Beam commissioning of SuperKEKB rings at Phase-2

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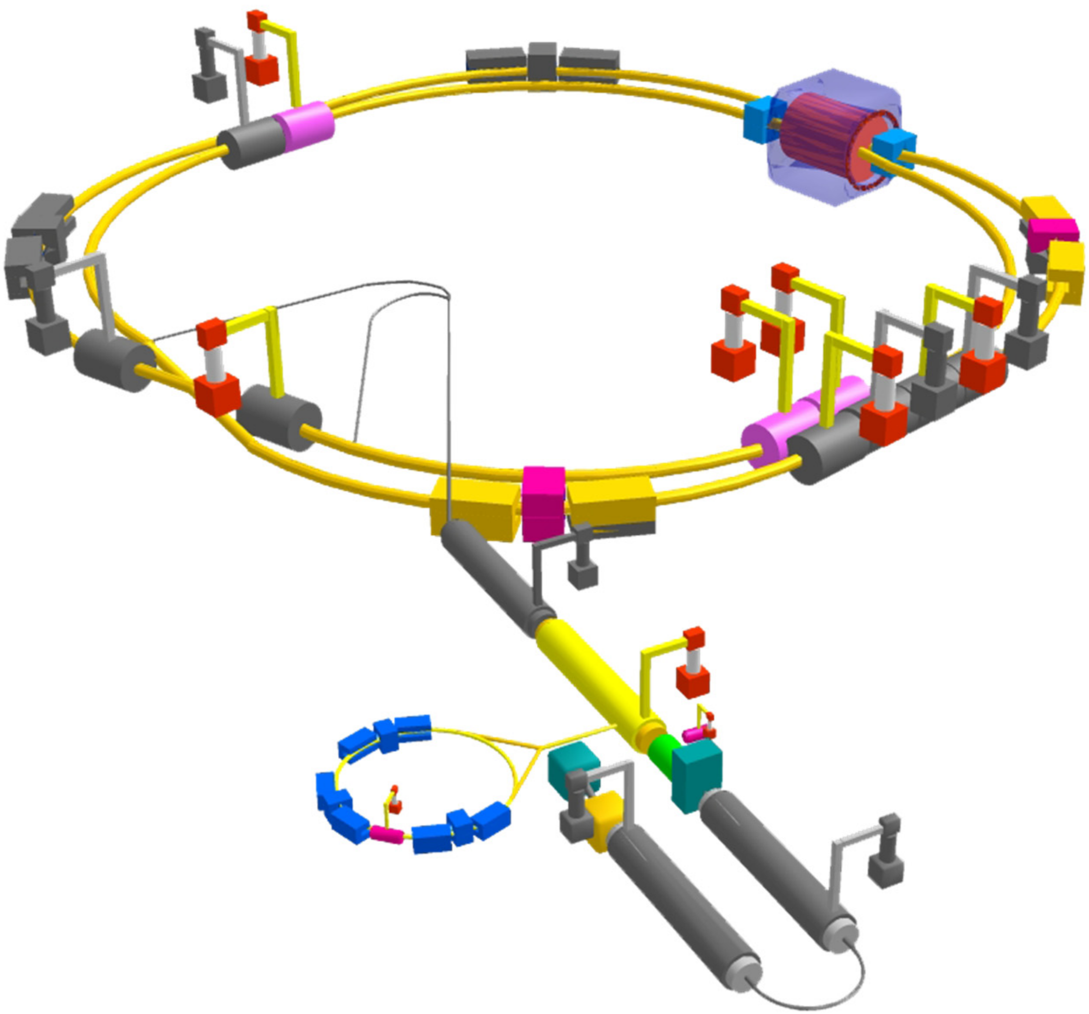
(KEK Accelerator Laboratory and SOKENDAI)

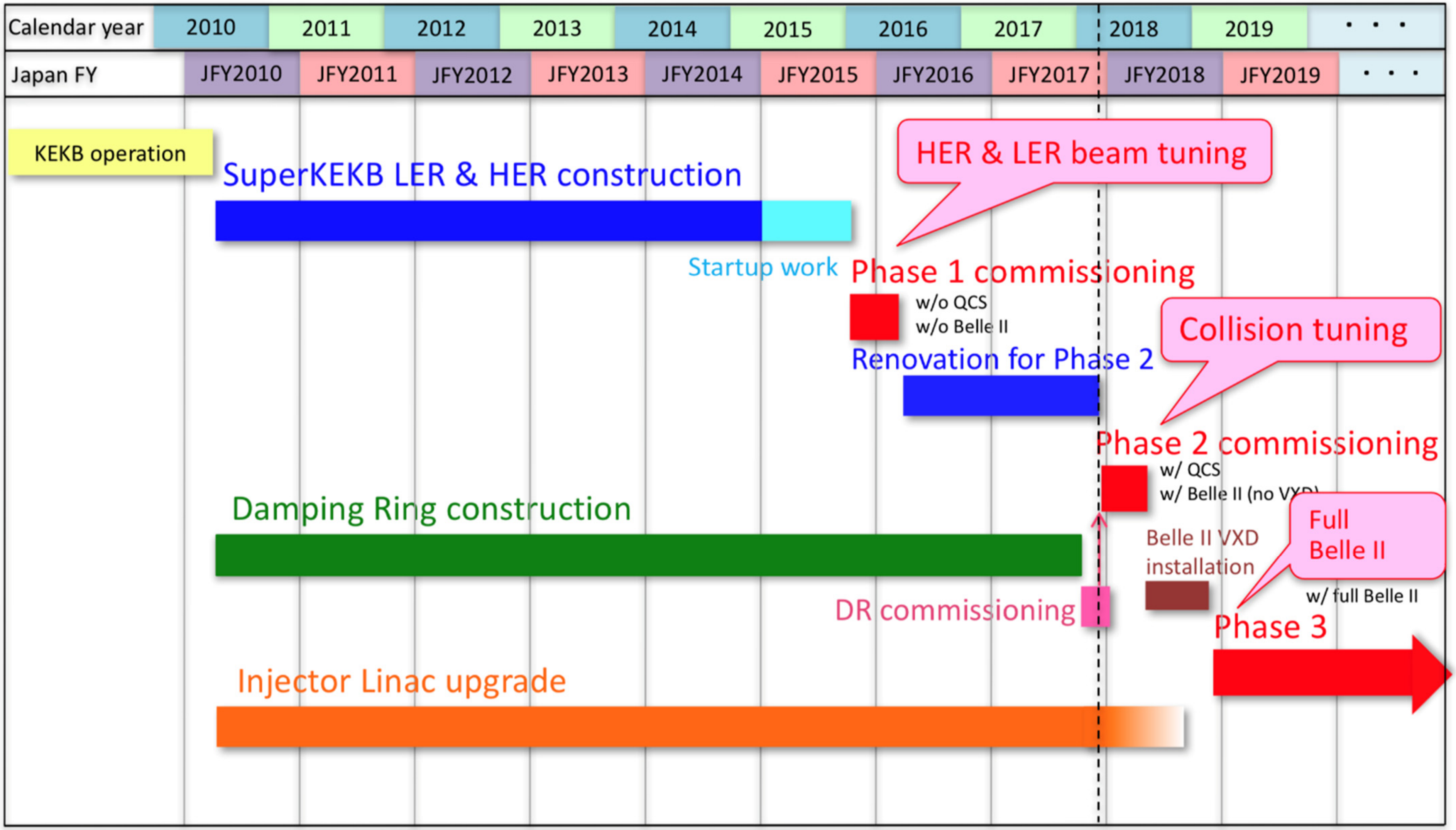
G. Varner (U. Hawaii), G. Bonvicini (Wayne State U.)

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 80x10^{35}
  - x40 of KEKB

Project History and Near-term Plan



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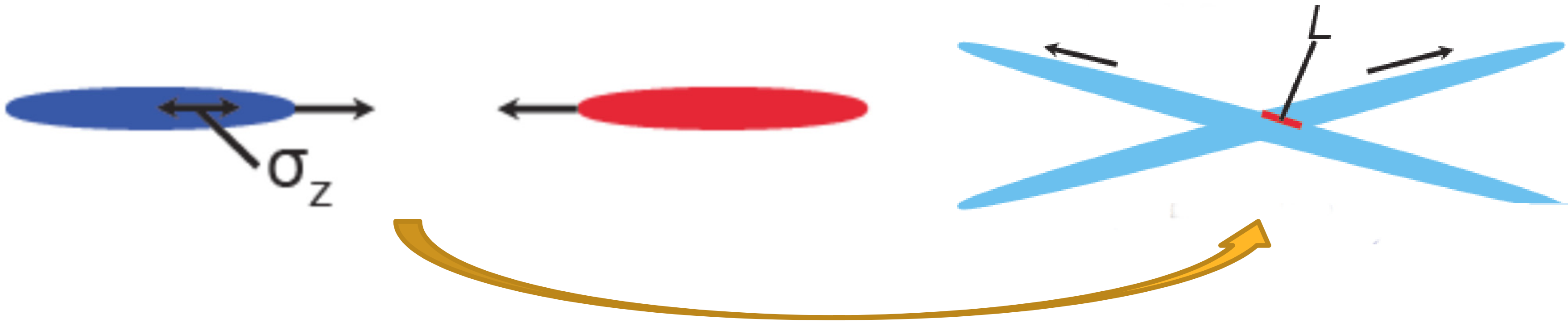
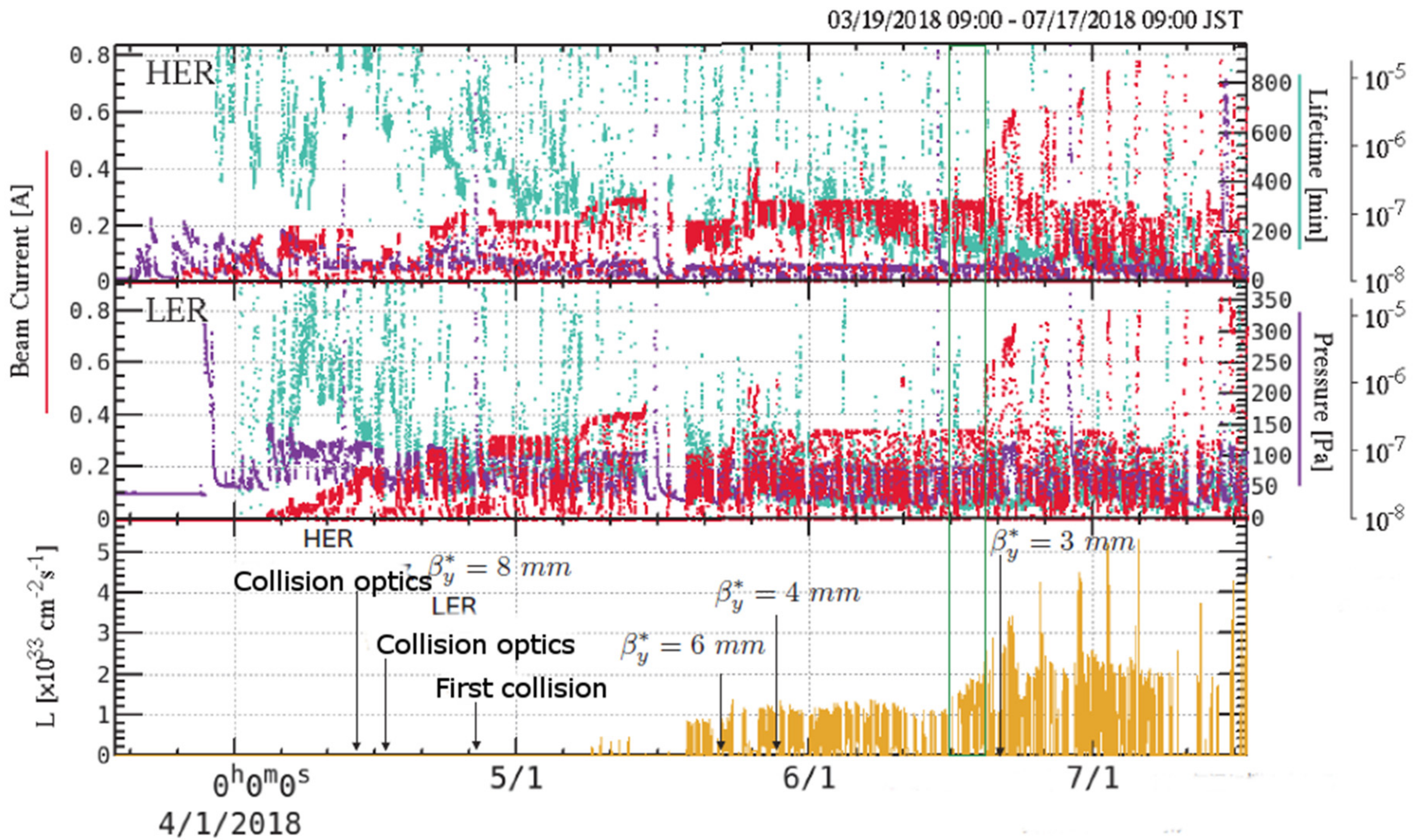
Target of Phase-2 operation

- Verify the “Nano Beam scheme”.



- Achieve a machine luminosity of O($10^{34}/cm^2/s$) and see a clear path to further improvement.
- Examine the VXD background to verify that we can install the VXD at the start of phase 3 and then operate it for the initial first few years of phase 3.

History of Phase 2 operation

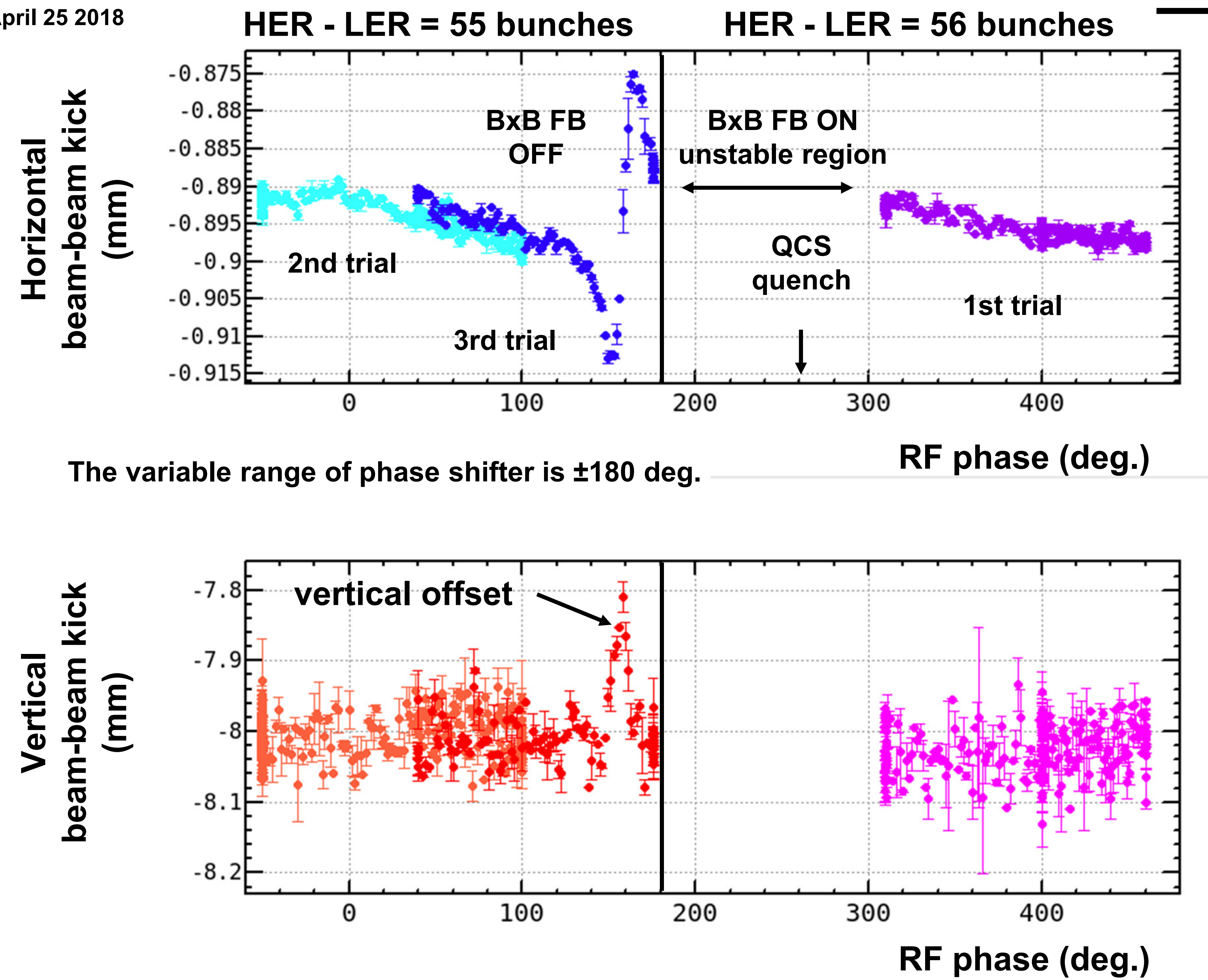


Peak luminosity > 5x10^{33} /cm^2/s

First observation of beam-beam deflections

HER - LER = 57 was also surveyed.

April 25 2018



The variable range of phase shifter is ±180 deg.

First hadronic event on 26/Apr

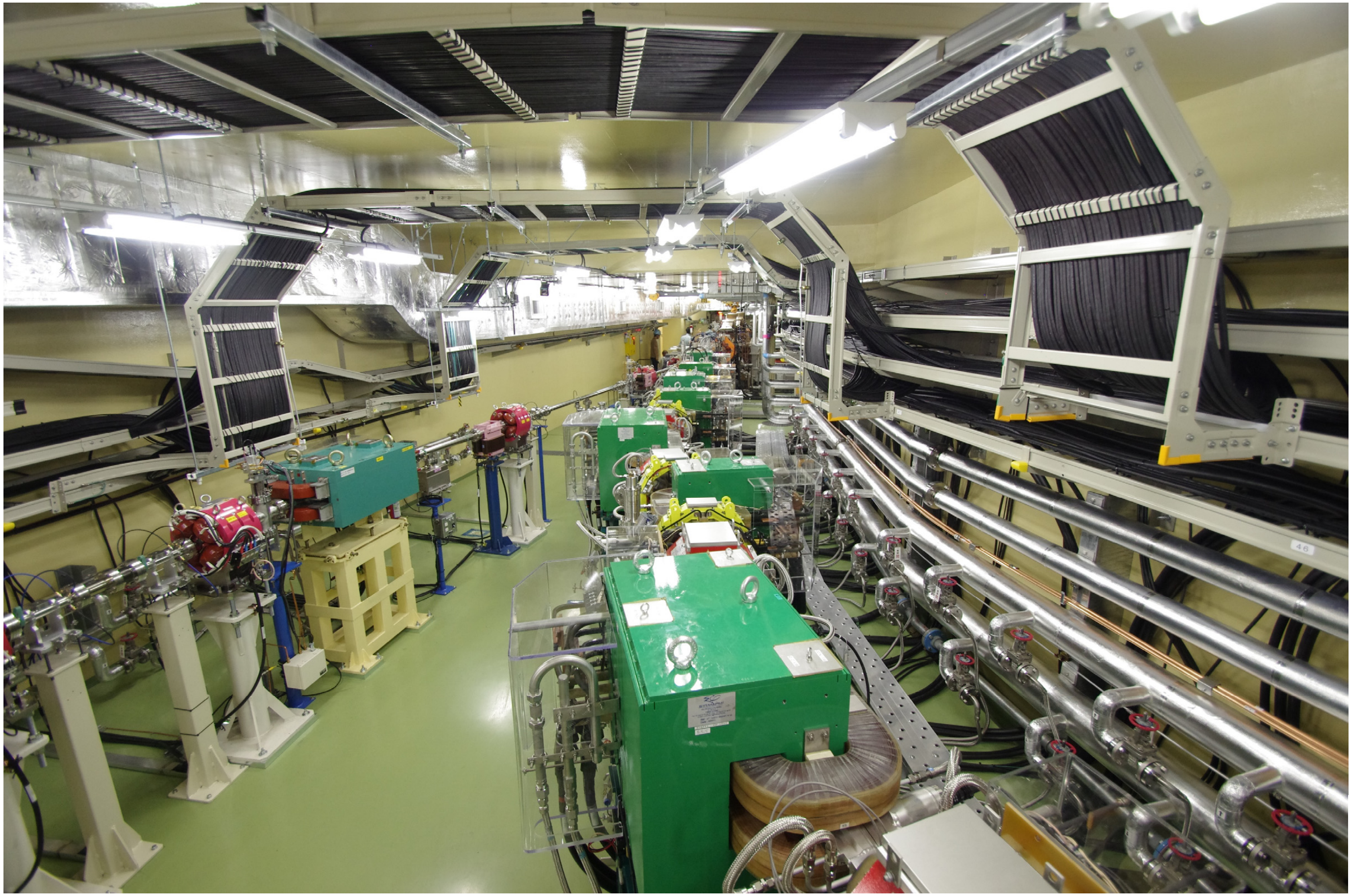
2018年　4月26日　午前0時38分

10

加速器コントロール・ルーム

Belle II測定器コントロール・ルーム

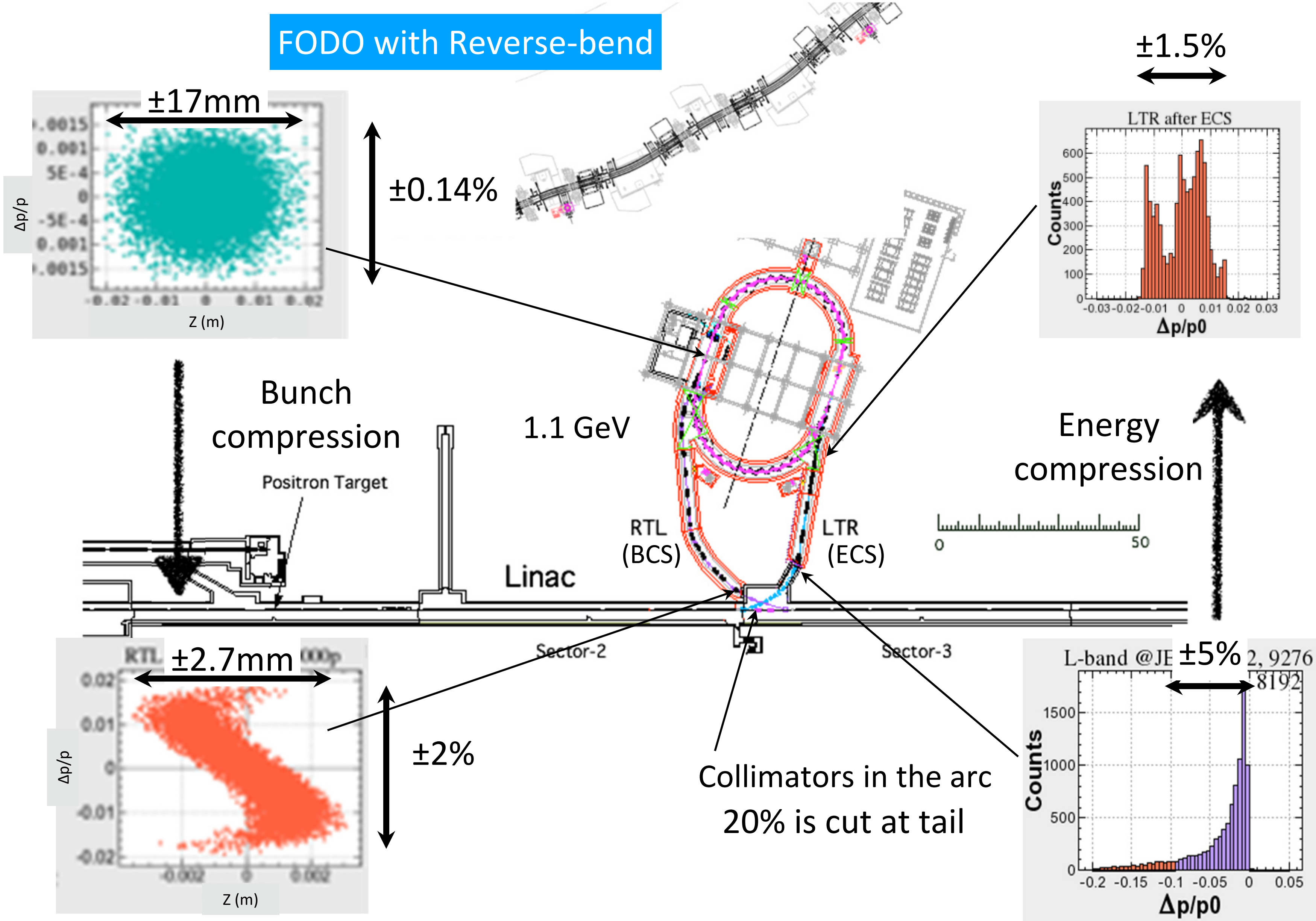
DR commissioning



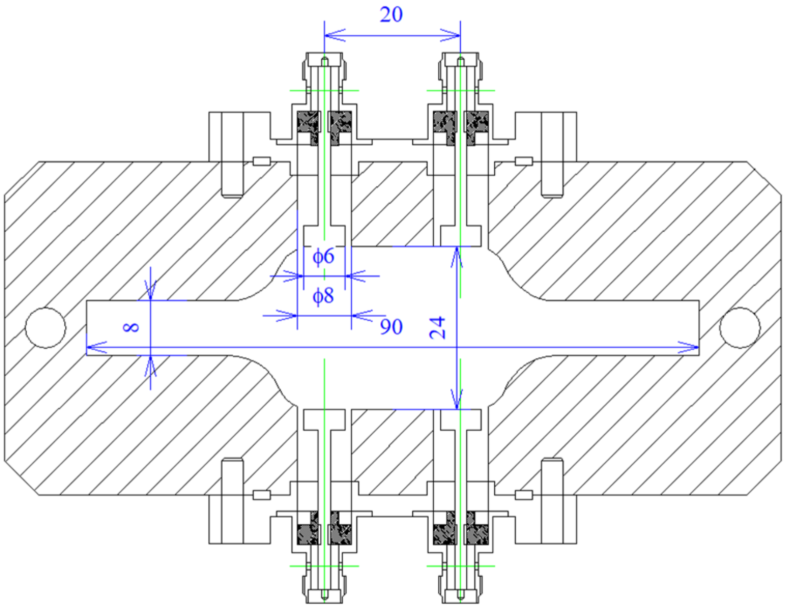
Detailed discussion will be shown by Dr. H. Ikeda at MOPA02

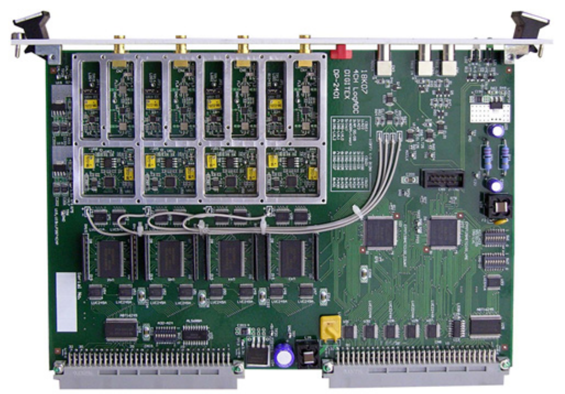
Positron Damping Ring

M. Kikuchi et al.

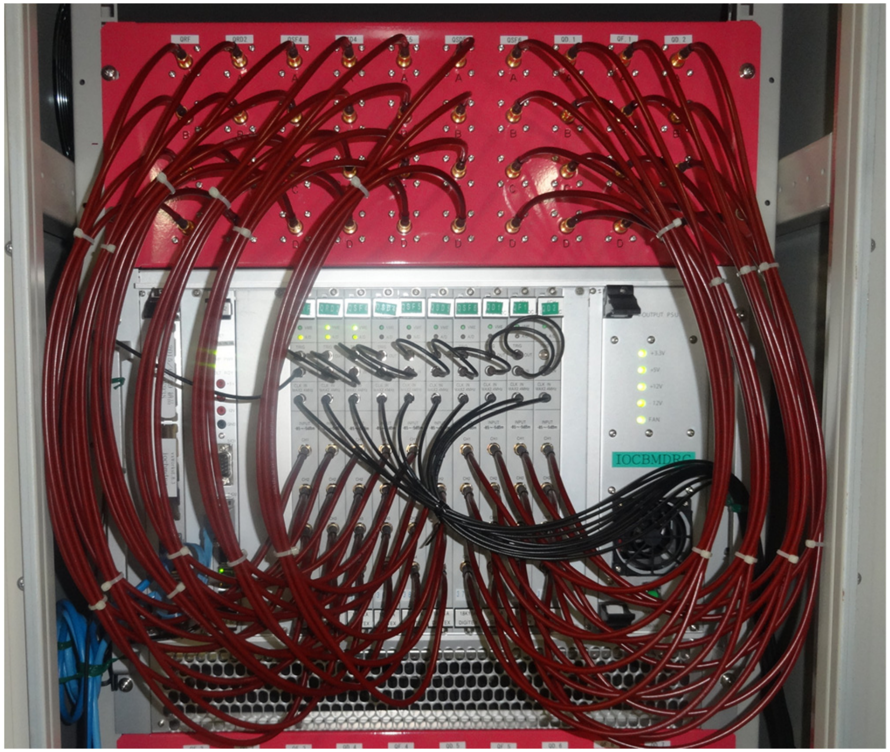


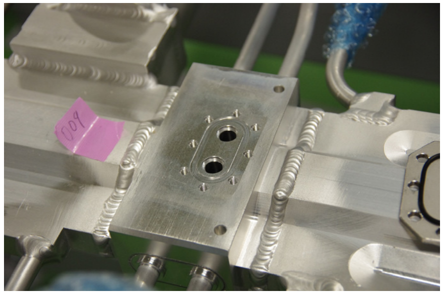
DR BPM





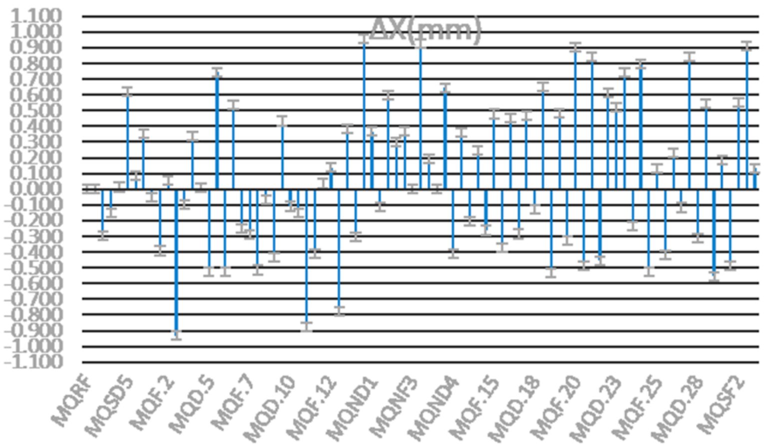
L/R wideband
Turn-by-turn
detector
(18K11)

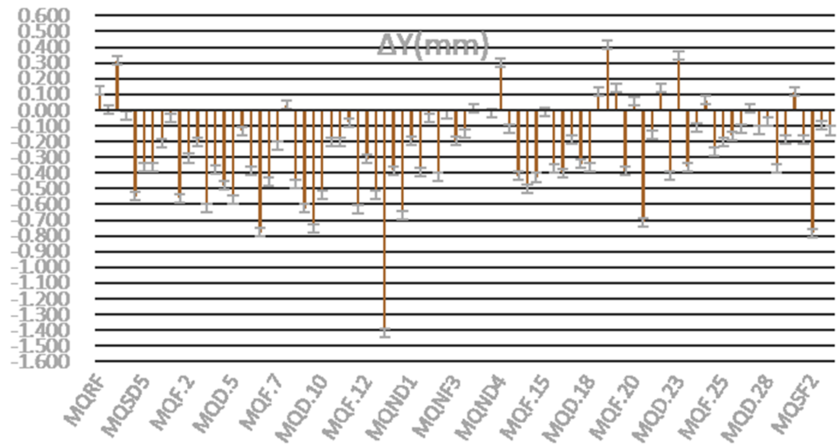




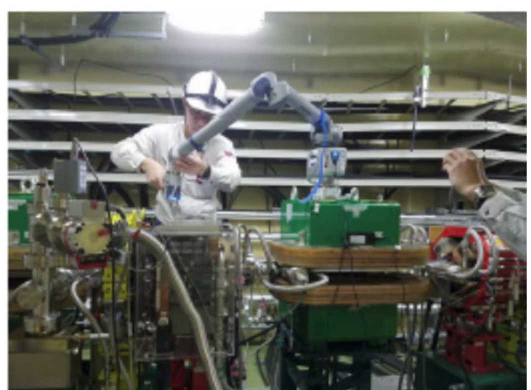
BPM block position survey

- Measured the BPM block position relative to Qmag using FARO 3D-arm.

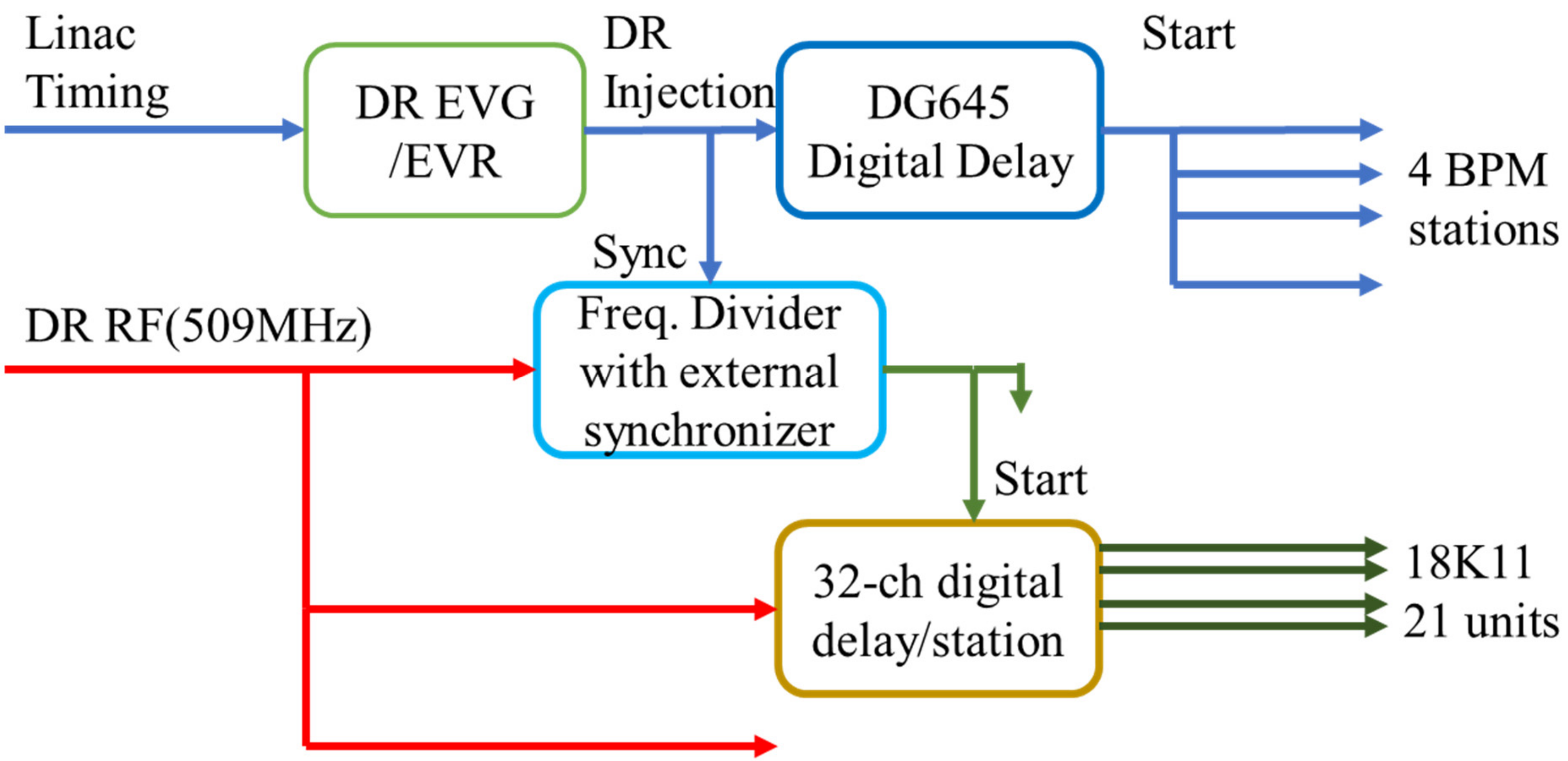




- 0.07 mm ± 0.47 mm　　　　−0.25 mm ± 0.29 mm

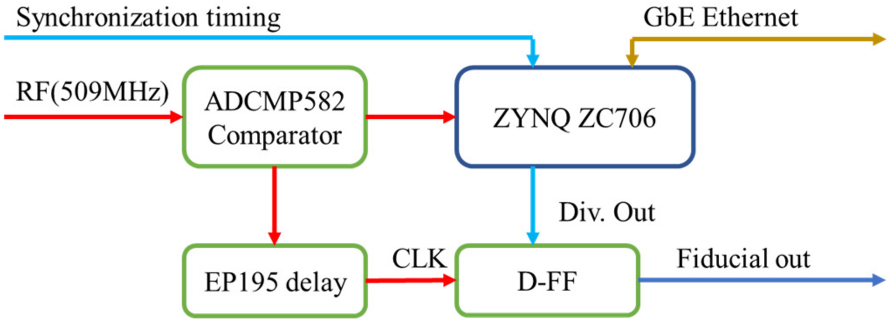


DR BPM Timing system

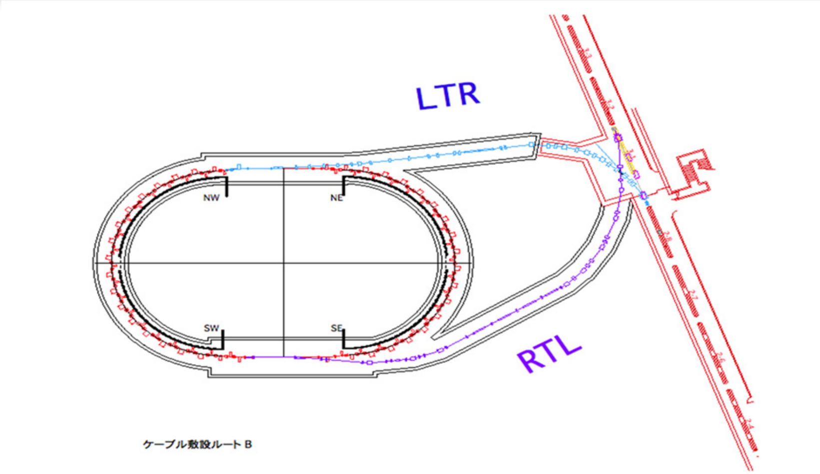


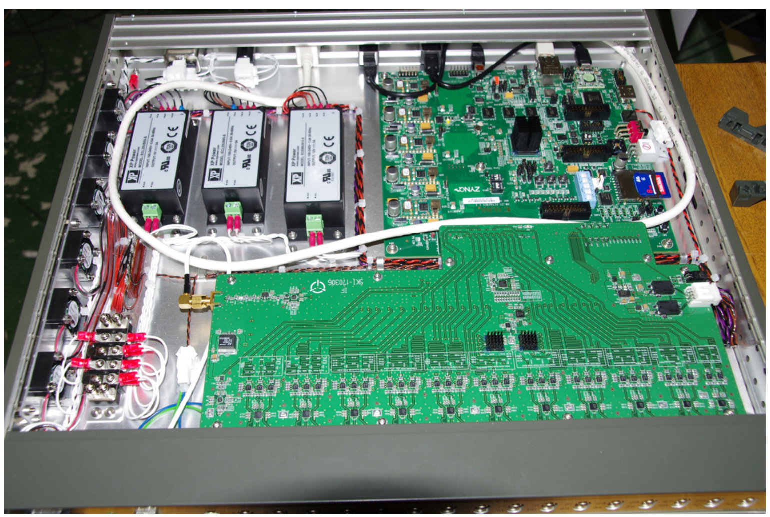
Freq. Divider with external sync.

- SKI-16115 32-bit 2ch frequency divider
- Working up to 720 MHz
- 32-bit divider and 32-bit delay
- ZYNQ ZC706 FPGA



32-ch 32bit digital delay

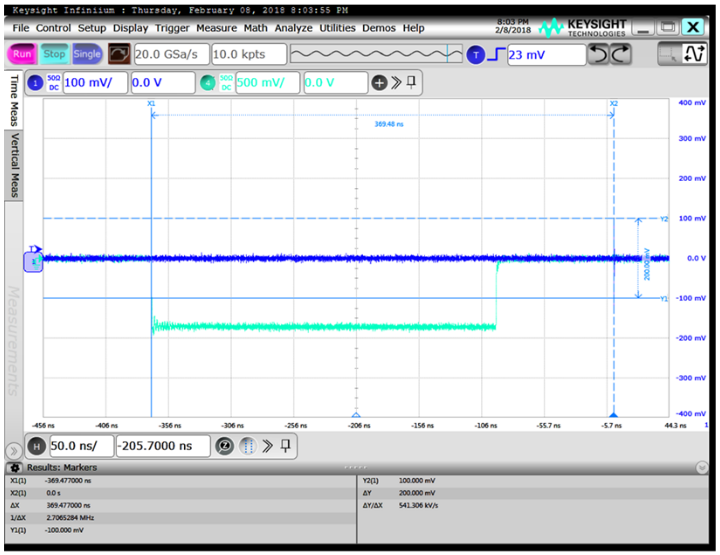


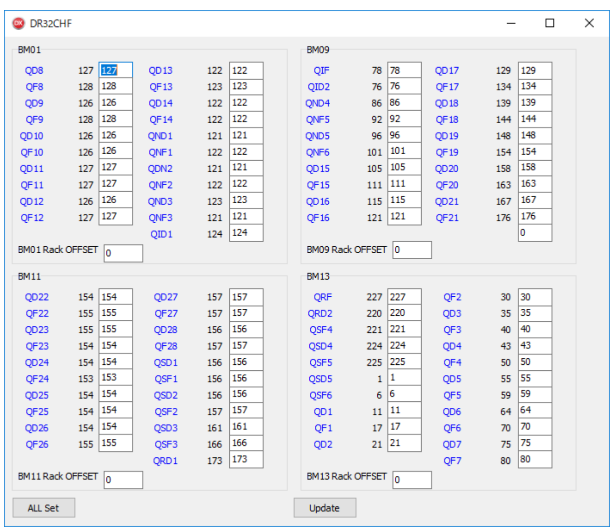


- Largest timing difference in a BPM station amounts to more than 180 ns.

- SKI-17029 32-ch delay working with 508 MHz Ring RF.
- ZYNQ ZC702 eval. board with a daughter card .

Timing adjustment using beam

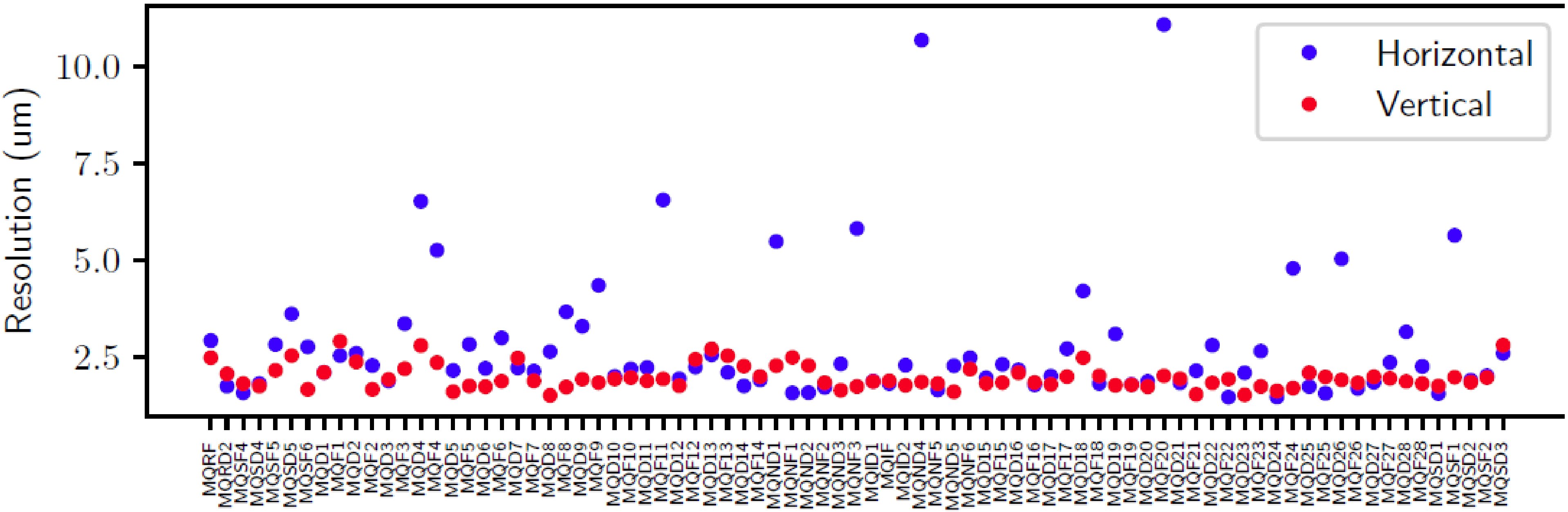




- Preset individual delay estimated from cable length and positions.
- Adjust the station timing offset by observing the injected bunch signal from most upstream electrode and the revolution timing from 32-ch delay.
- Add this offset to individual delays (21-units).
- Within 2-3 hours after first injection all the BPM timings have been adjusted.

BPM resolution

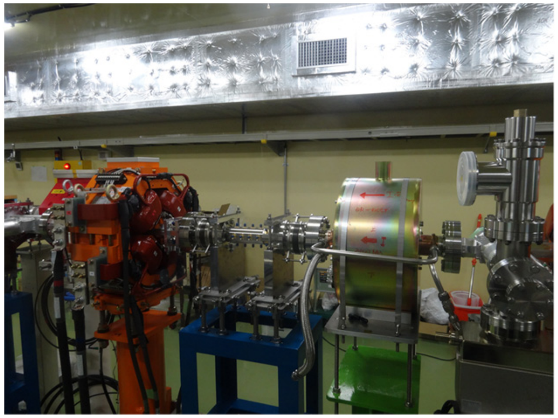
- Estimated using 3-bpm method.
- Mean beam position for 2k turns (could increase up to 32k turns).

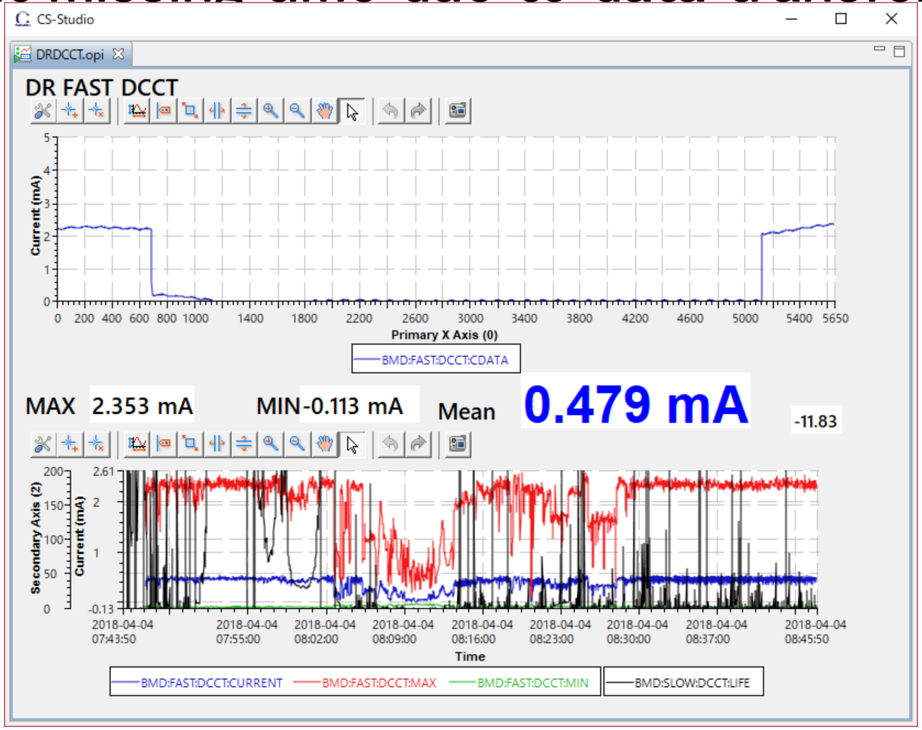


- Roughly 2–3 μm with 1nC bunch (2.4 mA)

DCCT

- Measure the current with Keysight 34465A DVM with roughly 5kSPS without missing time due to data transfer.

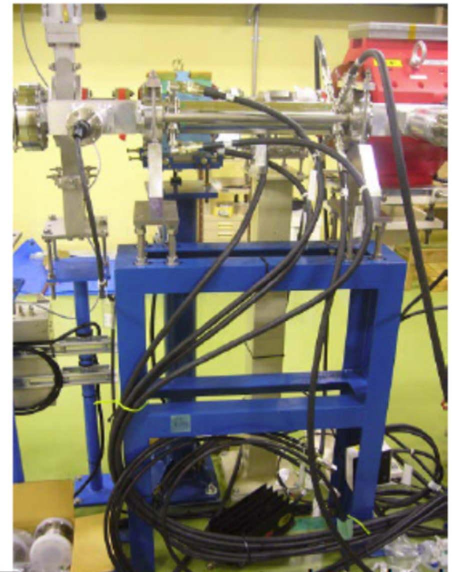




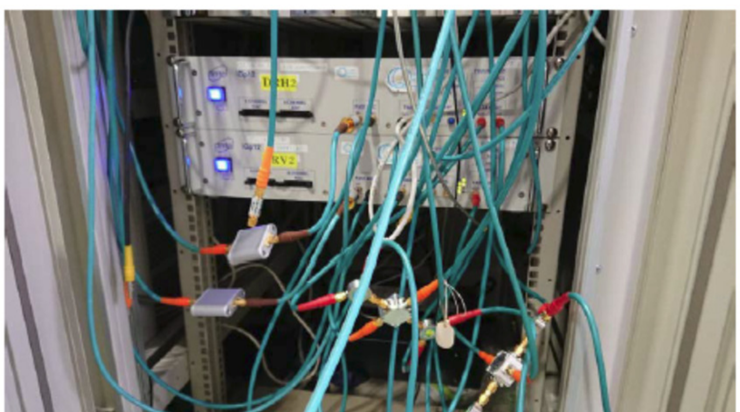
- Reflects imperfect step response of DCCT

Bunch feedback system

Monitor chamber



Transverse strip-line kicker

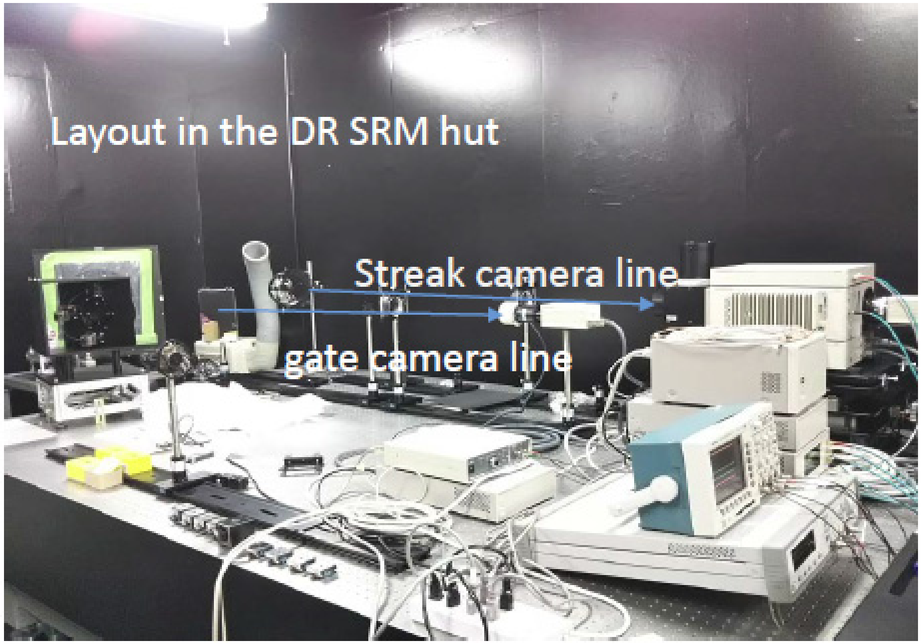


iGp12 feedback processor

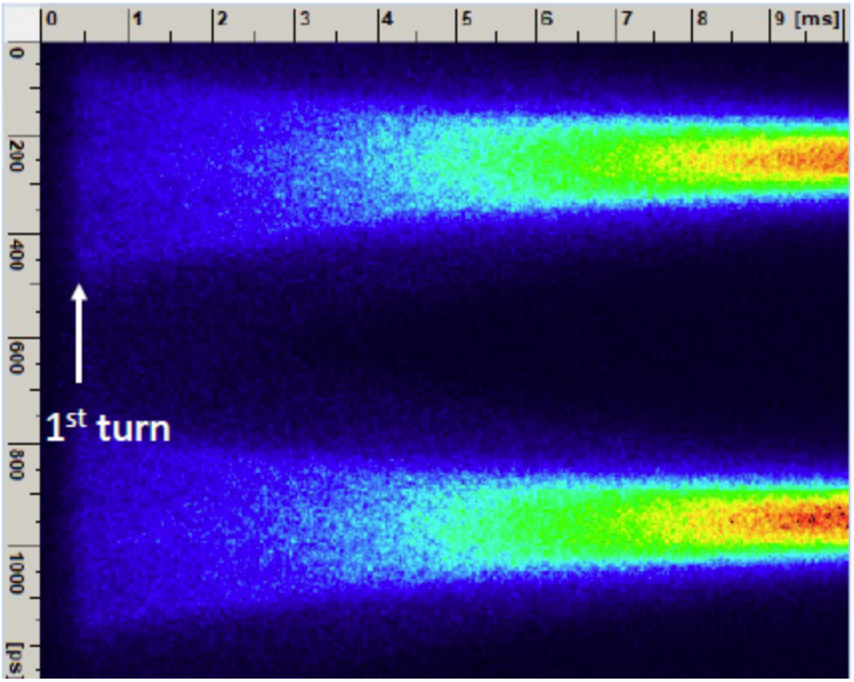
bunch detector

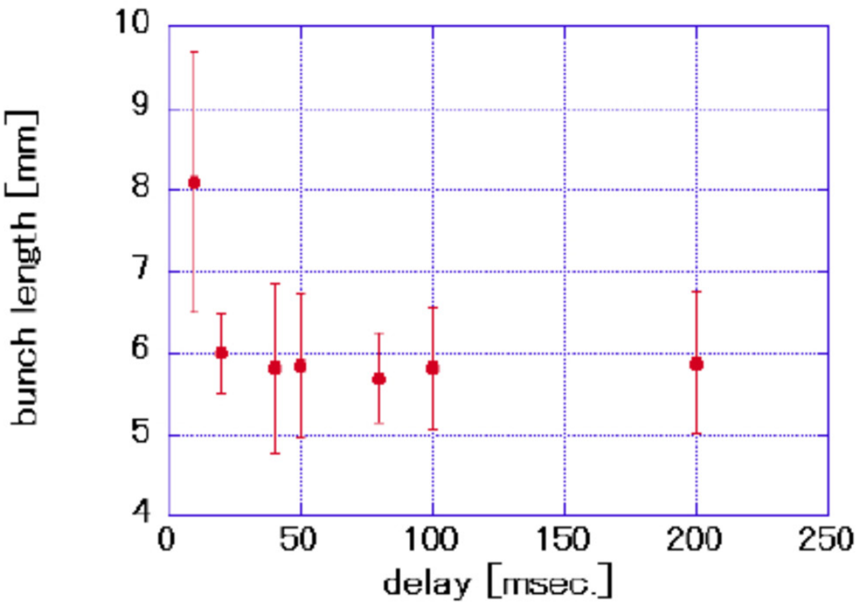
SRM


Extraction chamber


Layout in the DR SRM hut
Streak camera line
gate camera line

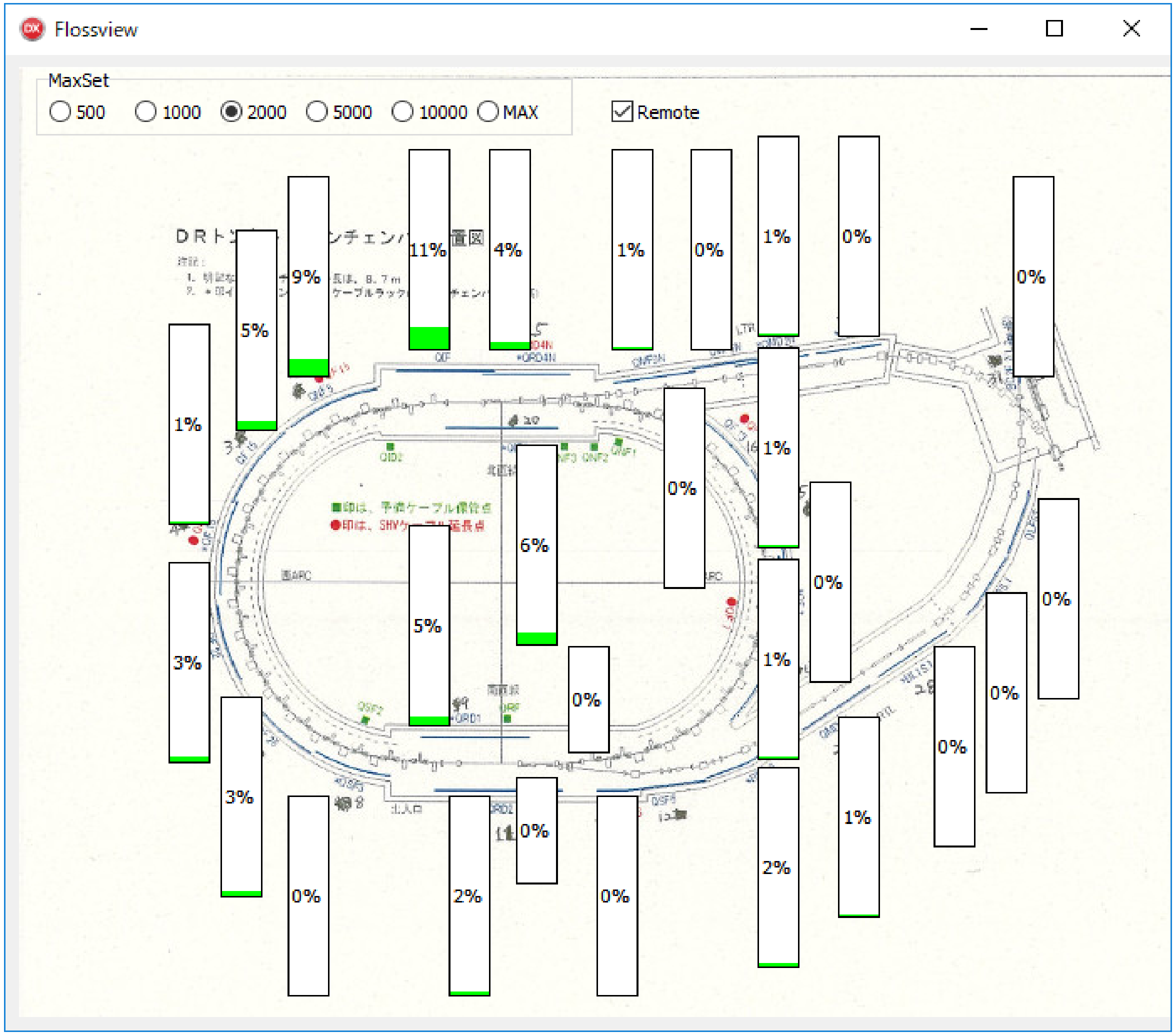
Bunch length after injection





- Damped around 20 ms after injection.
- Equilibrium value (6.5 mm) consistent with design bunch length.

Loss monitor

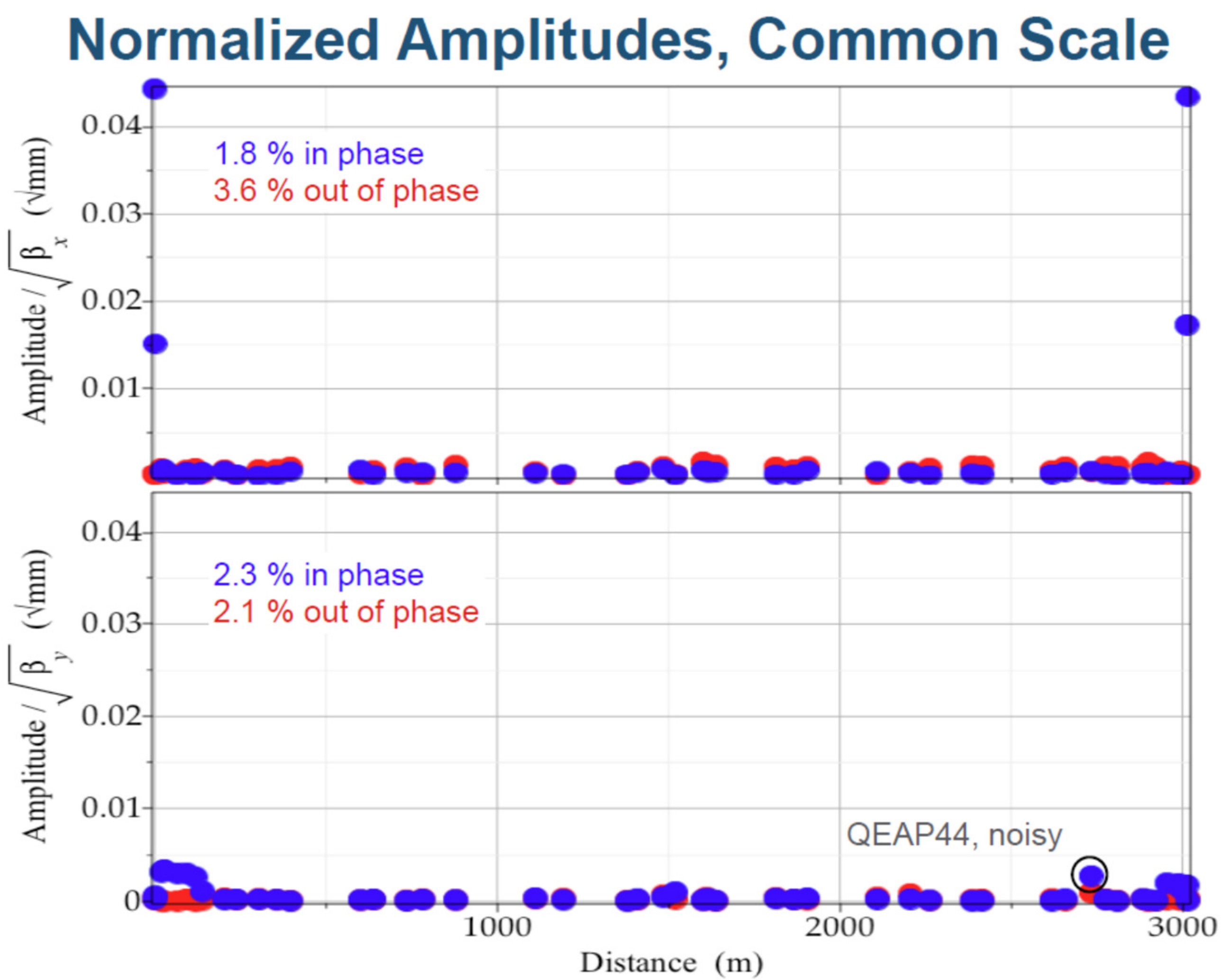


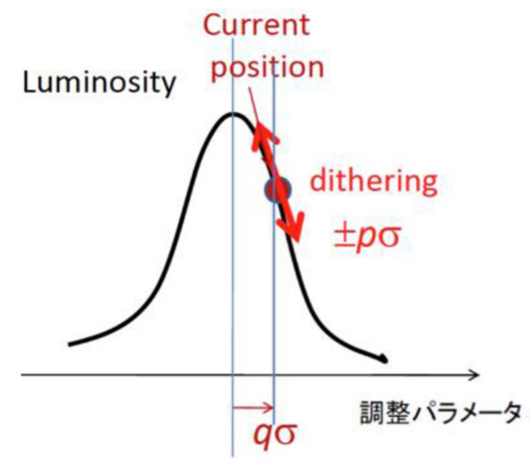
28 Ion Chambers around the ring and the transport lines
Stop injection when loss exceeds threshold value

HER/LER commissioning

- **Gated turn by turn monitors**
  - Add 19 units (mainly around IR, local chromaticity correction sections)
  - Revolution timing at local stations have been changed due to
    - New positron damping ring
    - Collision timing tuning (definition of bucket 0 has changed)
    - HER : +920 ns
    - HER : +880 ns
  - Used for
    - To reduce the injection oscillation (kicker timing and amplitude)
    - Optics measurements, corrections especially around the IP
    - Tuning the orbit bump of dithering system (TUPC13)

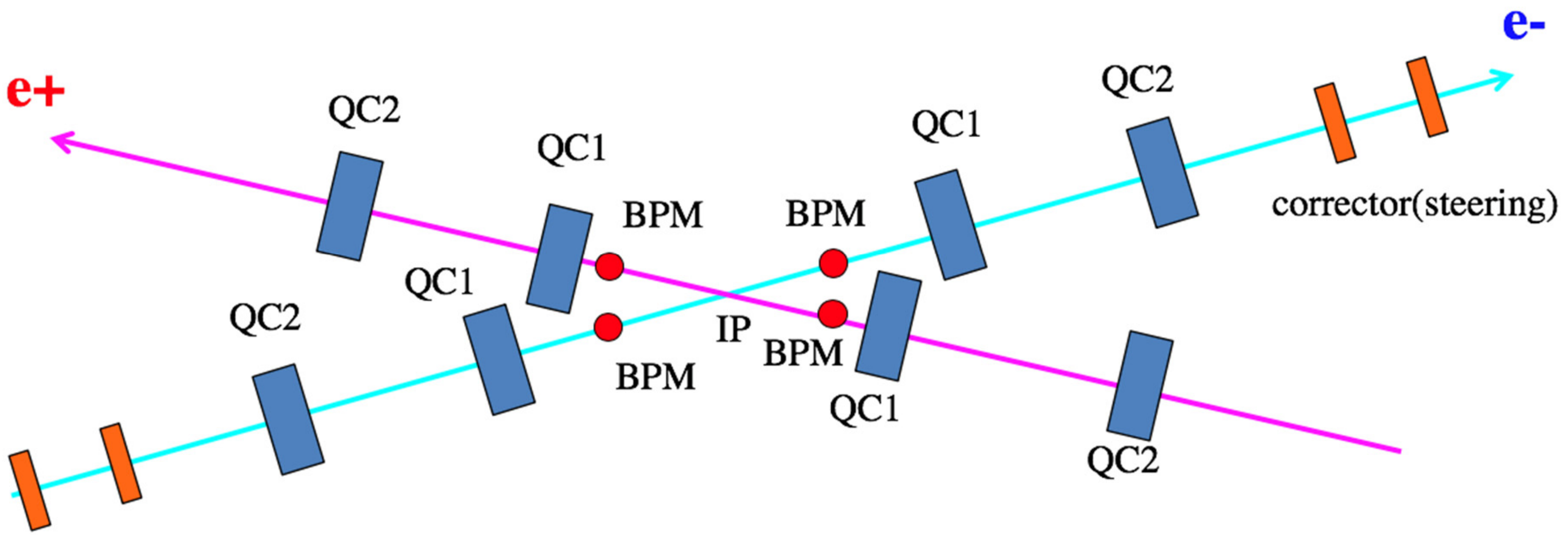
Orbit bump for dithering

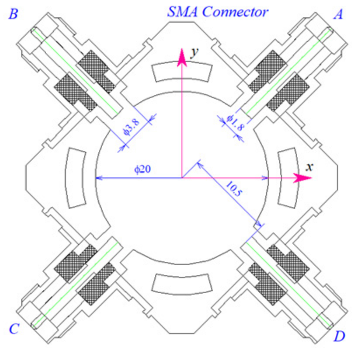


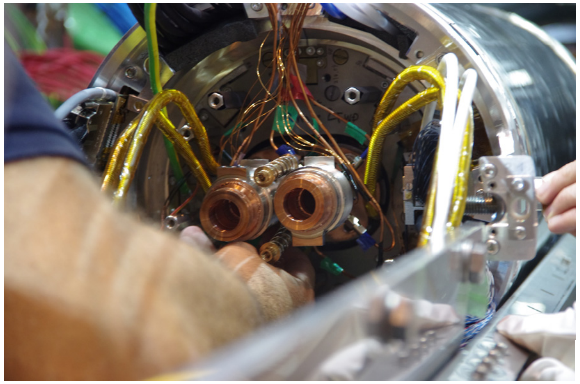


Modulate IP positions and angles with a sinusoidal signal (77Hz) and detect the frequency and phase response of luminosity monitor

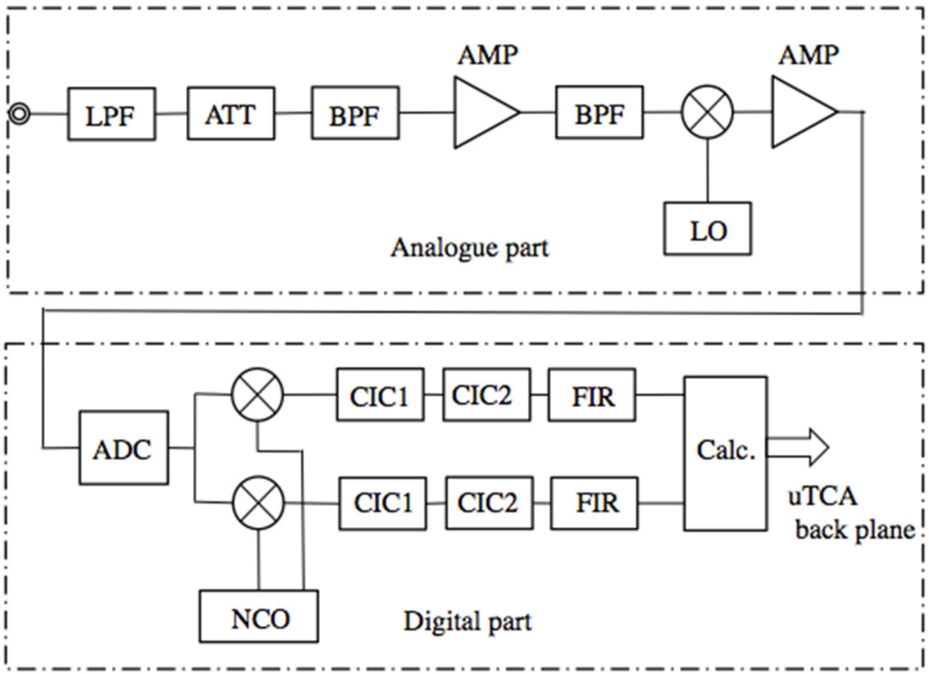
IP feedback systems

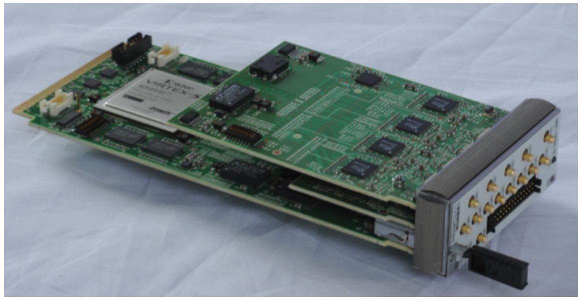






Detector



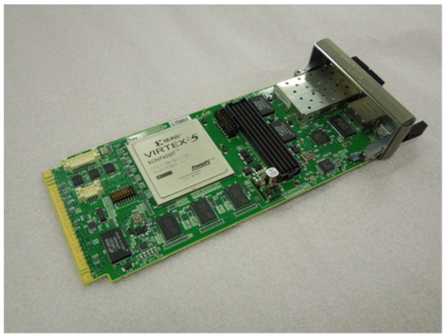


Digital LPF board

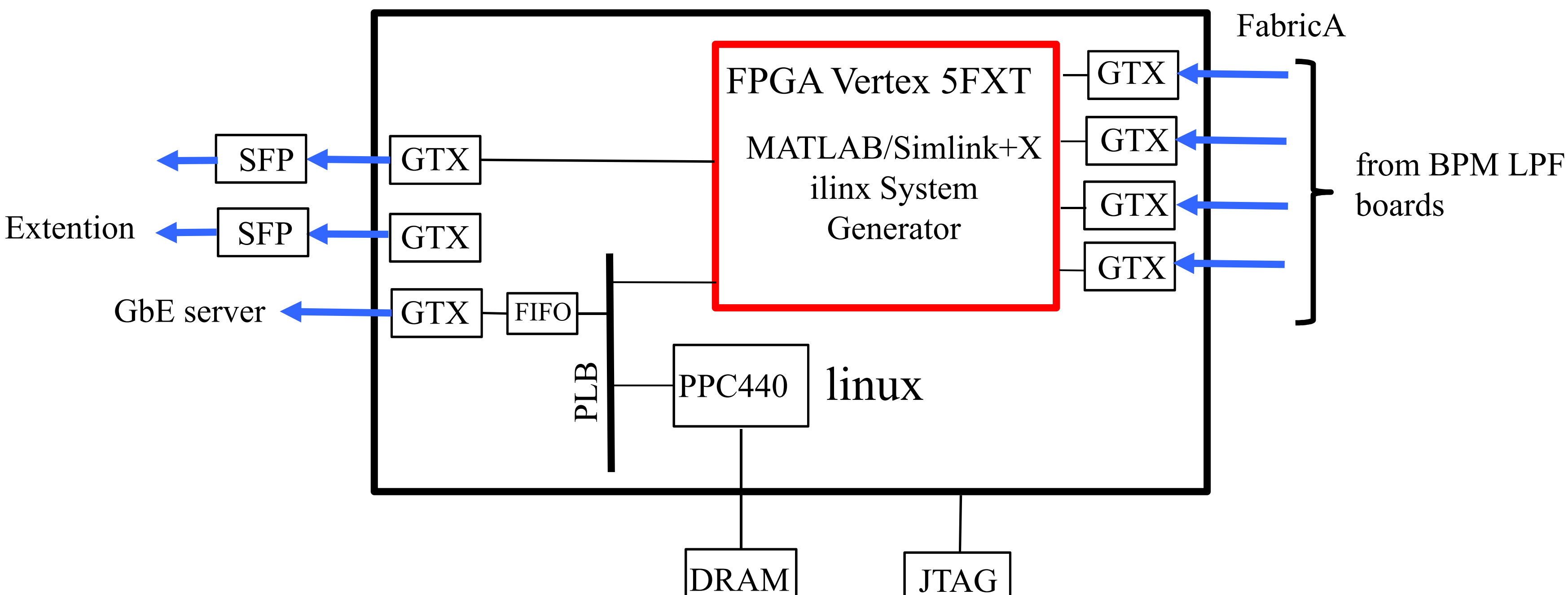
- The digital part is implemented in a μTCA board developed for SuperKEKB LLRF system.
  - EPICS is embedded in the board.

Required position resolution < 1 μm
Repetition 5kHz to 32kHz
Bandwidth 2kHz

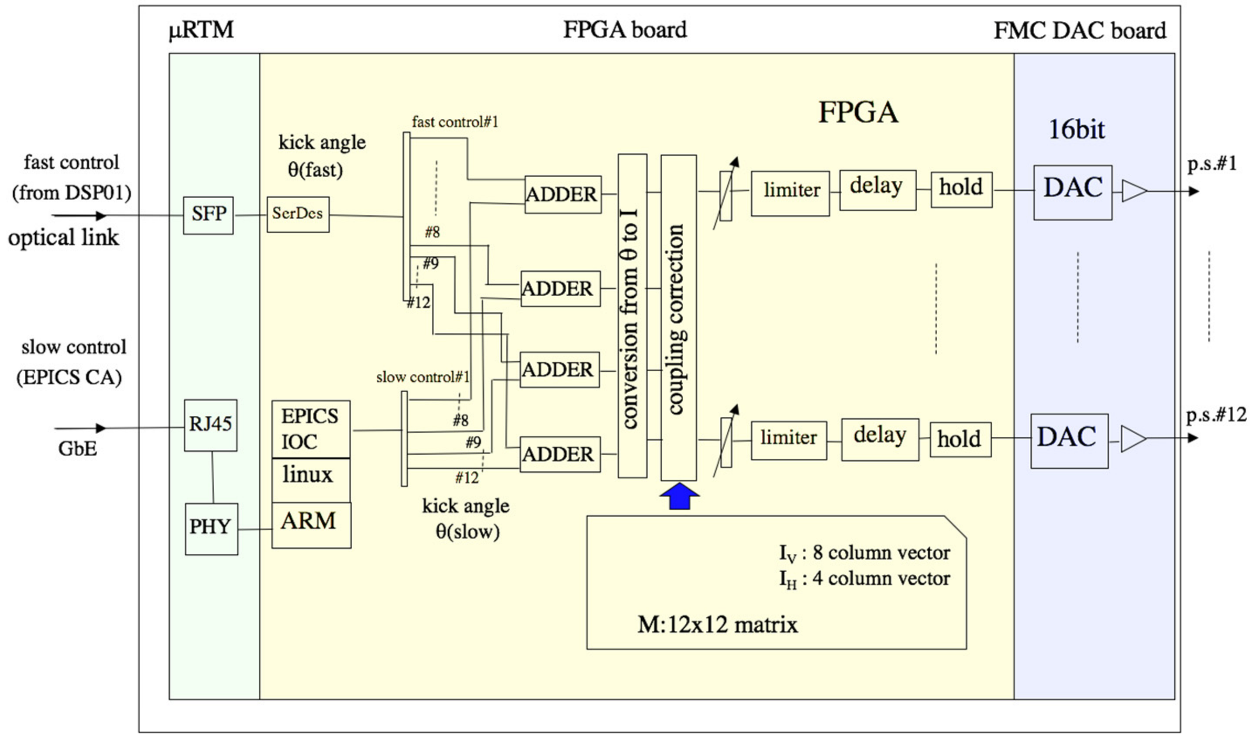
Processor board (DSP)



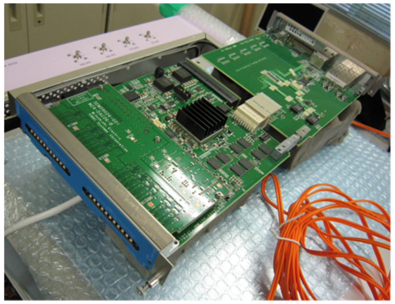
- Implemented with Matlab/Simulink with system generator for easy coding.
- Embedded EPICS
- Feedback repetition 32kHz



Power supply controller (MTCA.4)



RTM : Rear Transition Module FMC : FPGA Mezzanine Card
p.s. : power supply



slow control + fast control -> DAC

- **Simulated bandwidth of FB < 100 Hz.**

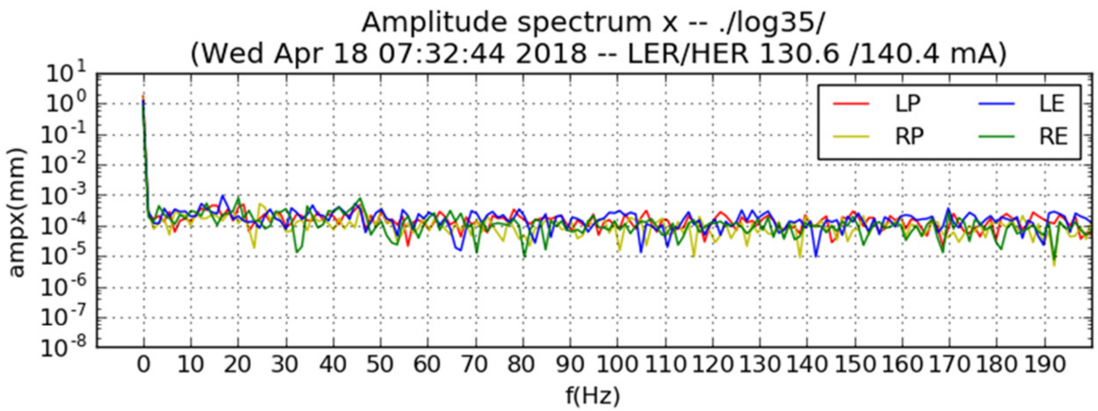
Example of beam vibration data

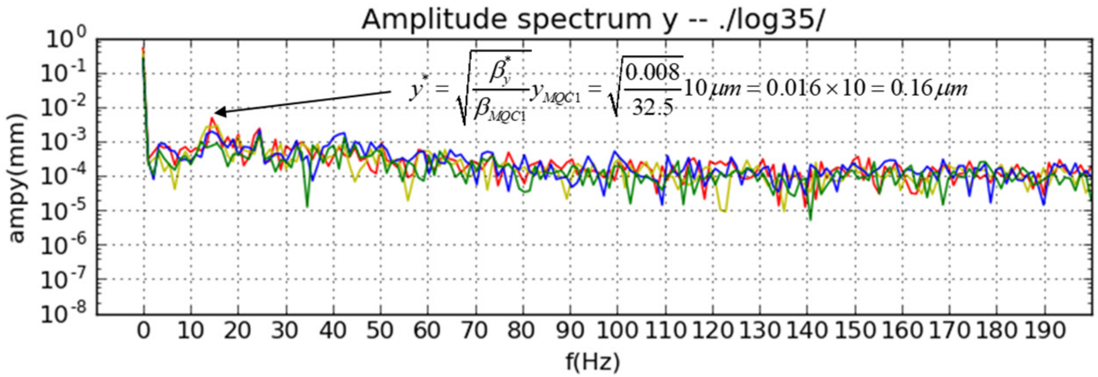
4/18 7:32 LER 130mA , HER 140mA

No collision

β*(H/V) LER 200/8, HER 200/8mm

β_{MQC1}(H/V) LER 1.5/32.5, HER 1.6/35.1m

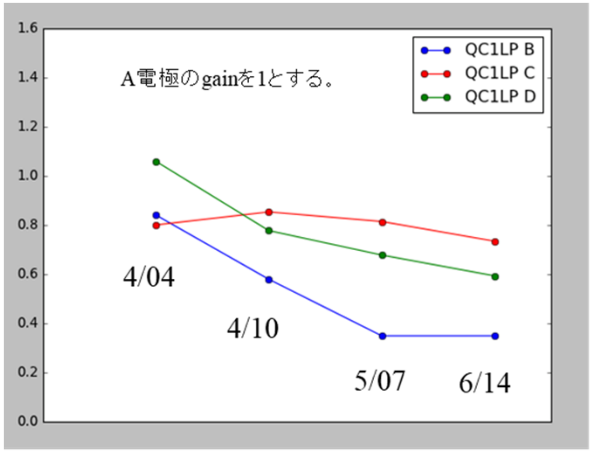


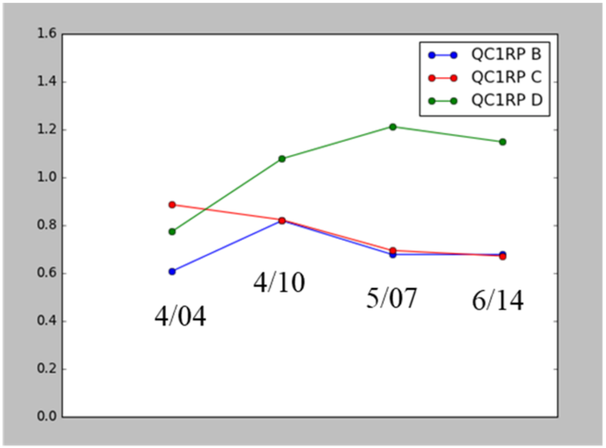


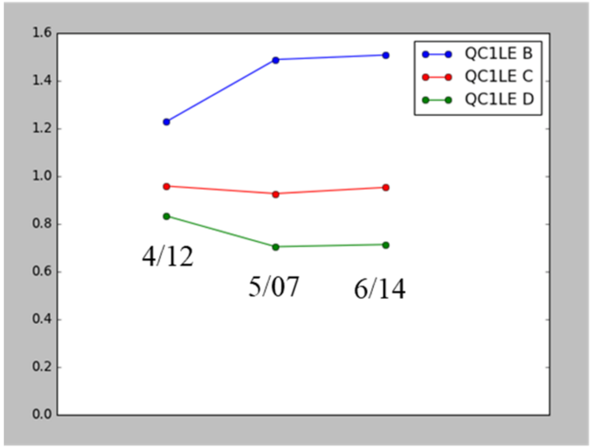
Vertical amplitude was the order of 1/10 of beam size at IP

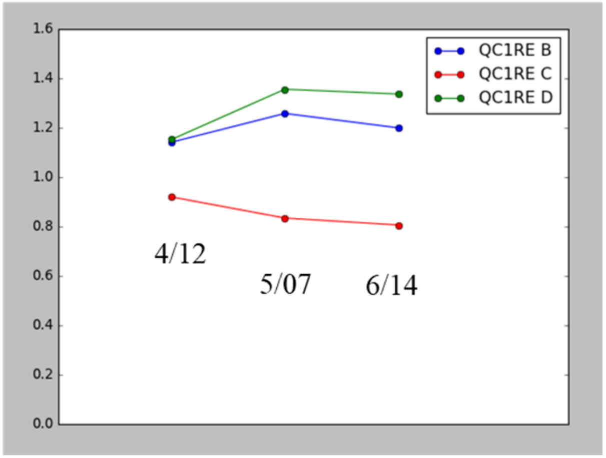
Difficulties (1)

- Huge gain imbalance in QC1 BPMs



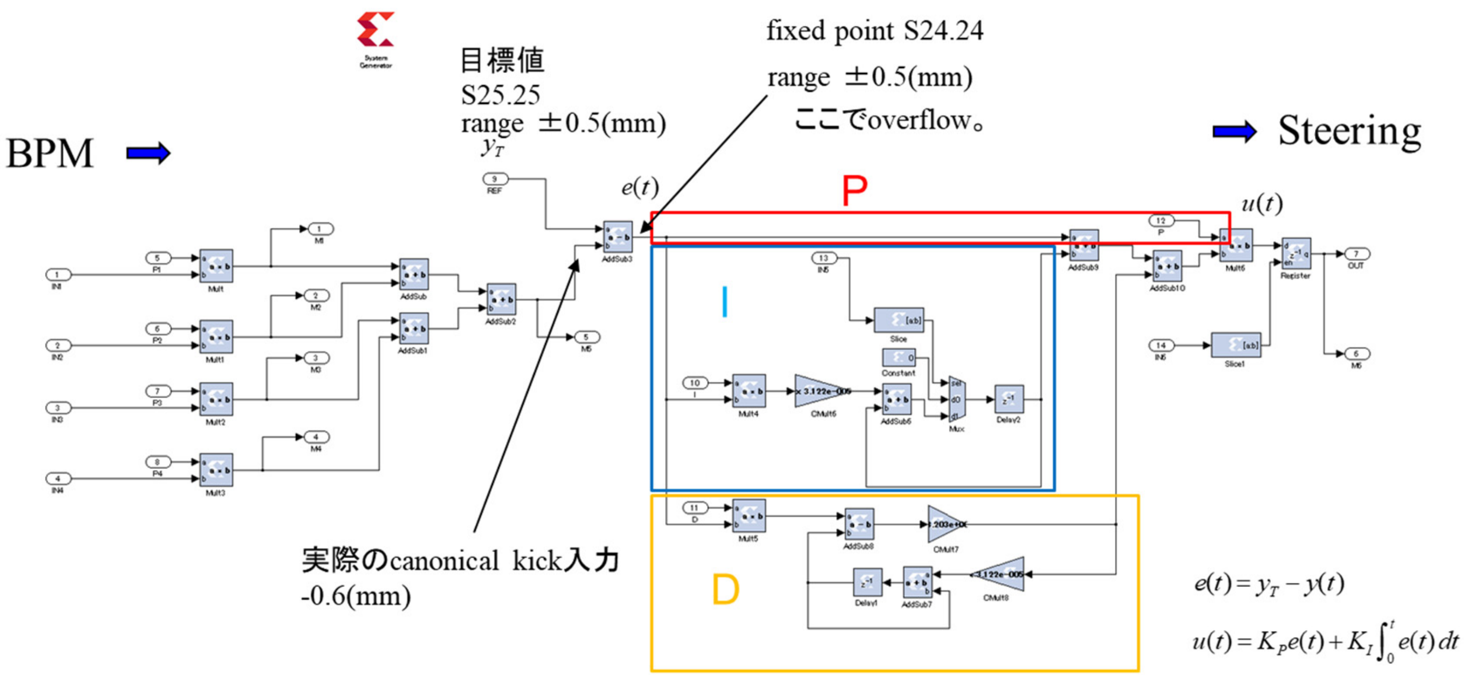






Difficulties (2)

- Overflow in the circuit, mainly due to huge beam offset coming from the gain imbalance.



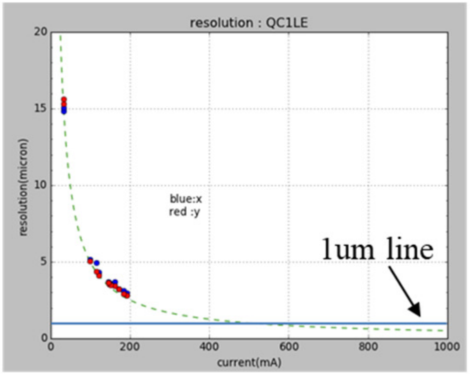
PID controller

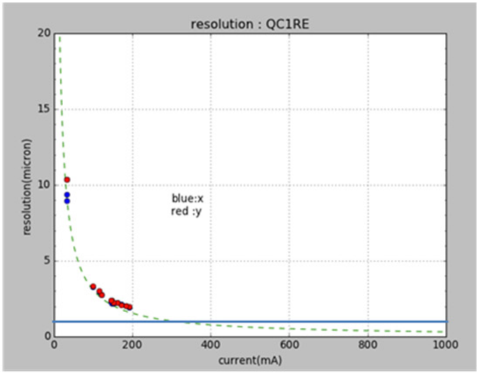
System Generator (Simulink)

Difficulties (3)

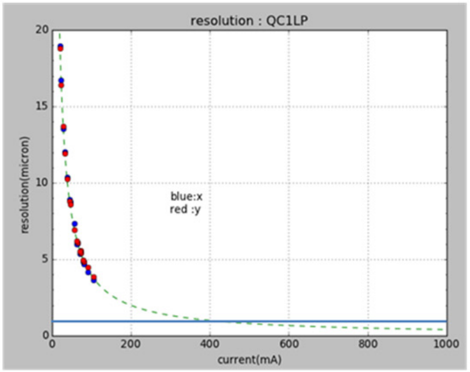
- **Unexpected larger loss in the coaxial cable complex**
  - Too long thin semi-rigid cables (diam. of 1.5 mm)
  - Longer cables path from L-side BPM

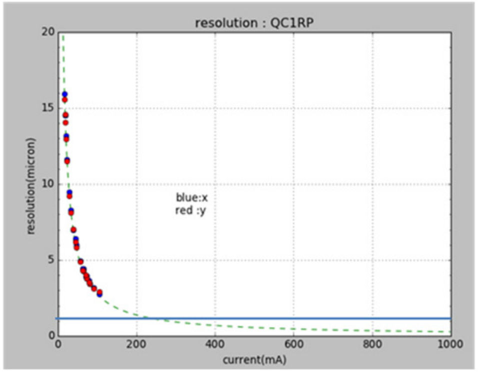
HER





LER

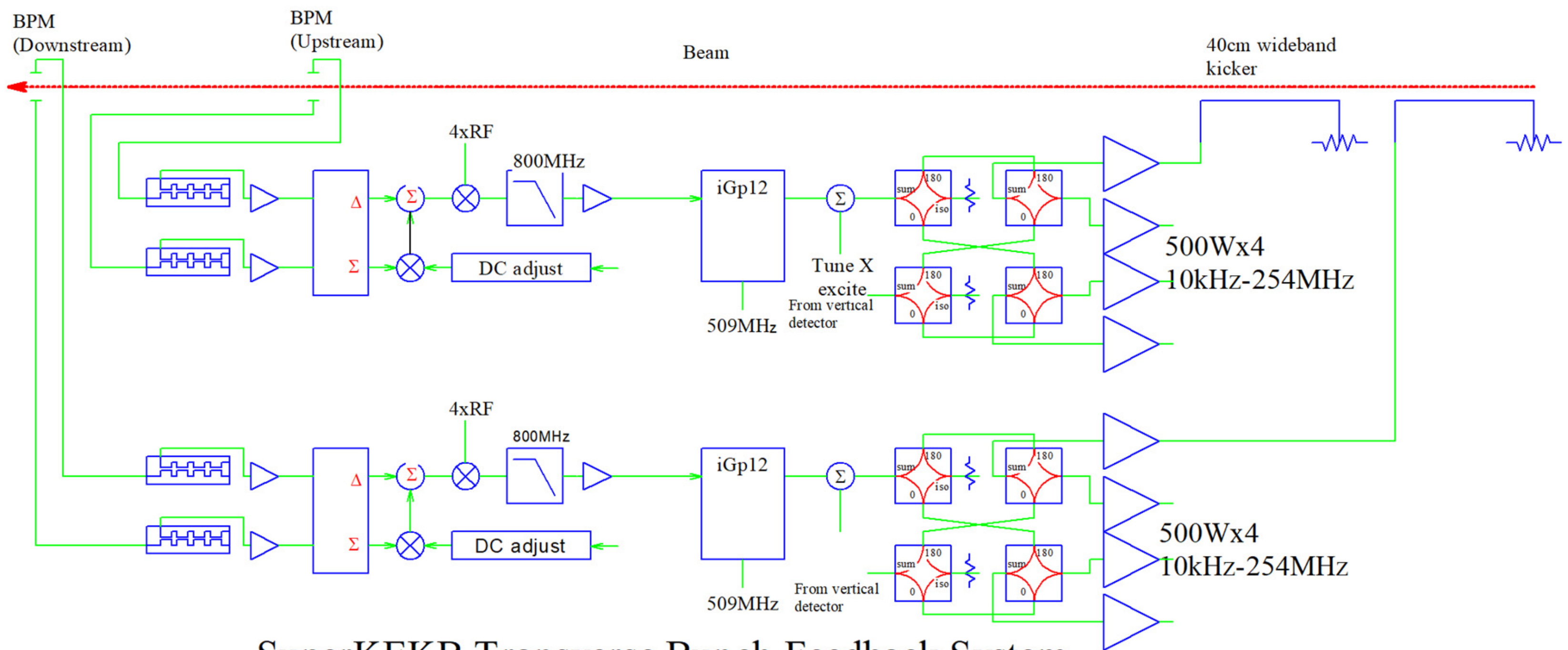




BPM resolution @ 100mA

5mm for L-side
2.5mm for R-side

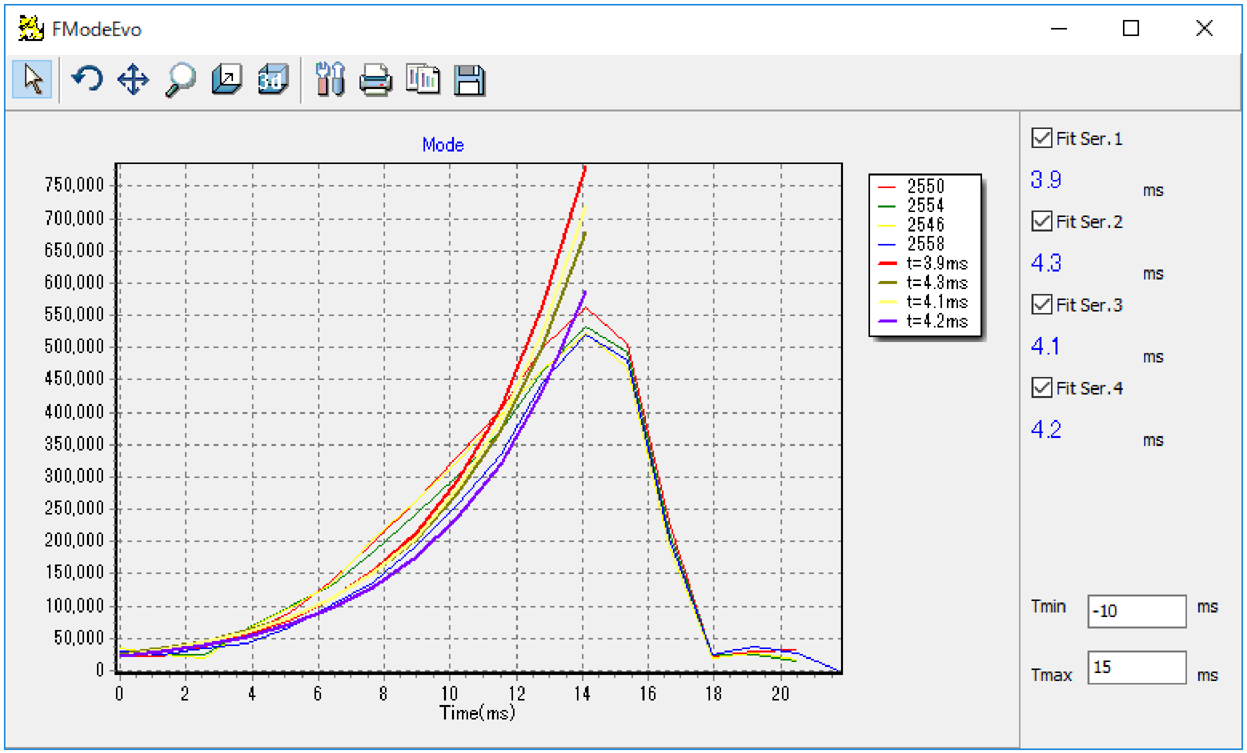
Bunch feedback systems



SuperKEKB Transverse Bunch Feedback System

Worked well, especially in the early stage of the commissioning to suppers instabilities.
Several failures in the final power amplifiers due to breakdown of chips of driver stage.
Tune measurements to excite only non-colliding bunch (iGp12) worked well.
PLL-based betatron oscillation excitation for optics measurements using GTBT worked well- still need to tune the amplitude due to fairly limited physical aperture.

Example of grow-damp experiment(LER)



ECE related instability growth time much slower than that of phase-1 (0.8ms->4ms)

Feedback damping time was the same (<1ms)

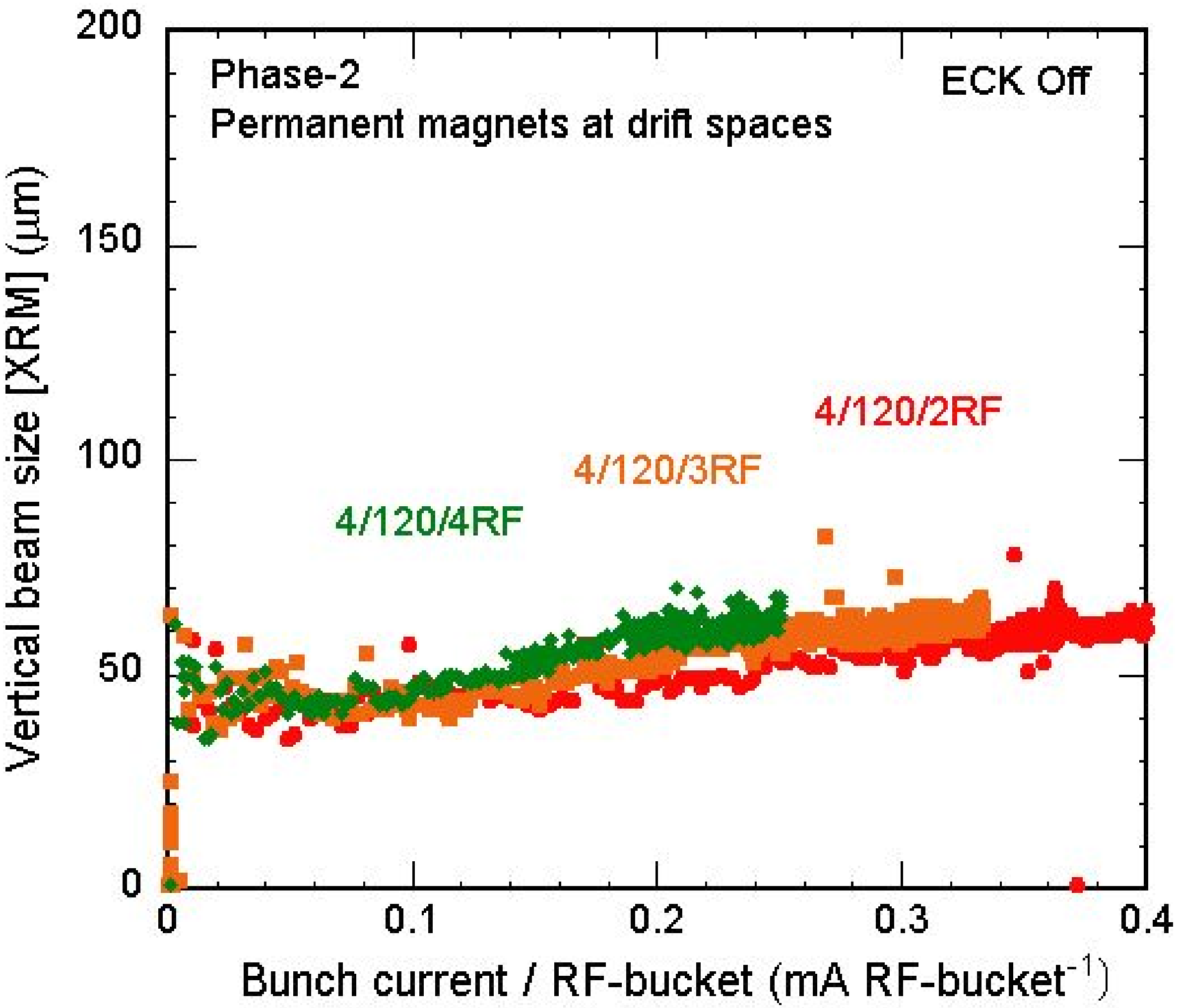
Photon monitors

- Deep-Si pixel detectors and the readout system was not in time -> Used scintillator with a CCD camera
- Detailed discussions will be presented in WEOC02
- Mystery of HER beam size at phase-1
  - Removed thick Be absorber in HER line (16mm->0.2mm)
  - Increased βy at the source point of HER (7.6m->28m)

↓

- Point spread function greatly reduced in HER
- Measured HER vertical size was consistent with that estimated from the optics measurements (x-y coupling)

Example of vertical beam size of LER during ECE exp.

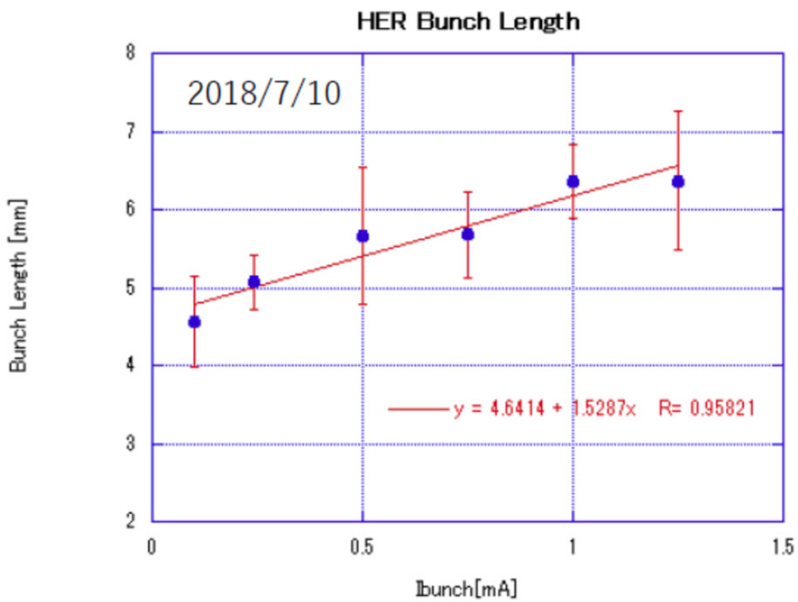


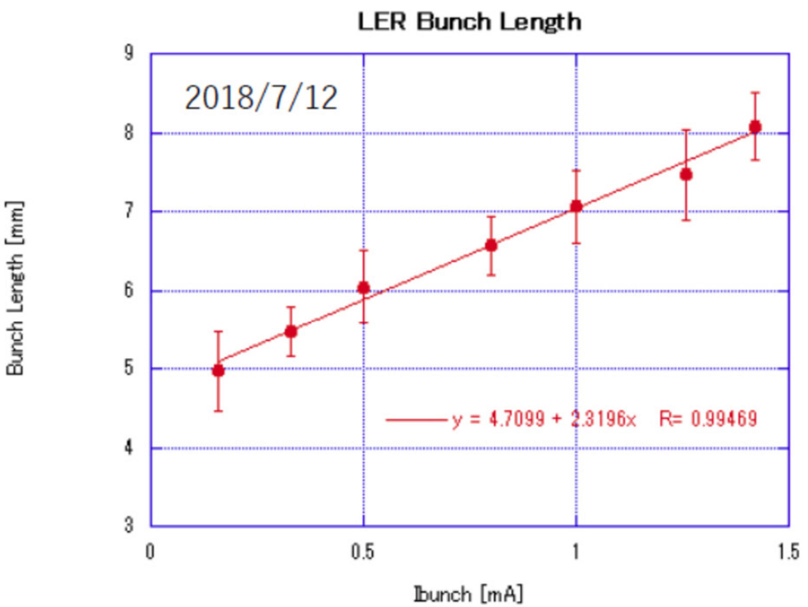
Visible SR line

- Exchanged diamond mirror with 200% large aperture to get much photons.

- Examined the streak camera at LER and found huge degradation of the streak tube.

Bunch length measurement





Vc=12.8MV

Summary

- **Beam instrumentations of SuperKEKB, especially DR have been successfully commissioned.**
  - All the system has shown excellent performance.
  - Helped very smooth beam commissioning of the rings
    - 1 month commissioning for DR from scratch
    - 3.5 month commissioning for HER/LER to achieve design target (luminosity, beam backgrounds..)
- **For Phase 3 (with fill set of Belle-II detector)**
  - Preparing to improve the instrumentation systems, especially
    - QC1 BPMs and IP feedback systems
    - GTBT systems
    - Longitudinal BxB feedback systems.