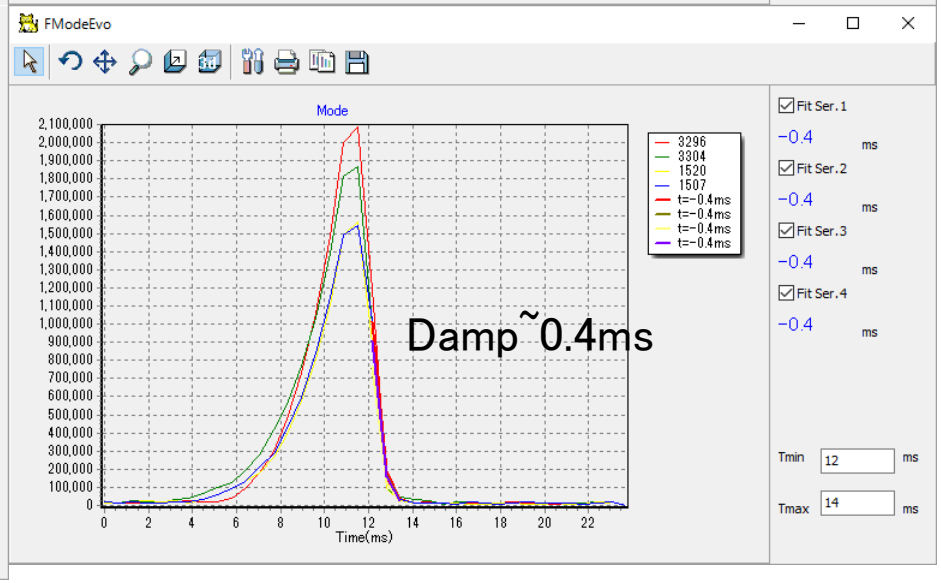
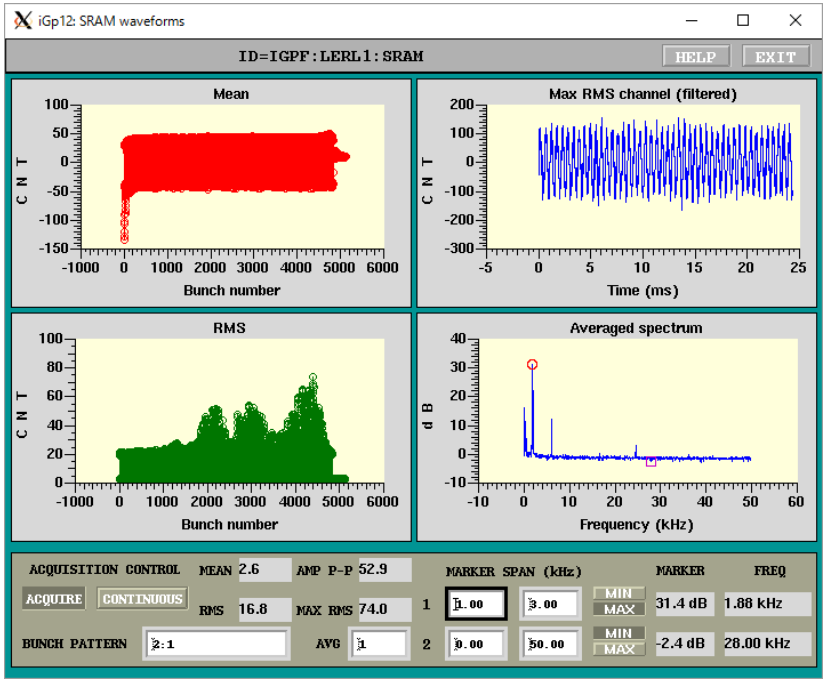
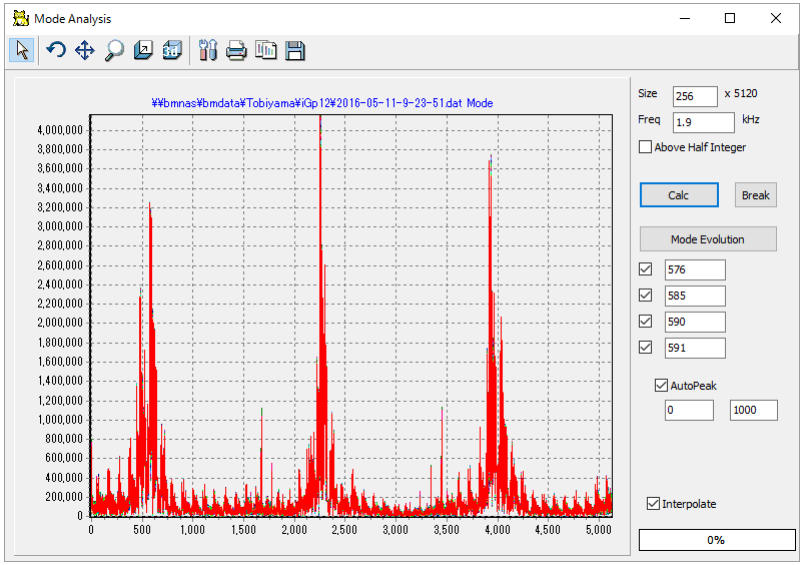

FModeEvo
Mode
Damp~0.4ms
3296
3304
1520
1507
t=-0.4ms
t=-0.4ms
t=-0.4ms
t=-0.4ms
Time(ms)
Fit Ser.1
-0.4 ms
Fit Ser.2
-0.4 ms
Fit Ser.3
-0.4 ms
Fit Ser.4
-0.4 ms
Tmin 12 ms
Tmax 14 ms

LER longitudinal FB

- Longitudinal instability starting with beam current >660mA with by 3 mode.
- Wide modes around 2500?





Performance of BxB feedback

- Successfully suppressed coupled bunch instability up to maximum beam current (1A in LER, .87A in HER) with minimum bunch space of 4 ns.
- Transverse feedback damping time around maximum beam current was about 0.5 ms (50 turns).
- Encountered unexpected LER longitudinal CBI, but successfully suppressed up to 1A.
  - Instability growth ~15 ms, FB damping ~13 ms.

Difficulty in FB systems

- **Saturation of FB bunch position detectors**
  - LNA just after comb filter saturates with bunch current >0.5mA
  - Couldn't stop abnormal single bunch injection >5mA/bunch
  - Changed power-balance in FB detector
- **Burn-out of the water-cooled dummy loads for LER longitudinal FB systems due to stop of water chiller.**
  - Status of the chiller and temperature around LFB system have been monitored but no automatic interlock was implemented.
- **High power attenuators (1.5kW) had failed during operation.**
  - Doubted frailer in transverse kicker but was not..
  - Mean power ~200W. Suspecting initial failure.

Photon monitor

- **XRM: X-ray beam size monitor**
  - Pinhole, Coded Aperture mask, etc.
    - σy (σx)
    - Details will be presented by E. Muliyani's poster (TUPG72)
- **SRM: (Visual) Synchrotron Radiation monitor**
  - Visible light monitor. Interferometer, streak, gated camera, etc.
    - σz, σx (σy)
- **LABM : Large Angle Beamstrahlung Monitor (IR)**
  - SR-like radiation from interaction point due to crossing of the colliding beams.
  - Can measure size ratios and relative offsets at collision point.
  - Phase 1 : No collision so only testing the beam background.

XRM: Hardware

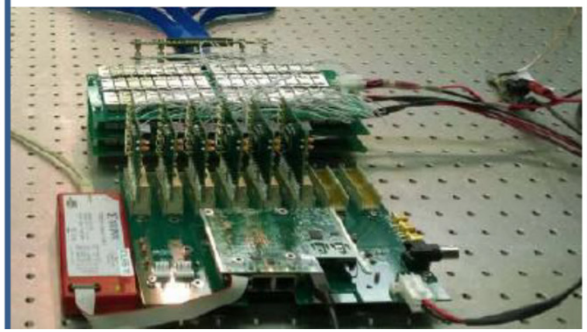
X-ray beam line under construction at LER

Masks: ~20 μm Au on 600 μm CVD diamond substrate

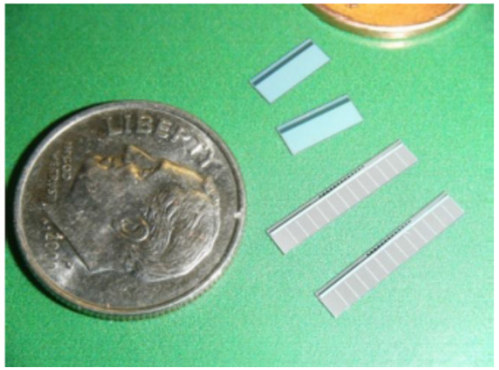
Water-cooled mask holder

US-Japan Collaboration (U. Hawaii, SLAC, Cornell U.)

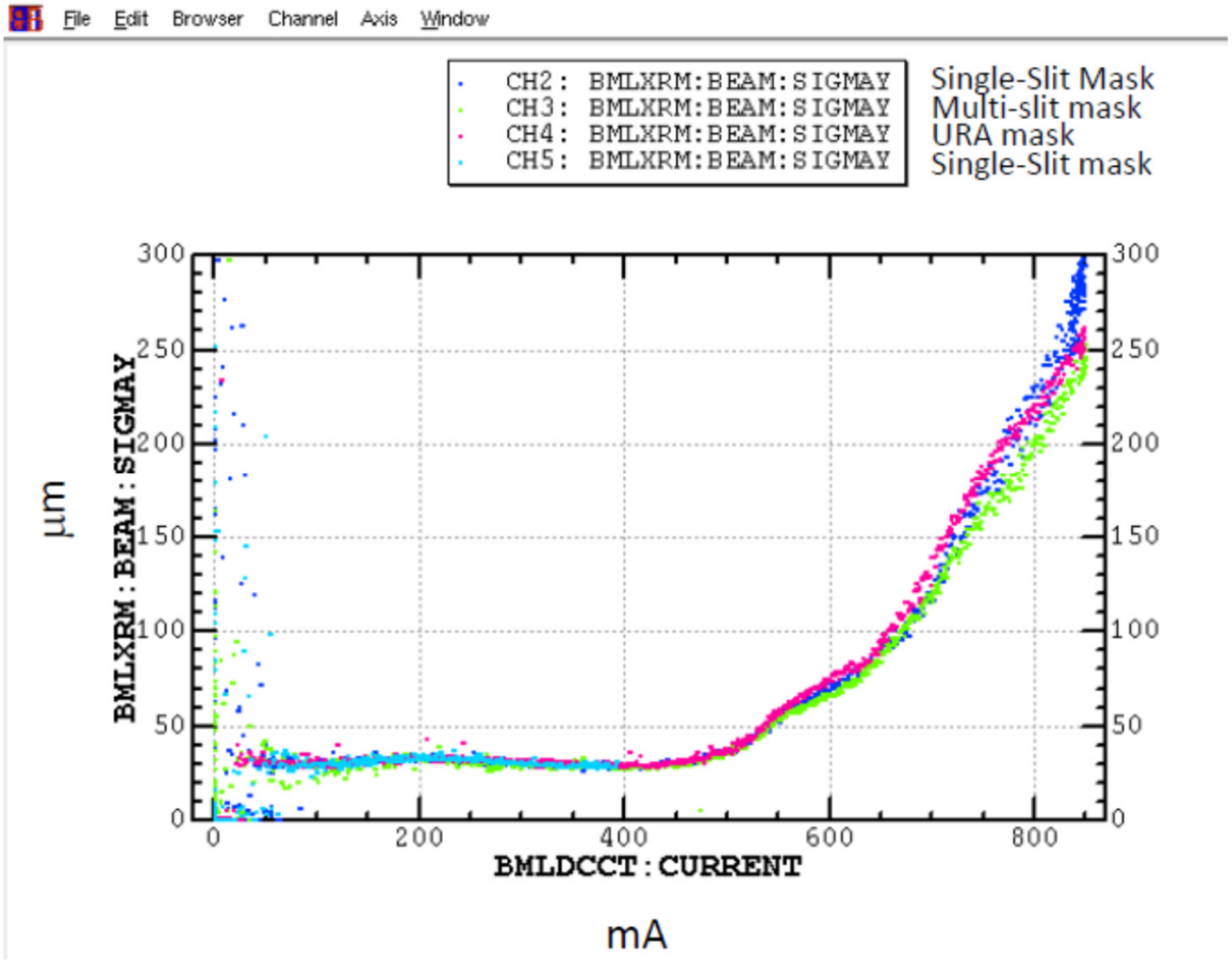
High-speed readout electronics for the X-ray monitor, being developed by U of Hawaii.



Deep Si pixel detector and spectrometer chips for the X-ray monitor, being developed at SLAC.



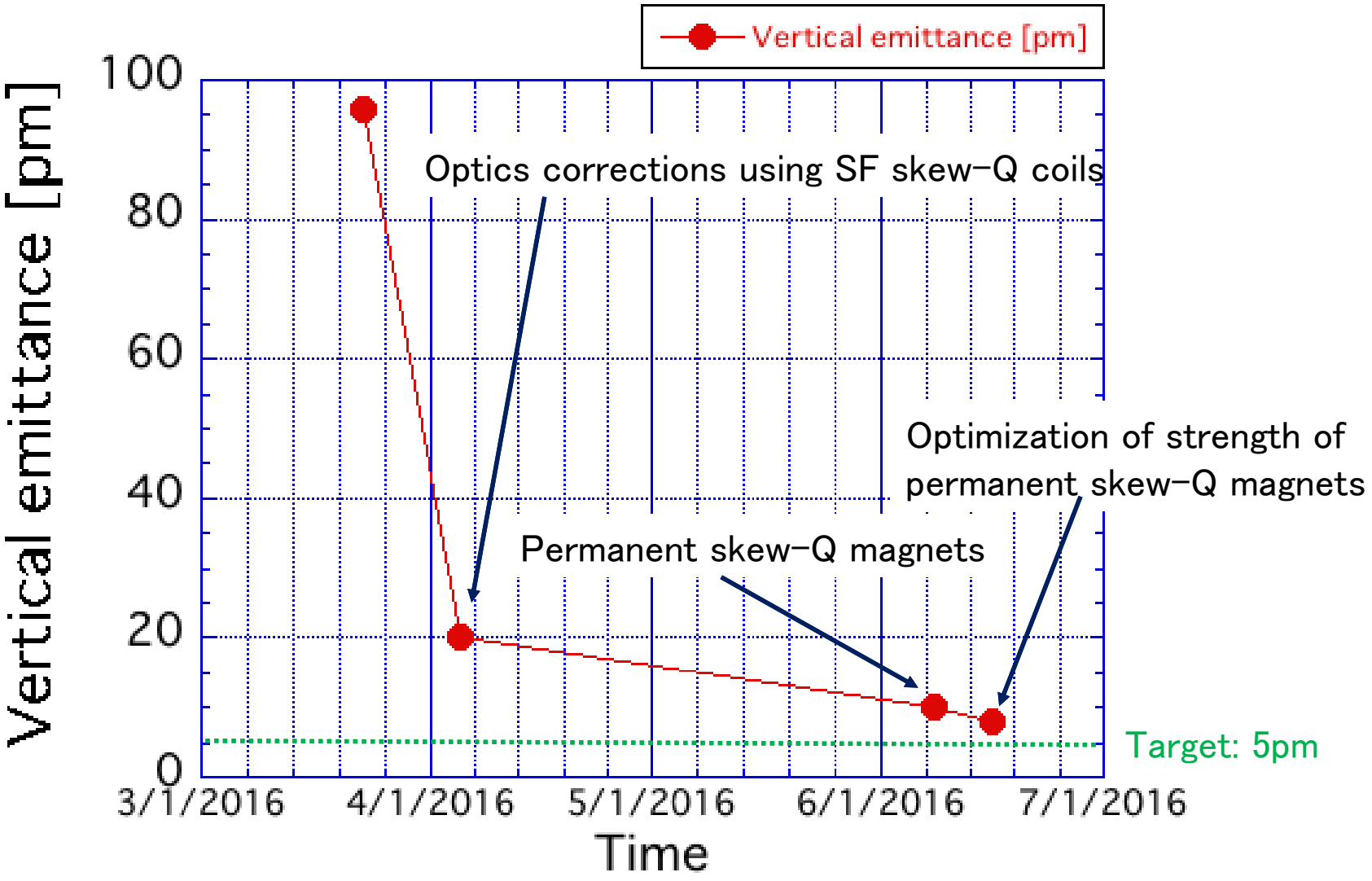
LER XRM: e-cloud vertical blowup study



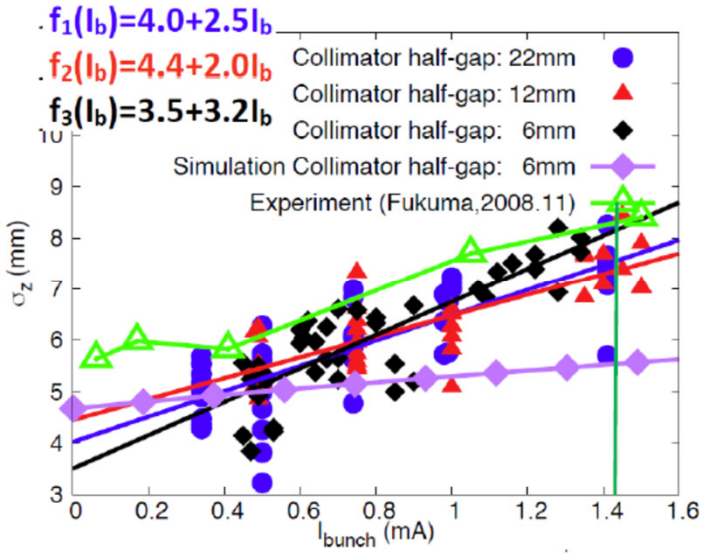
Very good fill-to-fill repeatability

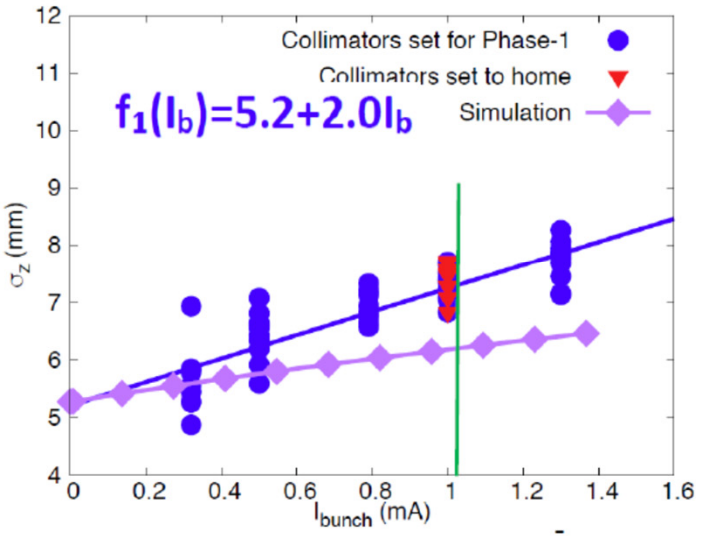
Very good agreement between different mask, especially below 150um.

Low emittance, low x–y coupling tuning



Bunch length measurement





- Measured by a Streak camera
- The behaviors are similar as KEKB for both of LER and HER. Bunch Lengthening is stronger than that of simulation (Larger impedance).

Difficulties

- **Huge difference between the measured HER vertical beam size via XRM and the estimated beam size from optics correction.**
  - Much lower βy at source point than at LER.
  - Beam tilt or motion at source point?
  - Unexpectedly large smearing in the beam line?
  - Systematics under study–> For details, see TUPG72.
- **SR beam size monitors did not work well in both rings.**
  - Large deviation between the measured magnification factor and the design (>2).
    - Misalignment of extraction mirror?
    - Will be checked in early October.

Summary

- **Most of the beam instrumentation prepared for SuperKEKB rings (phase 1) are working well.**
  - COD measurement system
    - Narrowband position monitors
    - Gated turn-by-turn monitors
  - Beam current/ bunch current monitor
  - Loss monitor
  - Bunch by bunch feedback systems
    - Tune monitors
    - Transverse FB (HER and LER)
    - Longitudinal FB (LER)
  - Photon monitor (transverse size, longitudinal size)