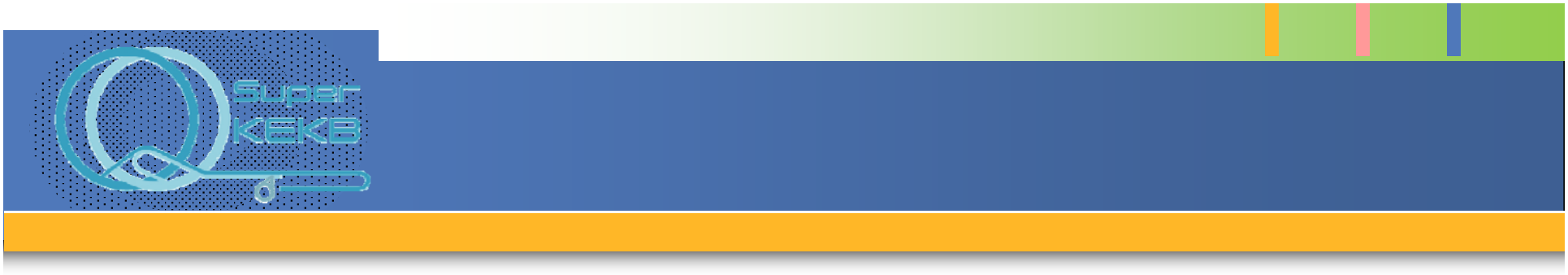


Beam Instrumentation and bunch feedback systems

Makoto Tobiyama

Introduction

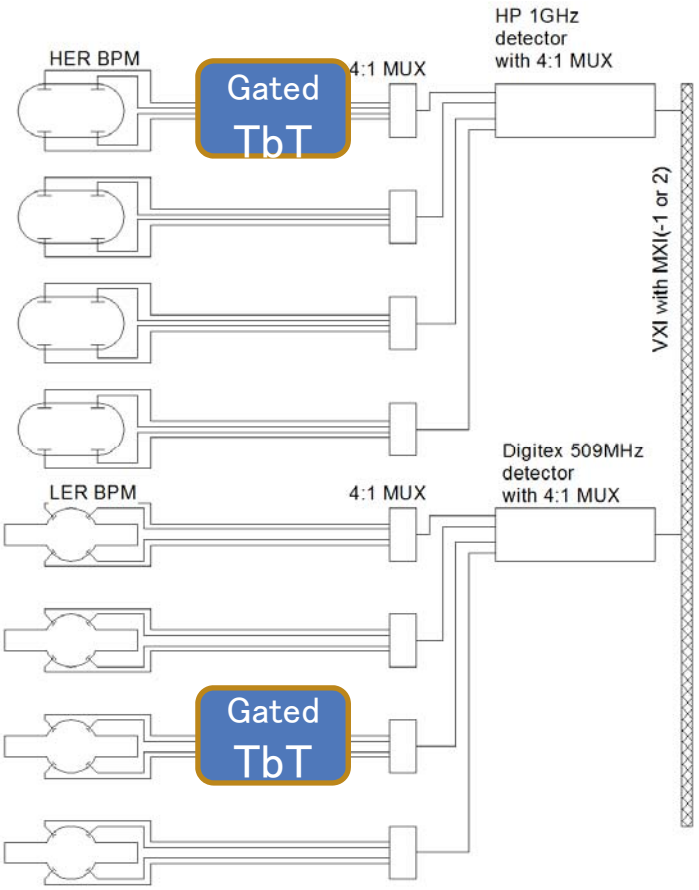
System	Quantity		
	HER	LER	DR
Beam position monitor (BPM)	466	444	83
Displacement sensor	110	108	0
Transverse bunch feedback system	2	2	1
Longitudinal bunch feedback system	0(1)	1	0
Visible SR size monitor	1	1	1
X-ray size monitor	1	1	0
Beamstrahlung monitor	1	1	0
Betatron tune monitor	2	2	1
Beam loss monitor	200		34
DCCT	1	1	1
CT	1	1	0
Bunch current monitor	1	1	1

BPM system at Phase 1

Type	Function	Resolution	Repetition	Number of units
1GHz Narrow-band system from KEKB	Closed orbit correction, CCC, optics measurement	3μm	0.25Hz	109
New narrow-band with 509MHz detection	As above	2 to 3 μm	0.25Hz	133
Gated turn by turn	Injection tuning, optics measurement	50 – 100μm	100kHz/data	117
Medium-band	Measurement of orbit variation	< 2 to 3 μm	10kHz	4
Fast orbit deviation	Orbit deviation abort	~10μm <10 turn	100kHz	4

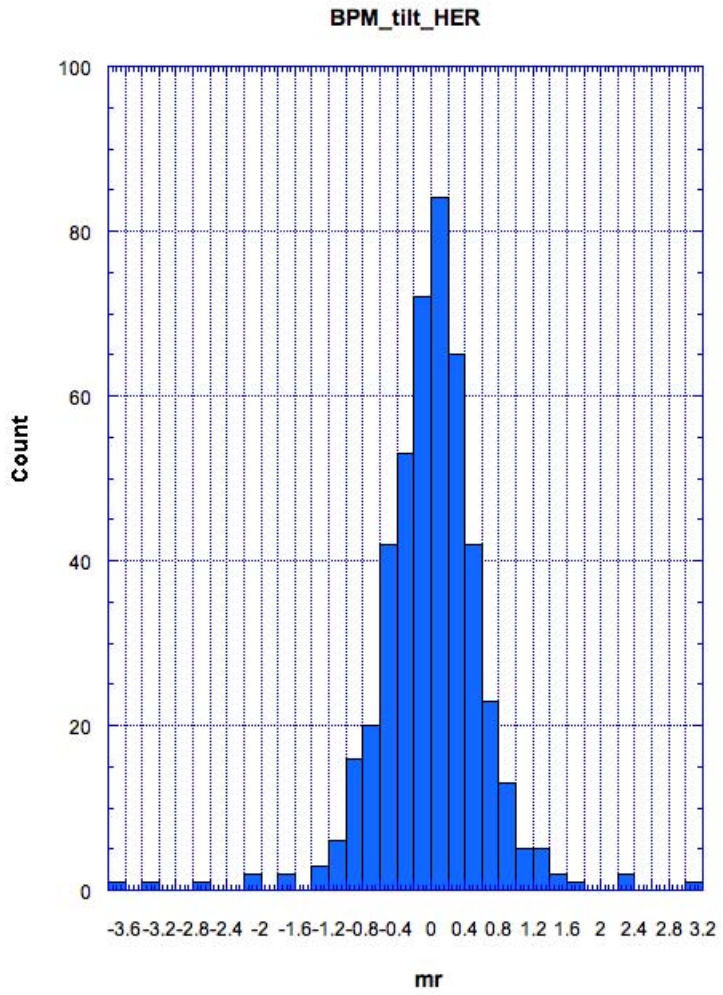
One narrowband detector covers four BPMs.

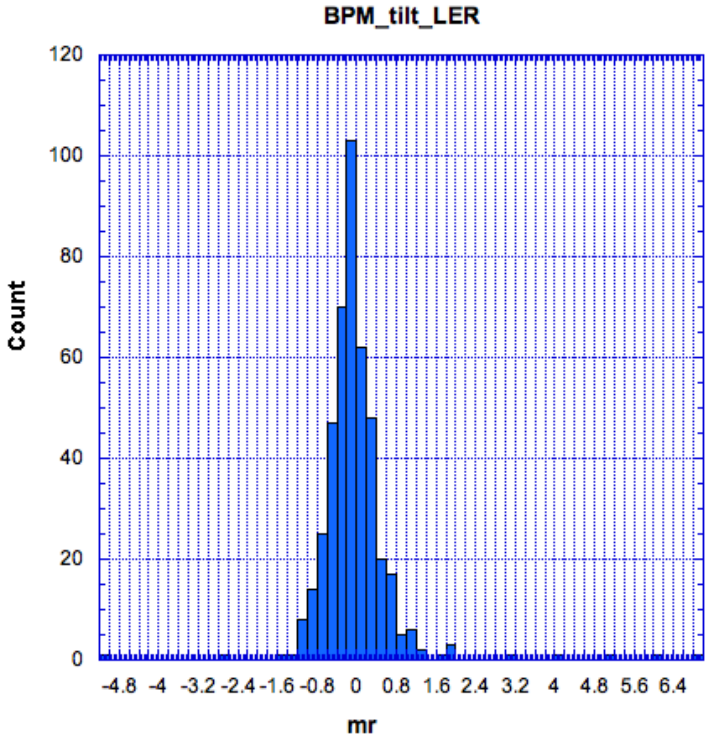
Configuration of main BPM system



- 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.

Measured rotation angle of BPM





Cabling check, Beam Based Alignment

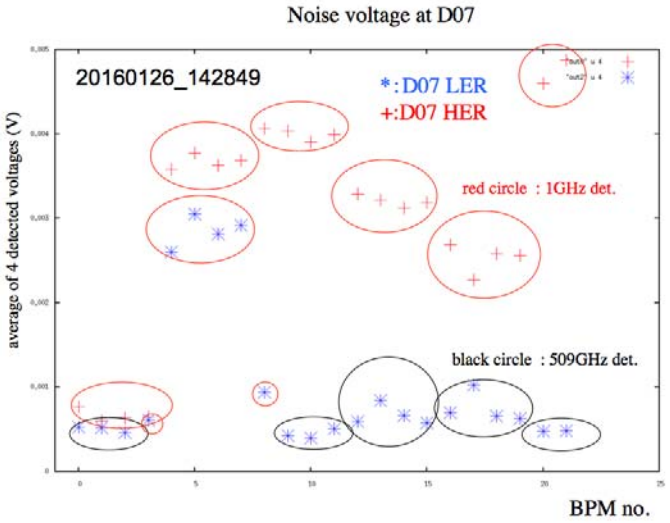
- **Cabling check**
  - Cabling was checked by beam because final cabling check was not done to reduce the cost.
  - Wrong cable connection was found at 25 BPMs, then corrected.
- **Position offset of BPMs**
  - Beam based alignment has been applied to get position offset between a BPM and the center of an adjacent quadrupole.
    - Sugimoto-san's talk ??

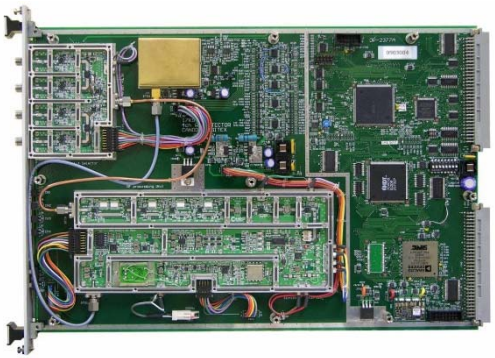
Obtained performance

- **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.
- **Stability of relative gain among four signal paths**
  - So called "consistency" is continuously monitored.
    - Consistency is defined as an rms value of 4 beam positions obtained by combination of 3 electrodes.
  - Consistencies are stable in LER where most feedthroughs and their cables are replaced.
  - Consistencies of some BPMs drifts or suddenly jumps in HER where old KEKB hardware (cable, FTs) are used.
  - Change of consistency is sometimes cured by cleaning of connectors and/or signal cables. Otherwise, the gain is to be calibrated again

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

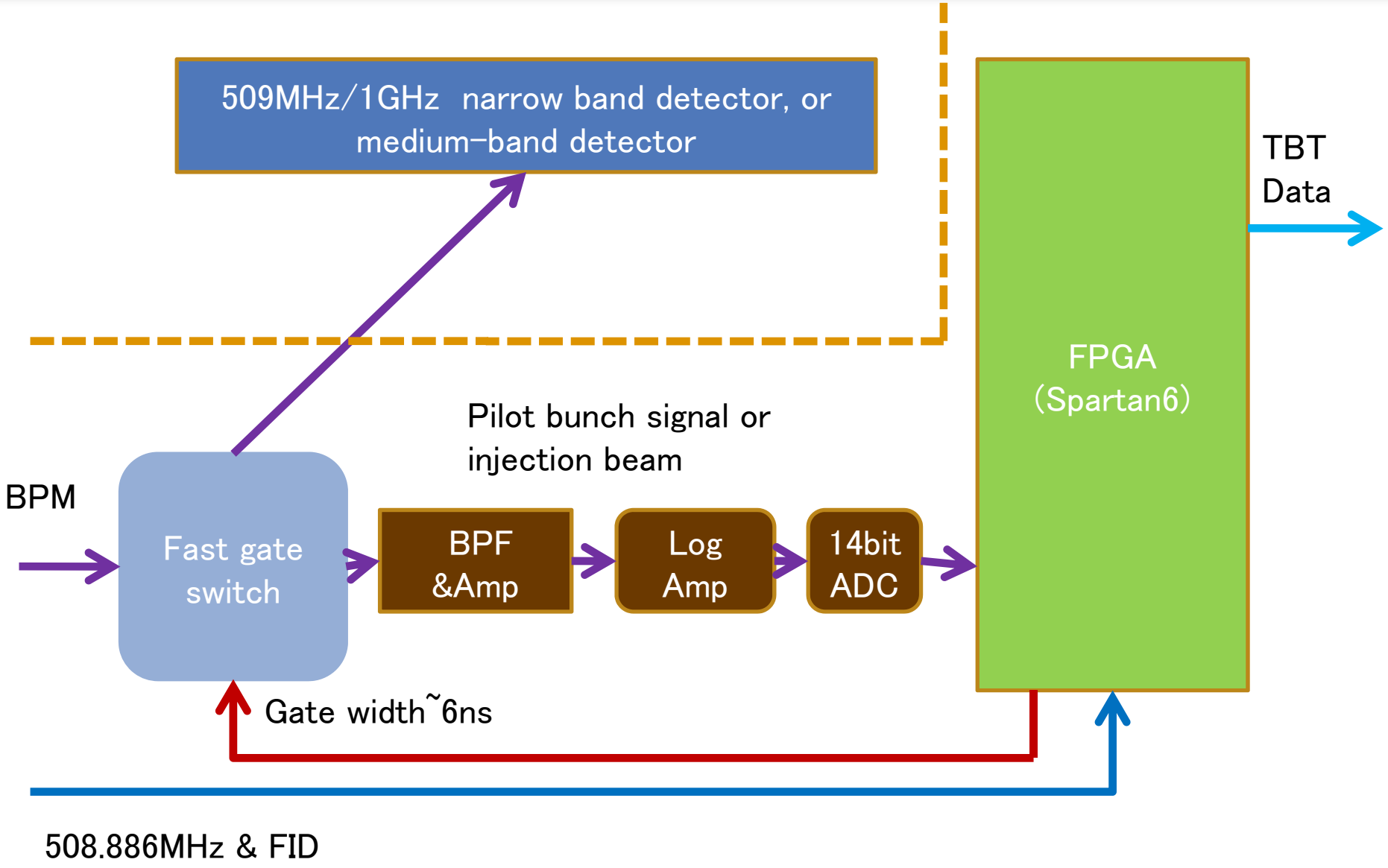




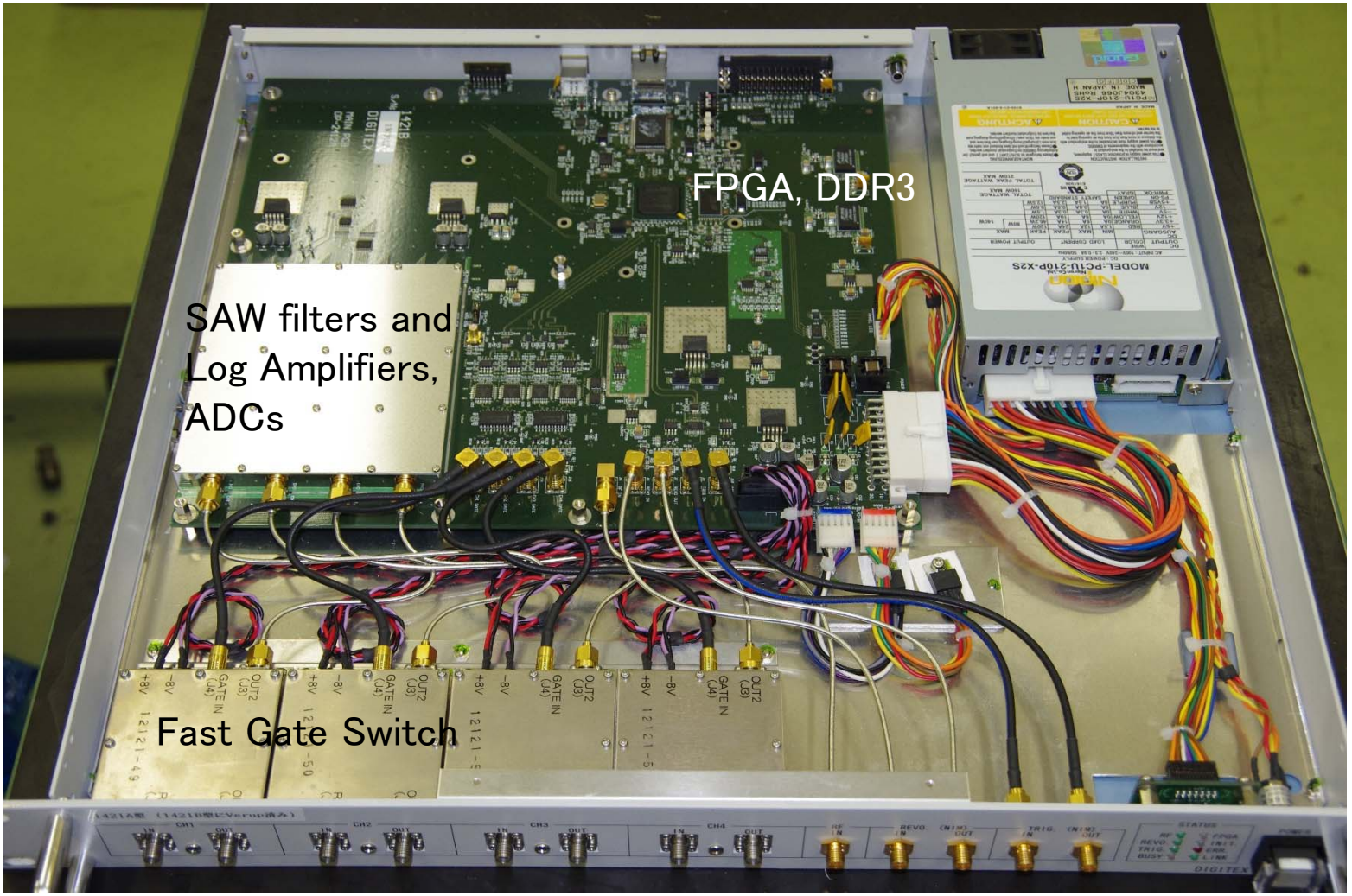
BPM troubles

- Two 509MHz detectors have shown very low level detection.
  - A disconnection was found in signal path in one of the detectors.
  - Another detector is being investigated. Probably an attenuator was not controlled correctly.
- Set up error of local oscillator's frequency was found at two 509MHz detectors, after rebooting.
- A damaged feedthrough was found at a LER BPM QD3P4.

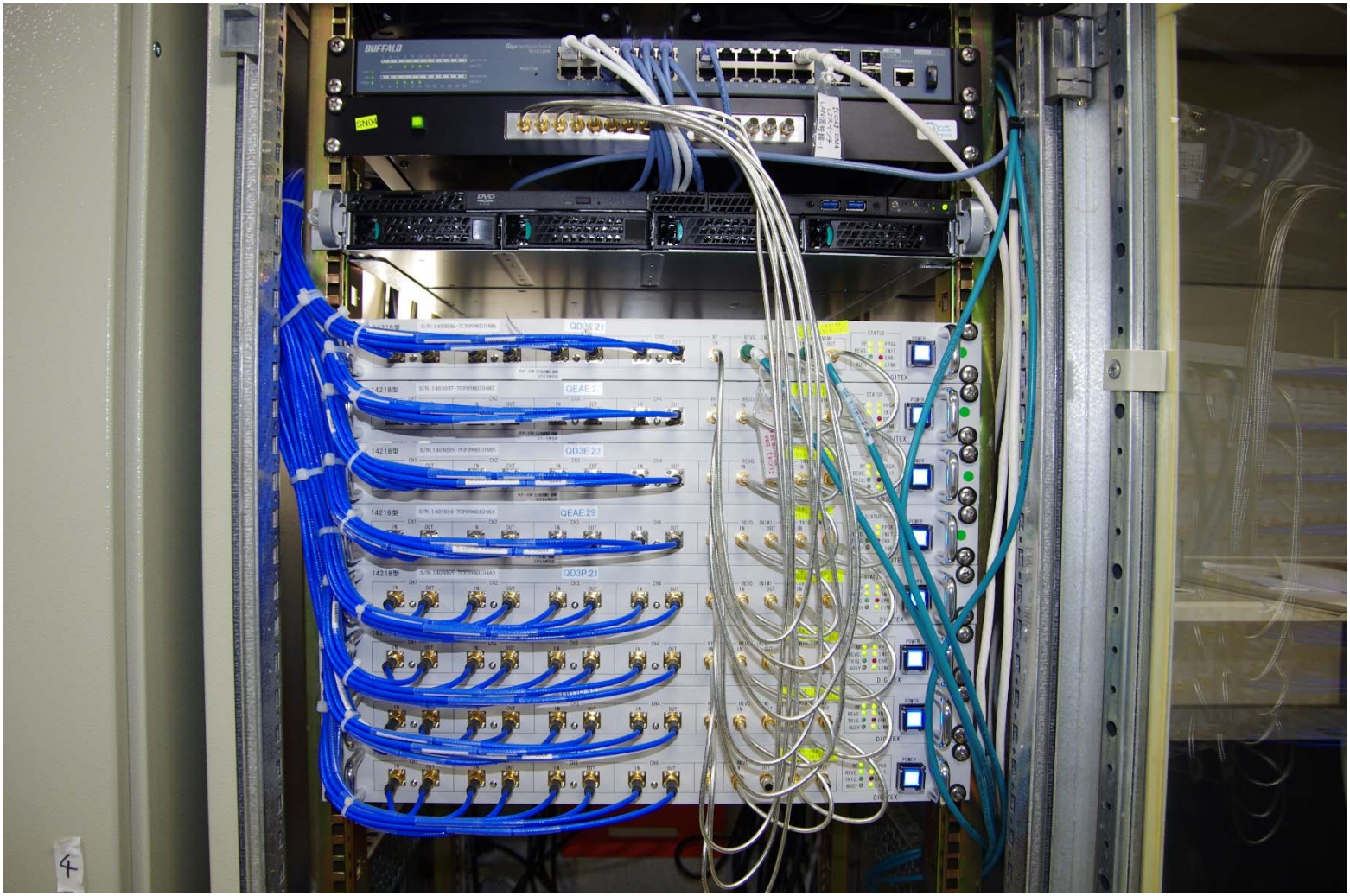
Gated turn-by-turn monitor



1421B Gated turn-by-turn monitor

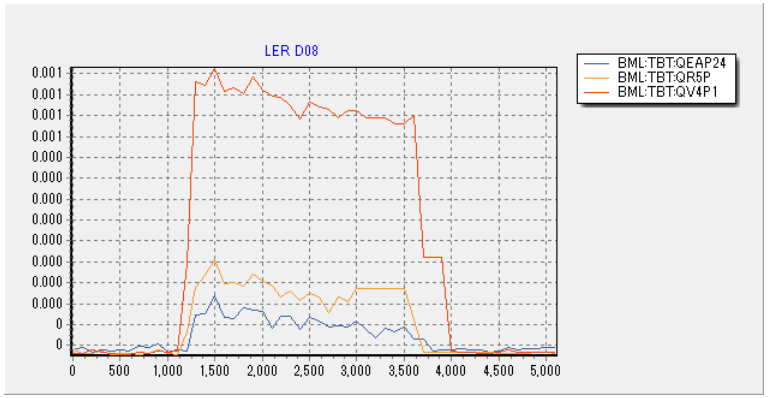


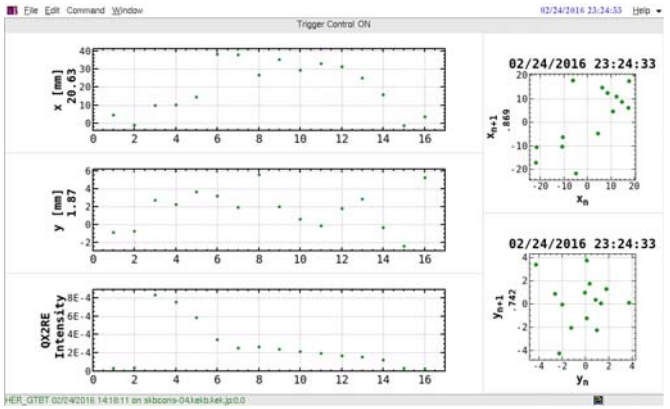
117 units have been installed



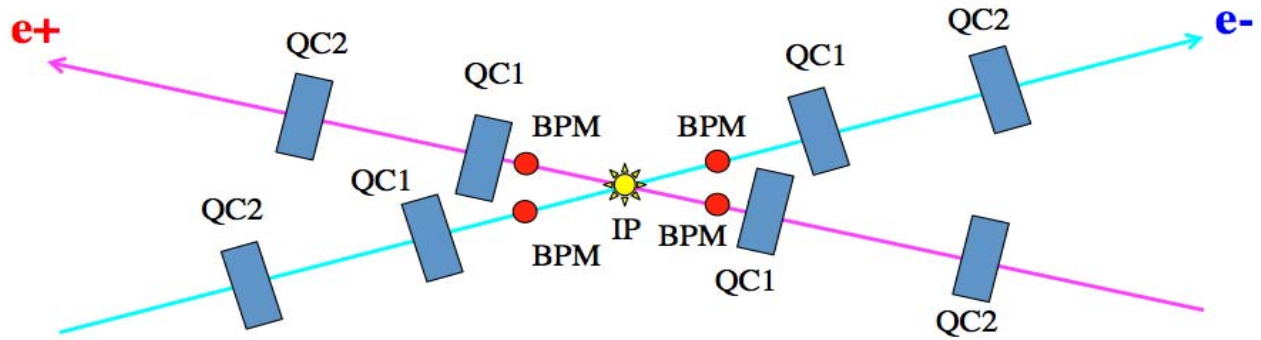
Commissioning of GTBT

- **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.**
  - Ready to use with fast gate mode.

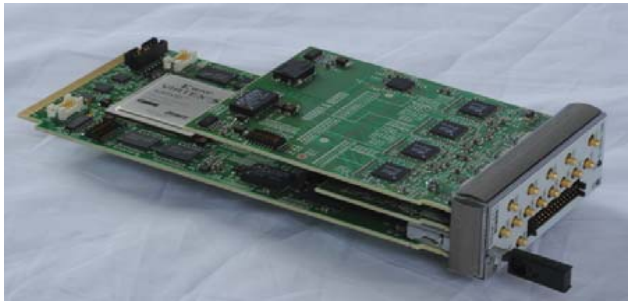


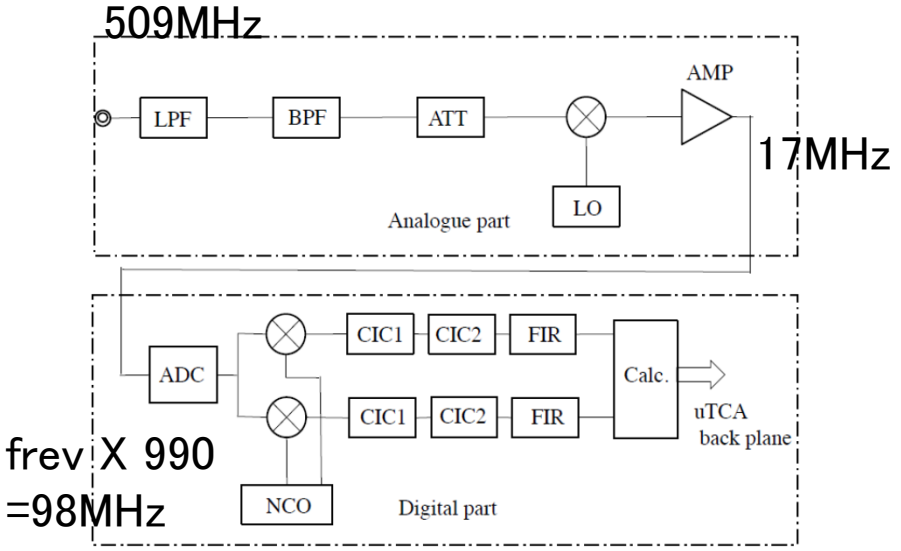


IP orbit feedback detector (bb kick)



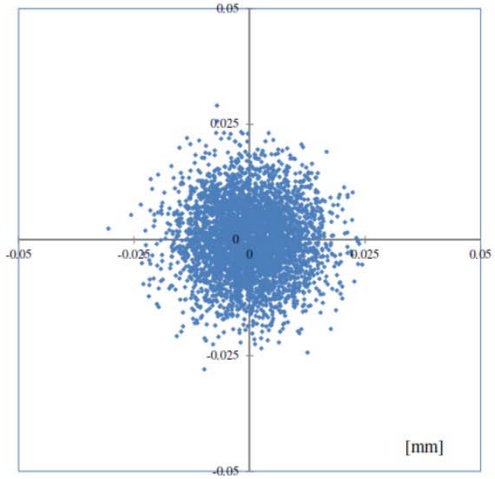
- **Specification**
  - Resolution <1um
  - Repetition 32 kHz
  - Bandwidth <100 Hz (FB)

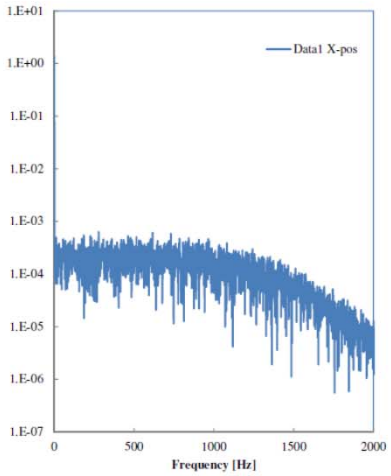


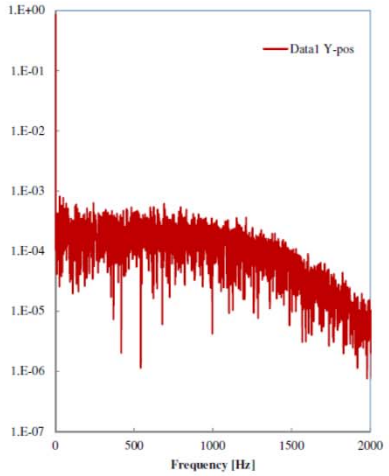



ORBIT FEEDBACK BEAM POSITIONING MONITOR
DOWN CONVERTER UNIT
AMTEL
AMTEL
AMTEL

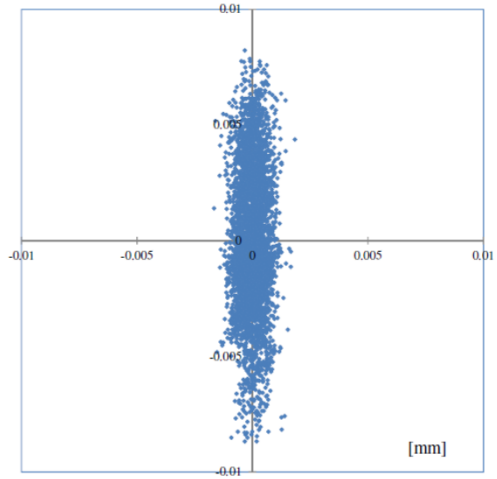
Preliminary data(LER)

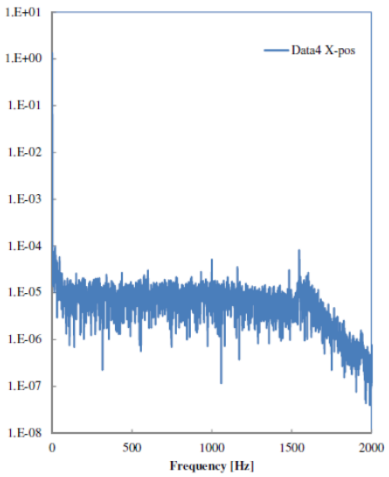


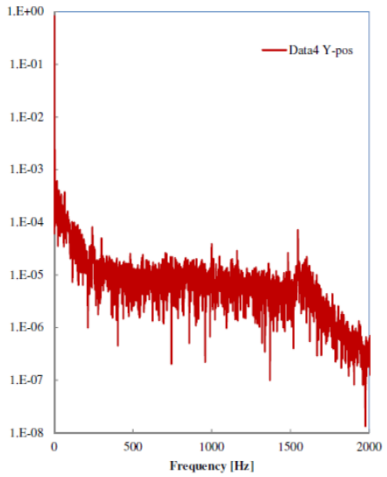




29mA



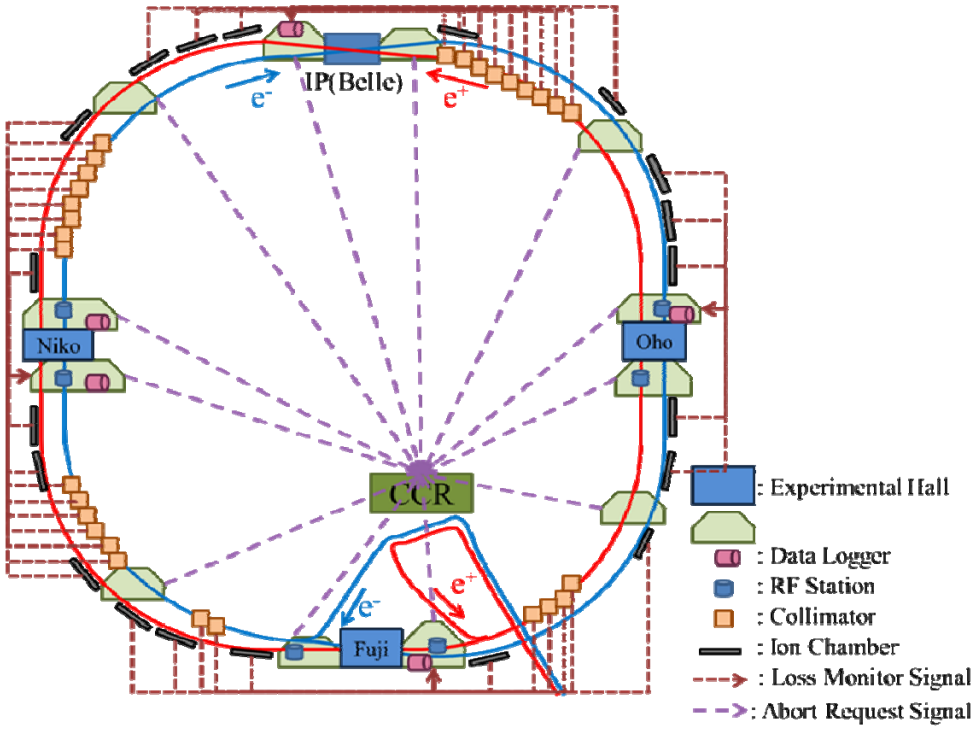


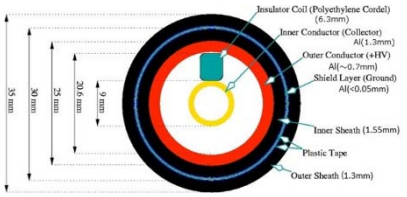


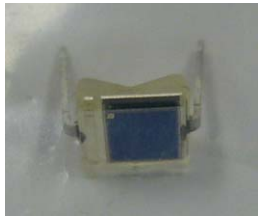
779mA

Loss Monitor

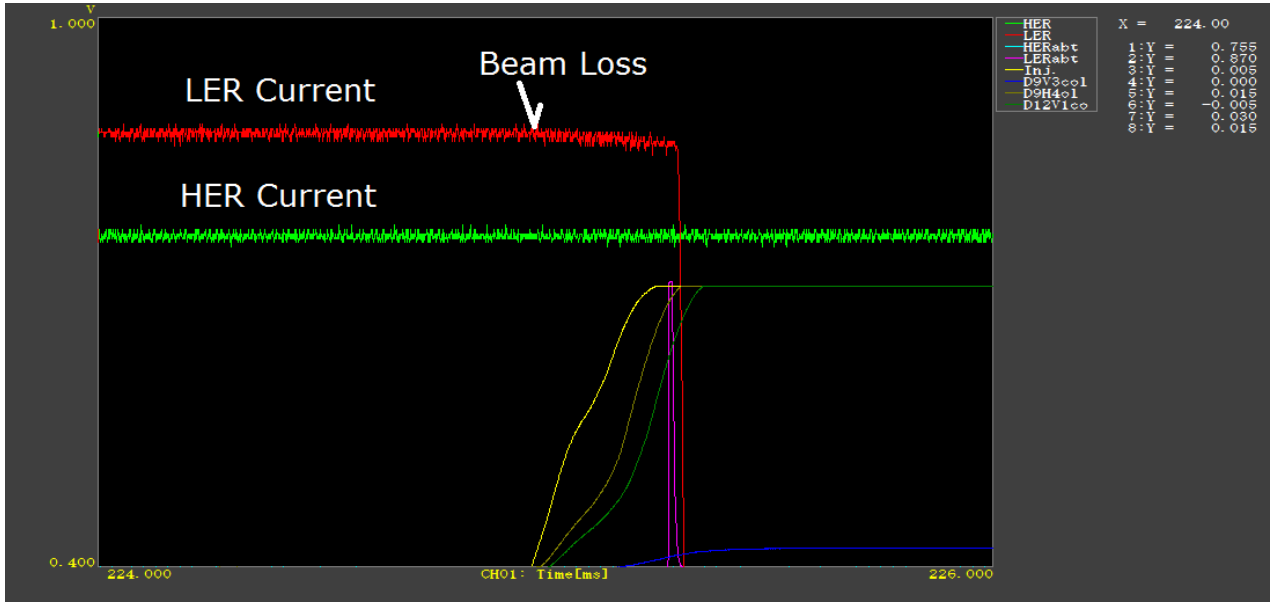
- We use beam loss monitors for protection of the hardware against unexpected sudden beam losses. The loss monitor system provides an trigger to the beam abort system.
- The sensors are ion chambers (32) and PIN photo-diodes (114).
- We optimize the threshold of the abort trigger and the PIN position by checking the beam information at each abort event.







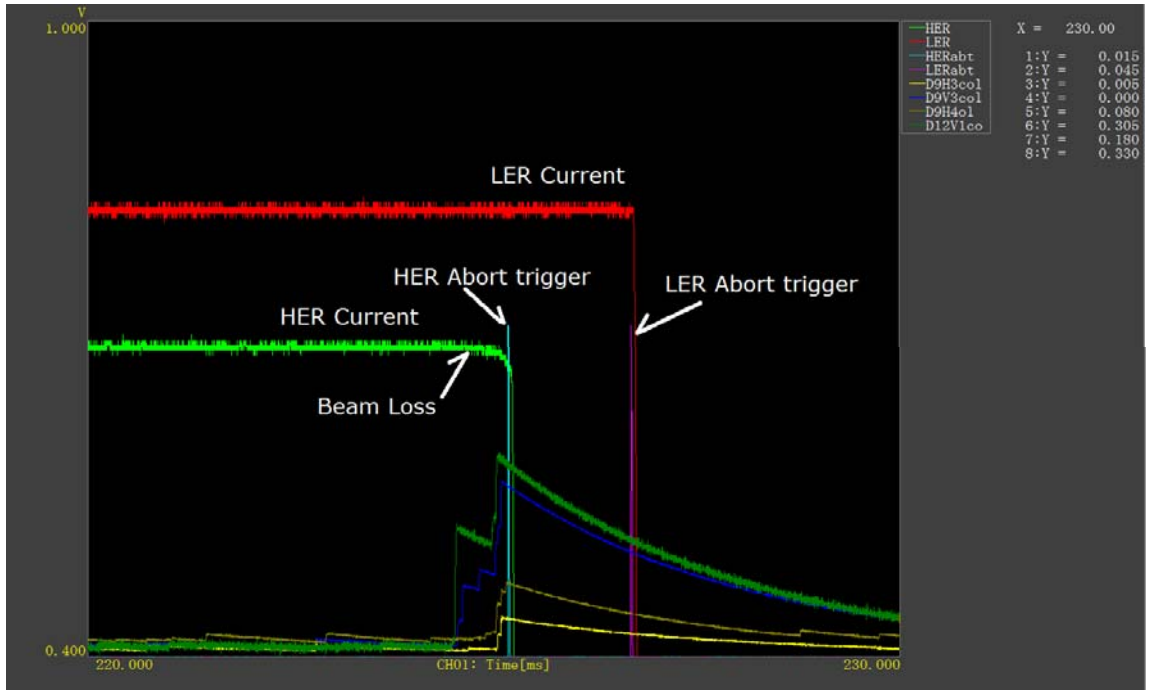
Loss Monitor : ex.1 LER Beam Loss



LER Vacuum Spike
↓
LER Beam Loss
↓
LM (PIN @ injection point) Abort
↓
LER Beam Abort

It takes ～300 μ s

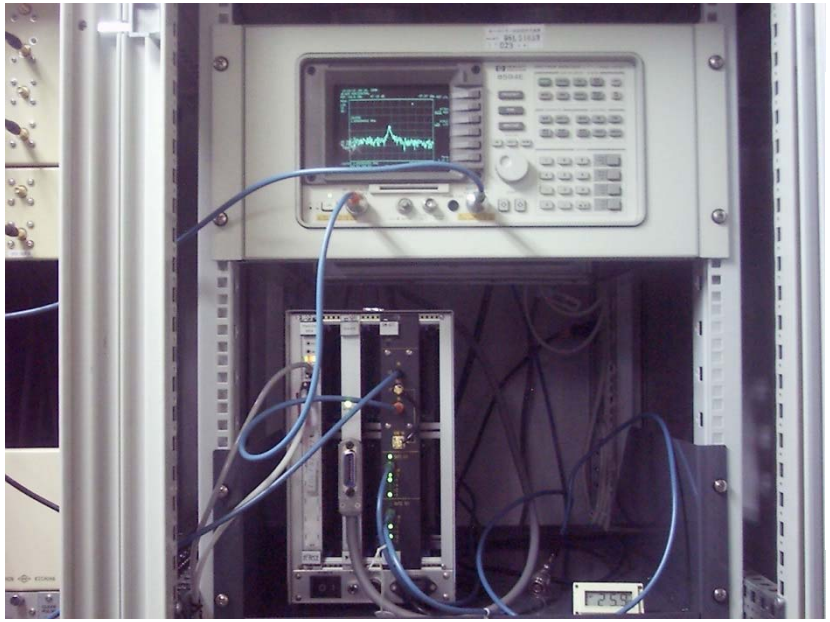
Loss Monitor : ex.2 HER Beam Loss

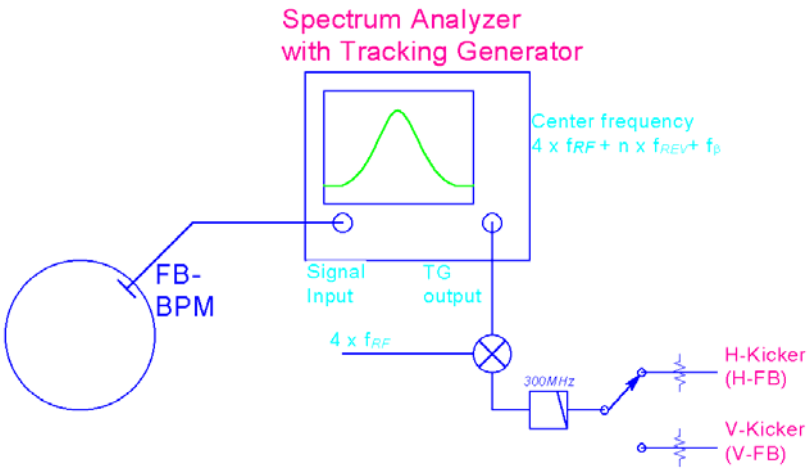


HER Vacuum Spike
↓
HER Beam Loss
↓
LM (PIN @ injection point) Abort trigger
↓
HER Beam was aborted after 600 μ s after beam loss started.
↓
LM (IC) Abort trigger
↓
LER beam was aborted 1.5ms after HER Abort.

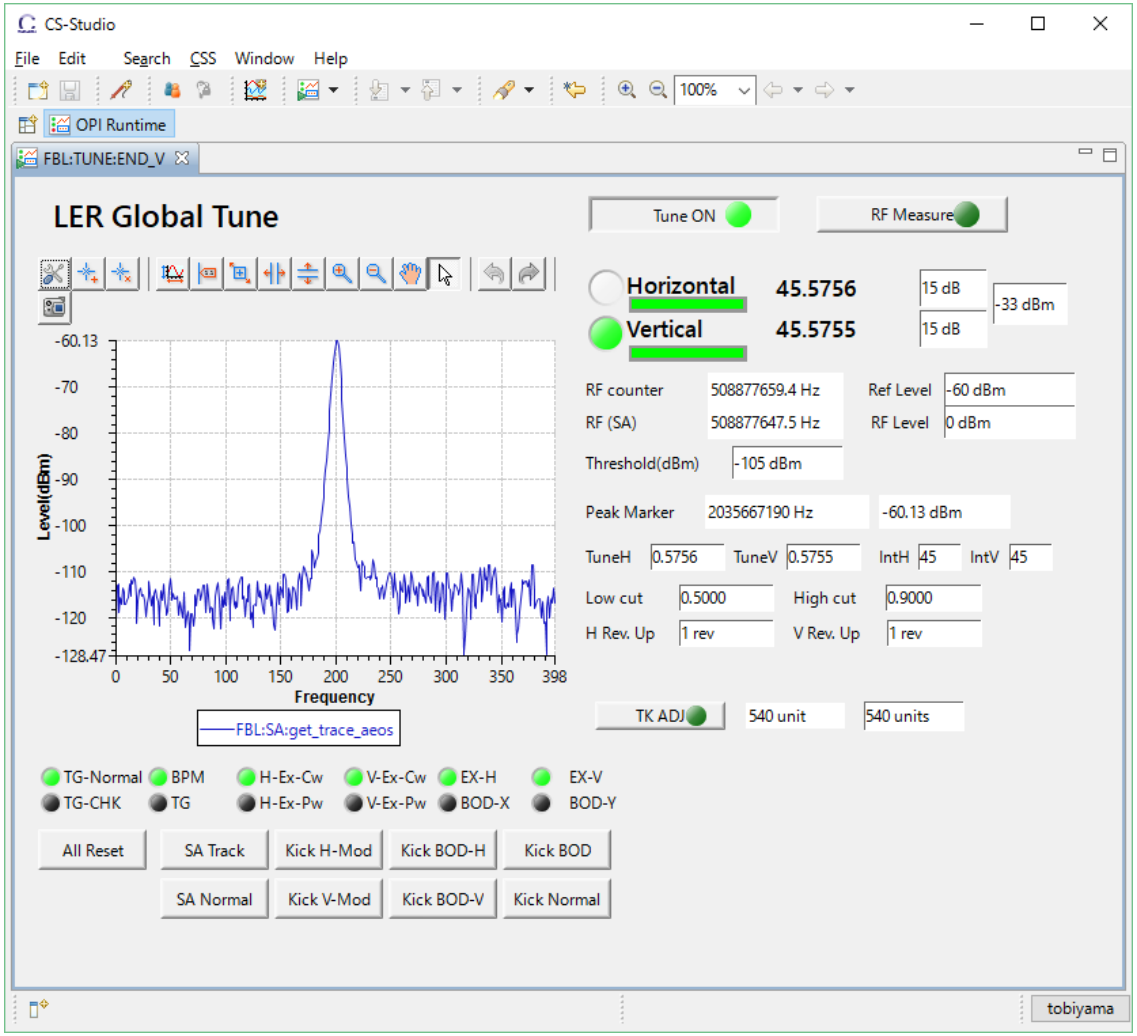
Betatron Tune measurement

- Global tune measurement for multi-bunch, small beam current
- Gated tune measurement for pilot (or selected) bunch only
- PLL excitation of the pilot bunch using iGp12

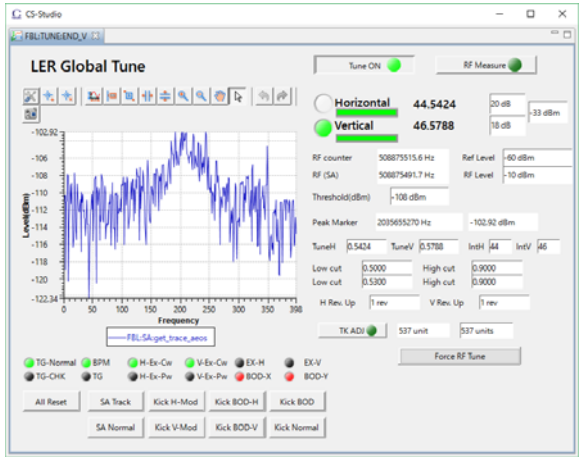




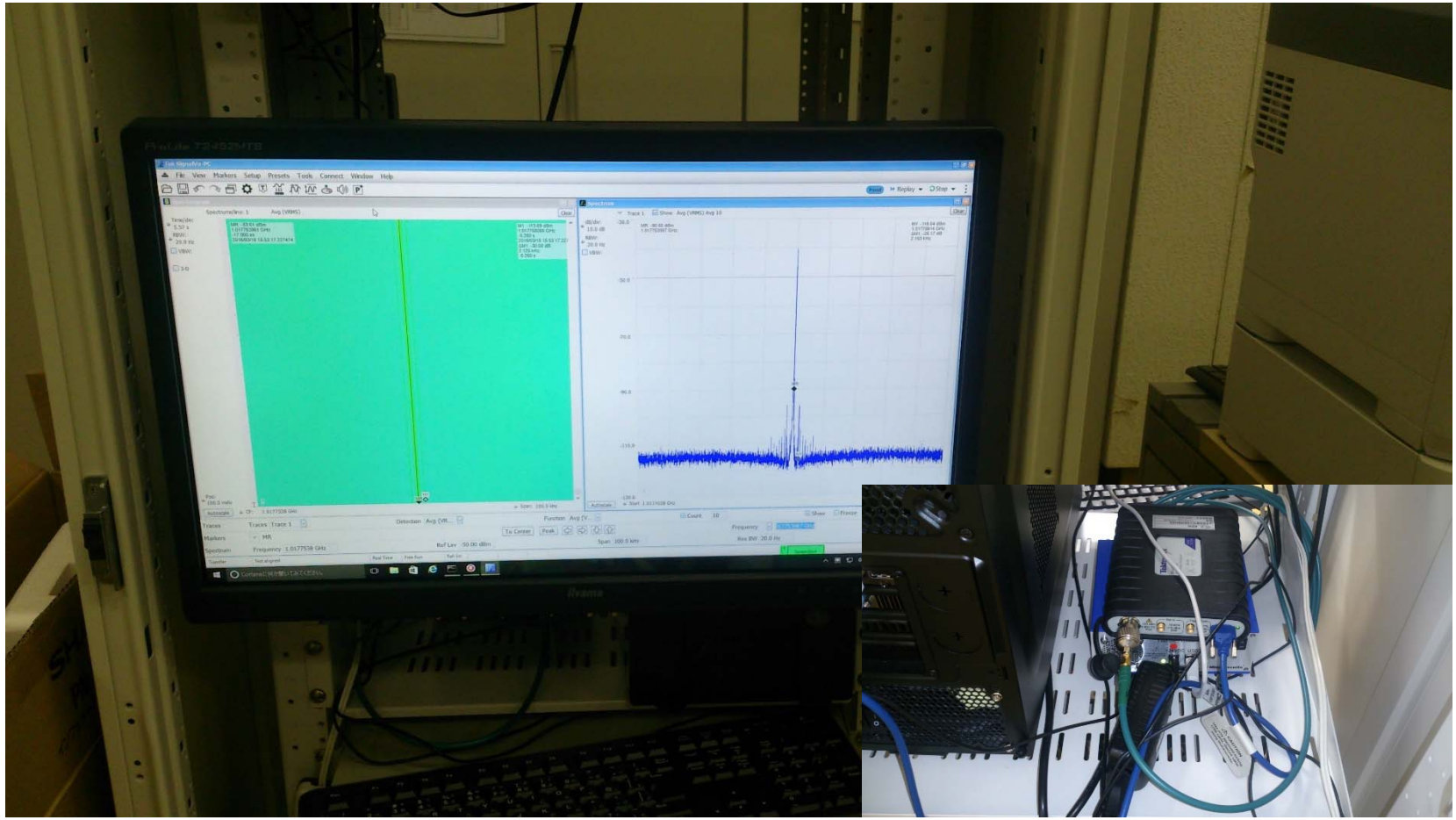
Tune measurement system



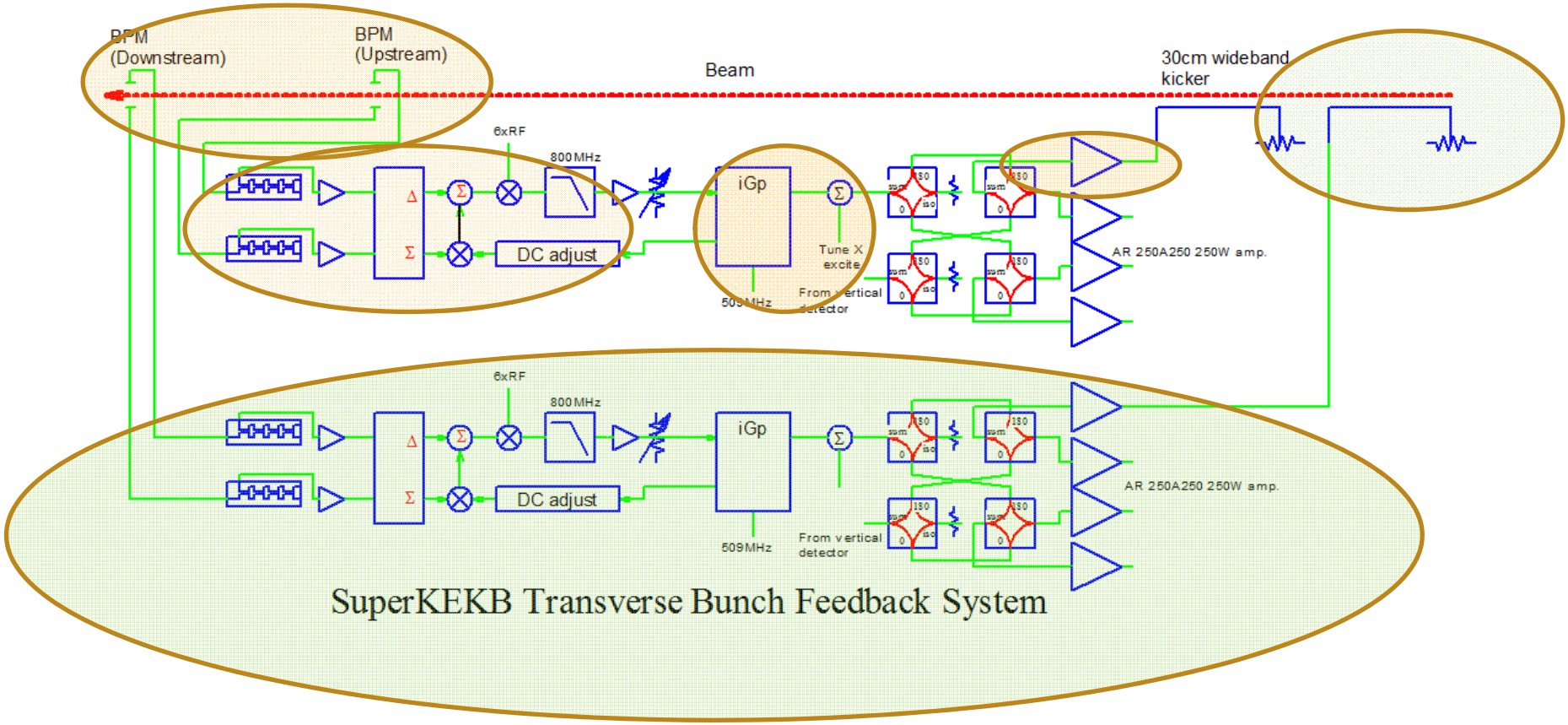
- Due to large feedback gain, the beam response at large beam current has been strongly damped.



Beam Spectrum @ CCR

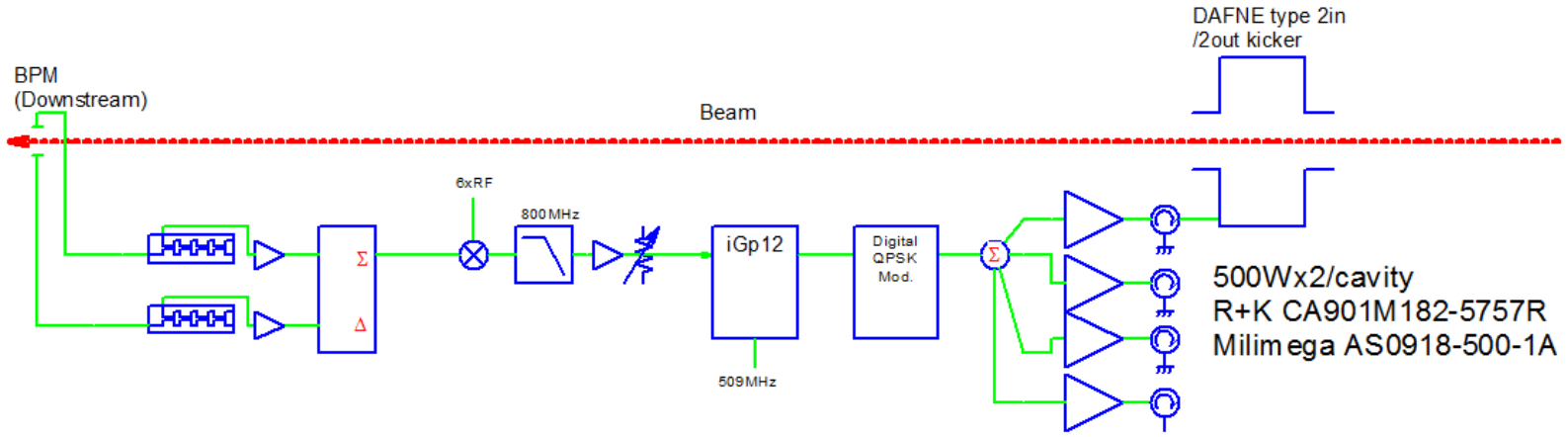


SuperKEKB Transverse FB systems

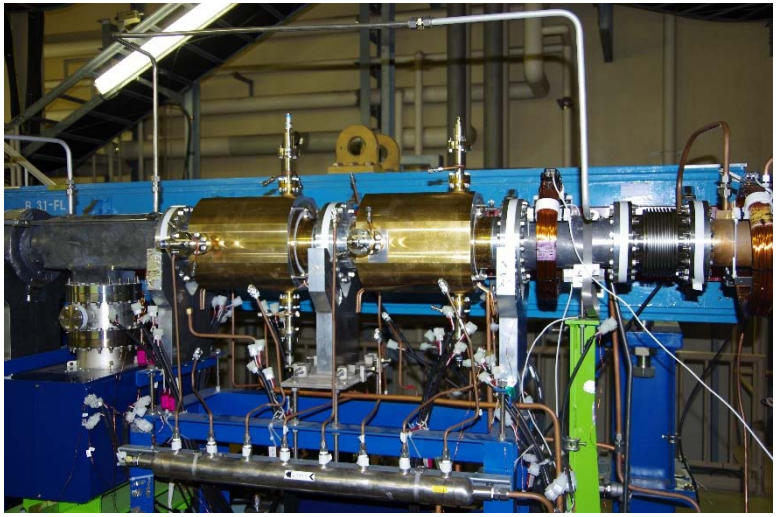


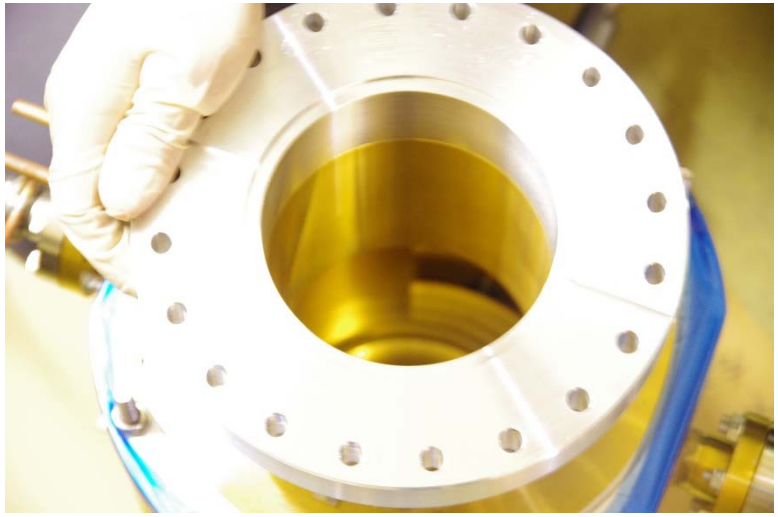
Collaborating SLAC(US-Japan) and INFN-LNF(KEK-LNF)

SuperKEKB Longitudinal FB system

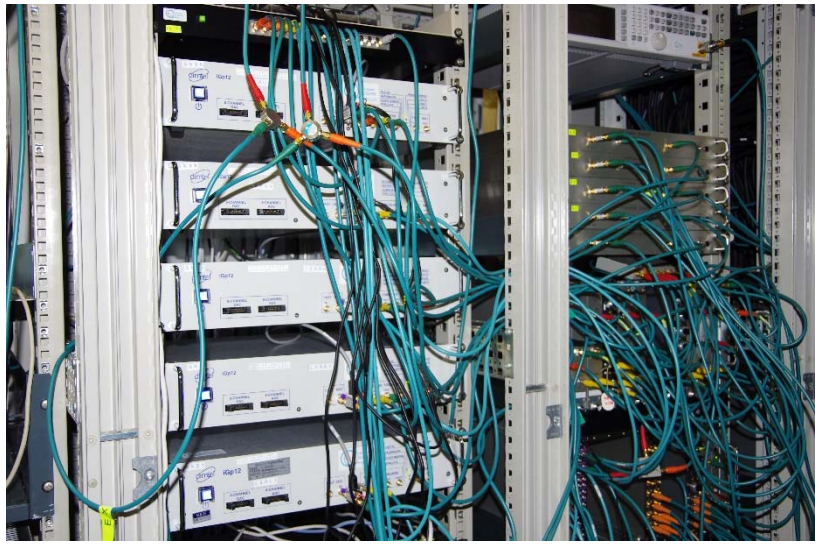


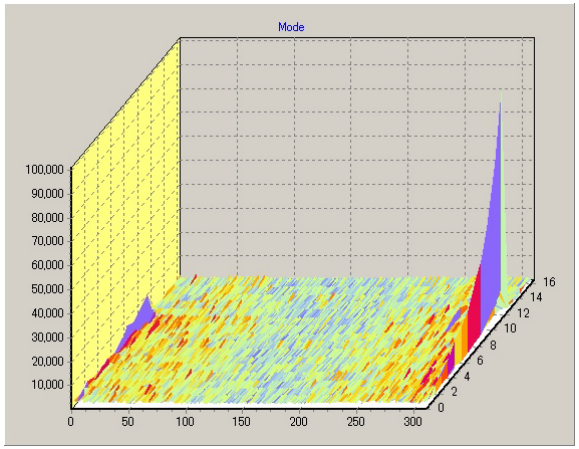
SuperKEKB Longitudinal Bunch Feedback System





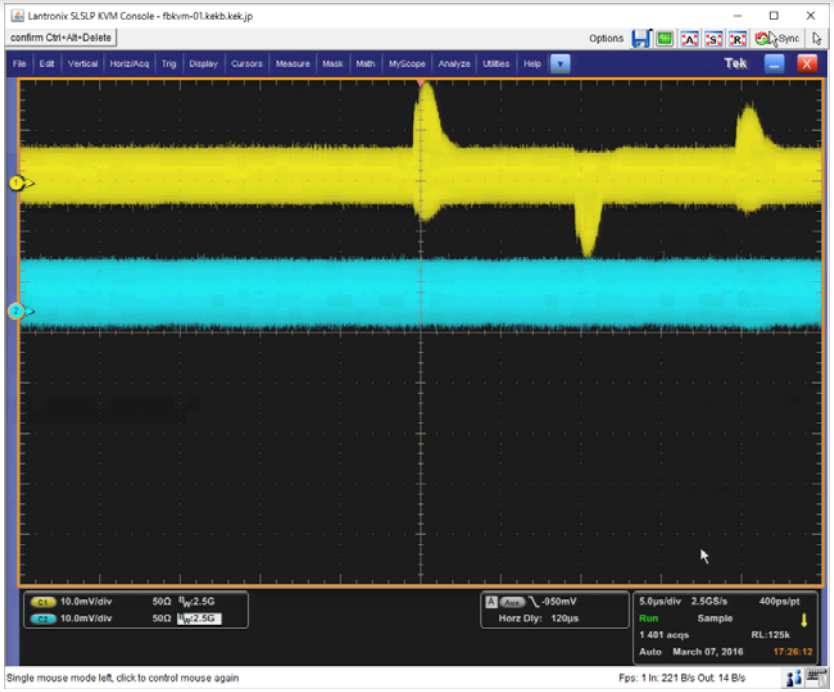
iGp12 digital feedback filter

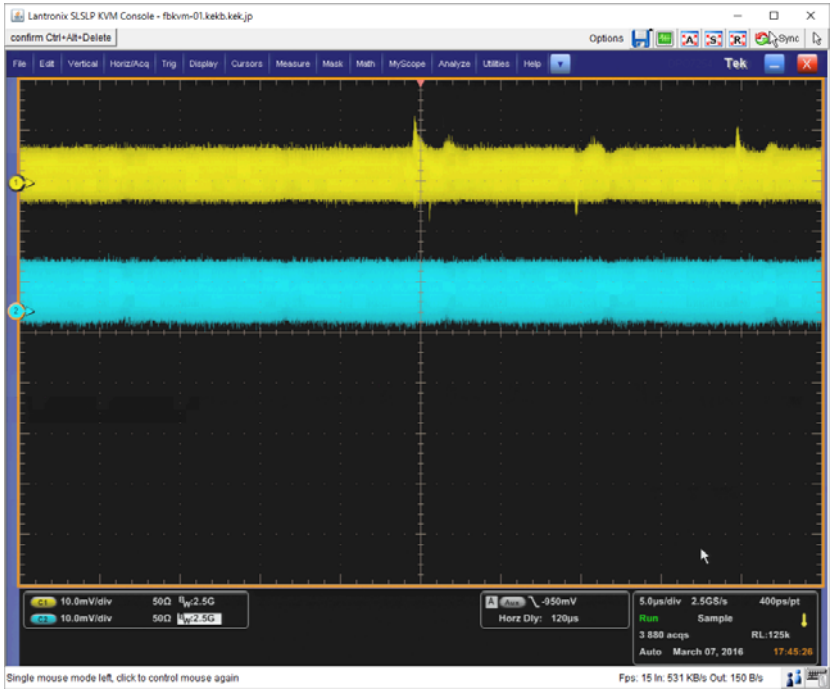




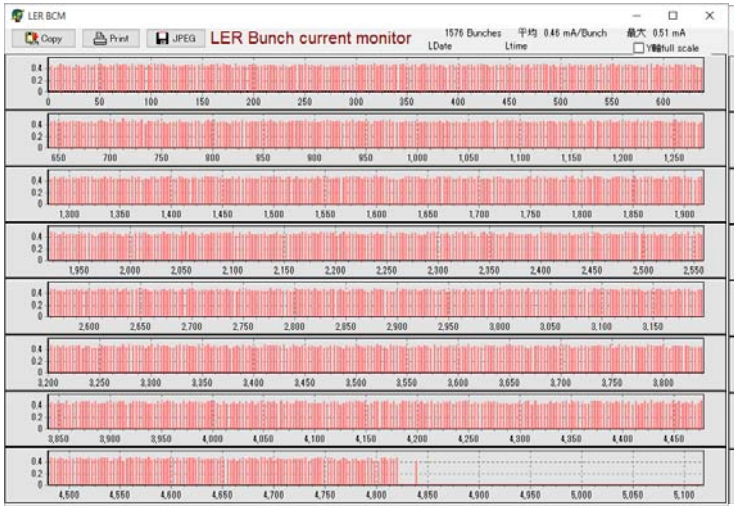
- **Successor of iGp digital filters developed under US-Japan collaboration with SLAC.**
  - 12bit ADC/DAC
  - 10 – 20 tap FIR filter
  - 12MB memory to analyze instabilities
- **10 iGp12s are used**
  - 8 with larger FPGA (VSX95T)
  - 2 with normal FPGA (VSX50T)
- **Single bunch excitation using PLL**

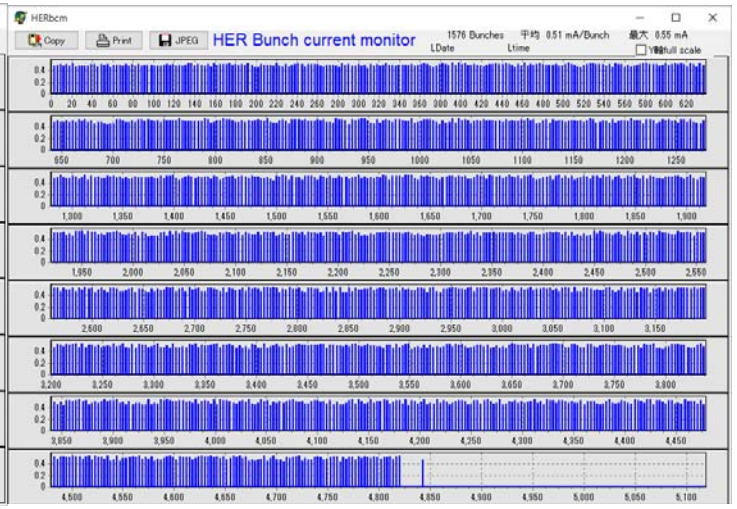
Injection kicker adjustment using FB detector





Bunch current monitor





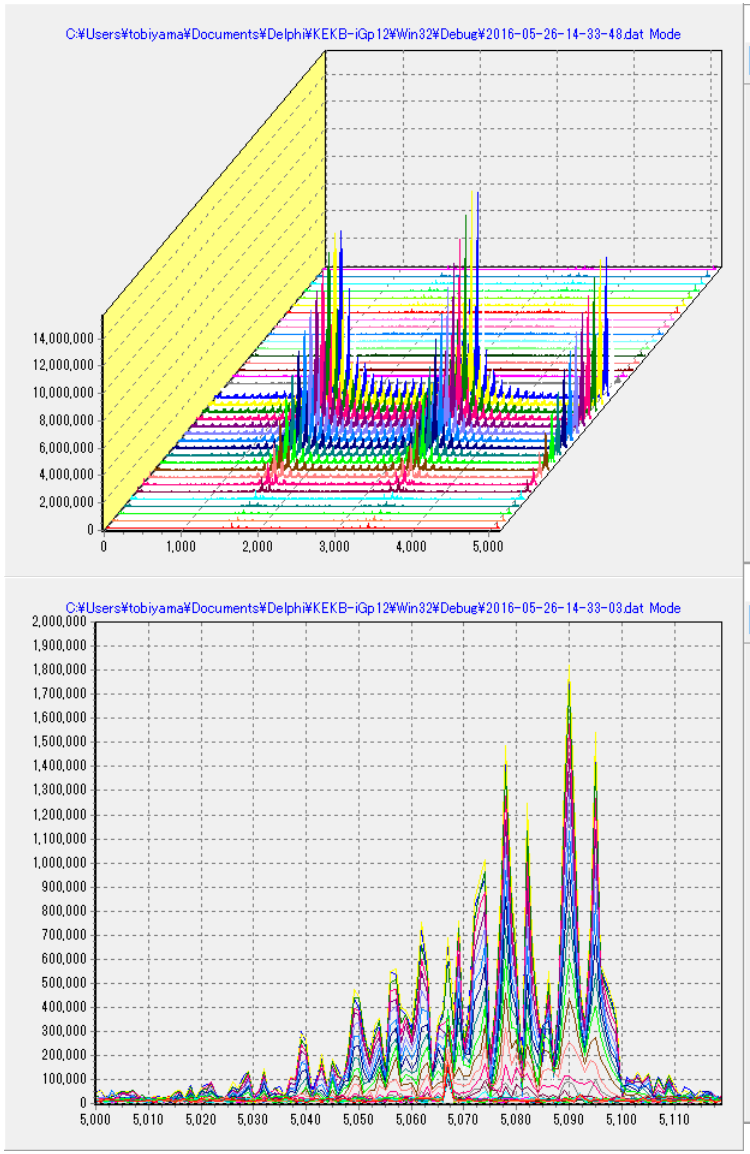
MAX108 8bit ADC
Spartan6 FGPA
VME 2W size

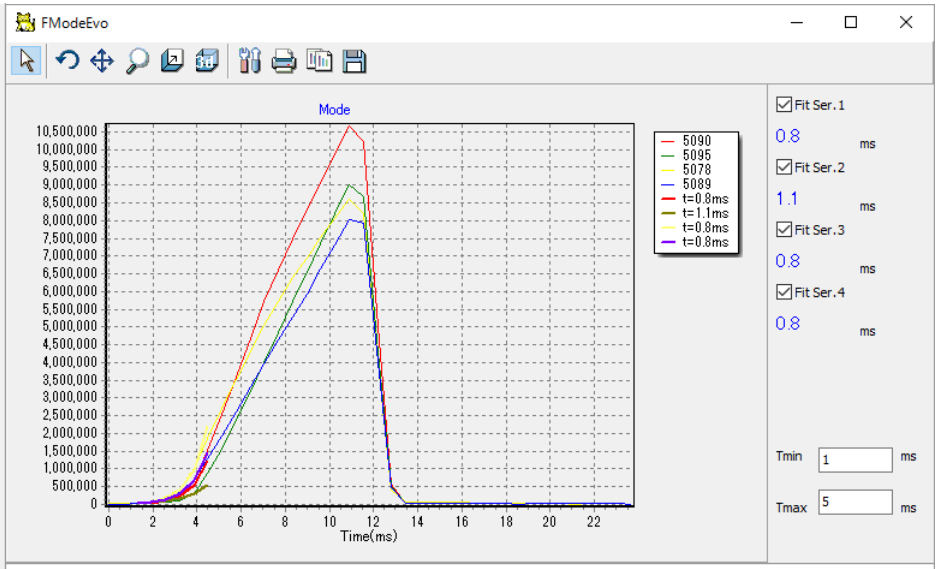
Bunch current information is sent through reflective memory (real-time) to the bucket selection system at linac during injection period(<20ms).

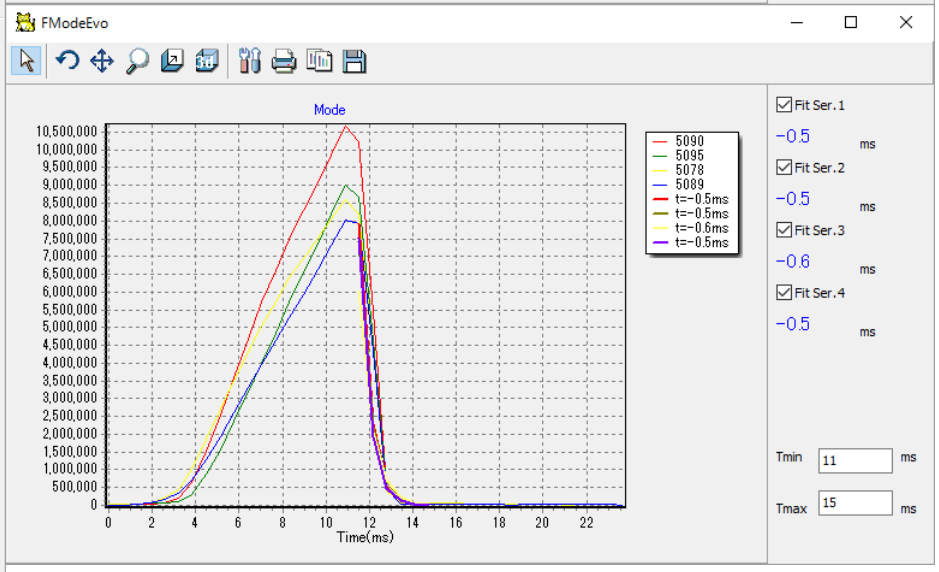
Performance

- **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)

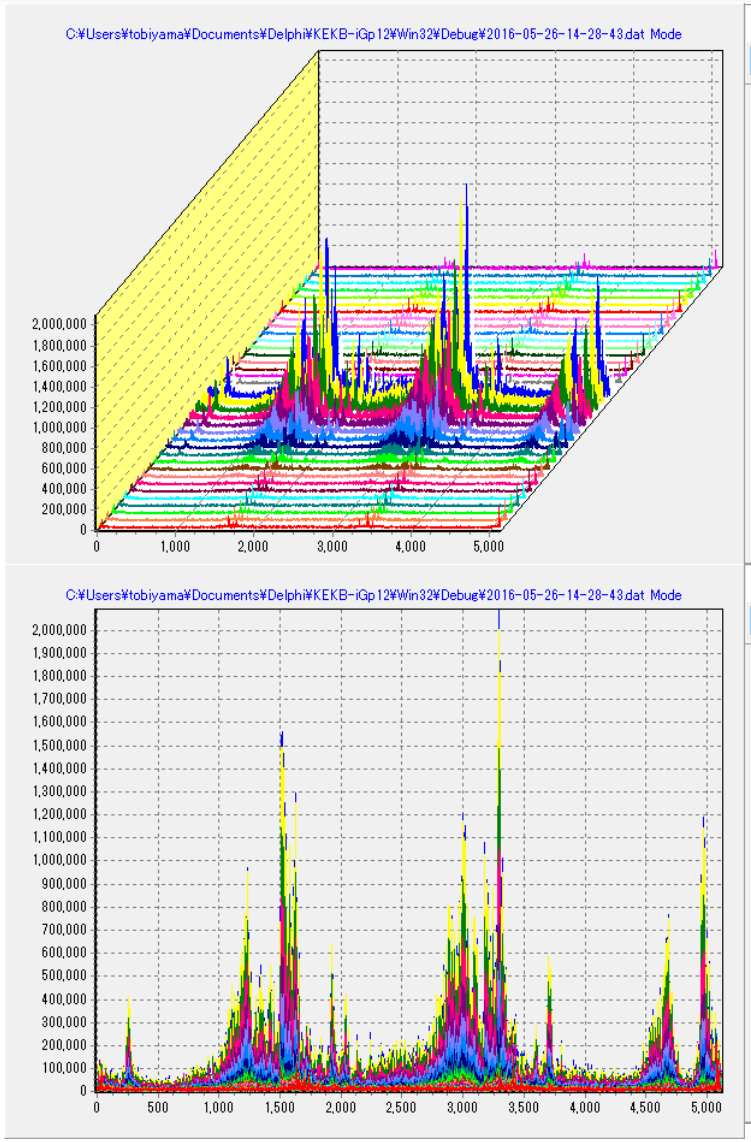
Example of G-D experiment(HER-H)







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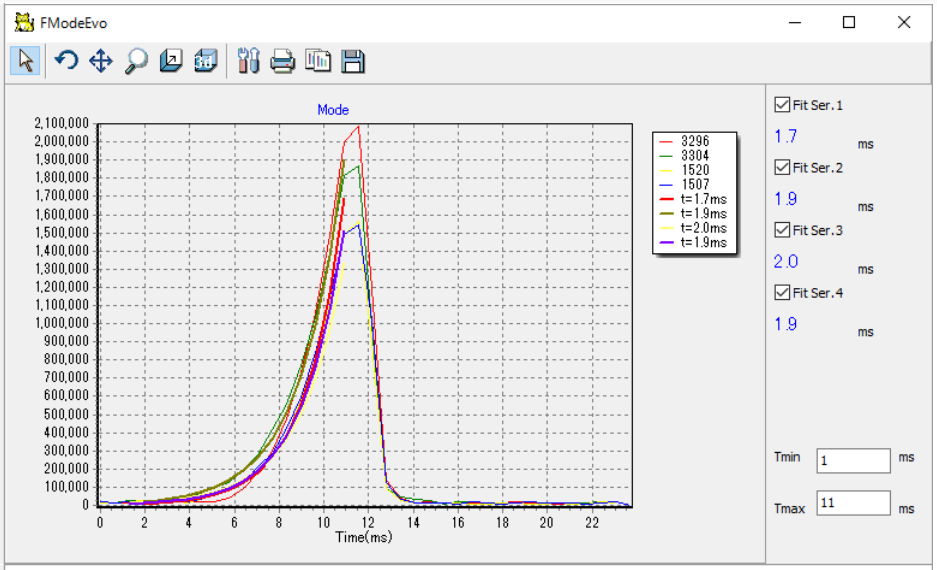
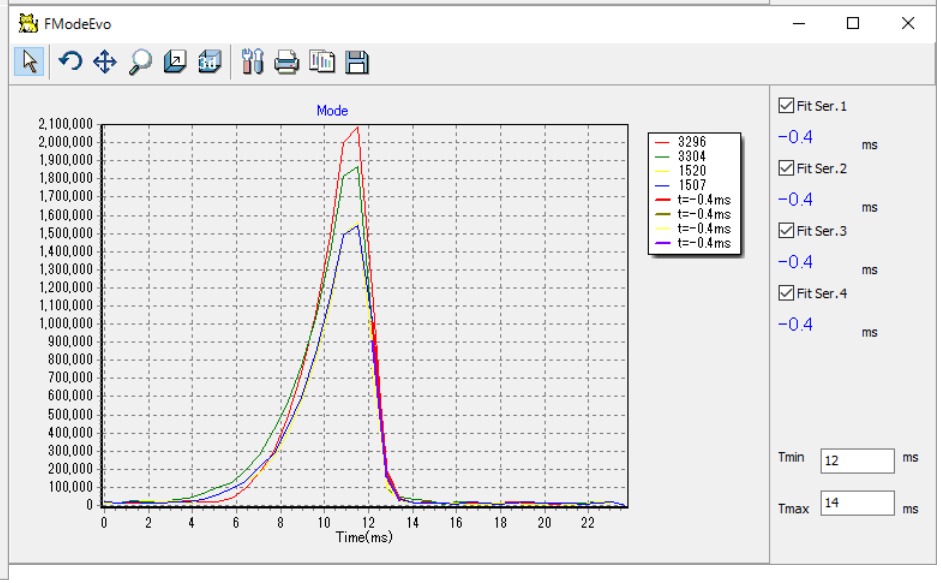
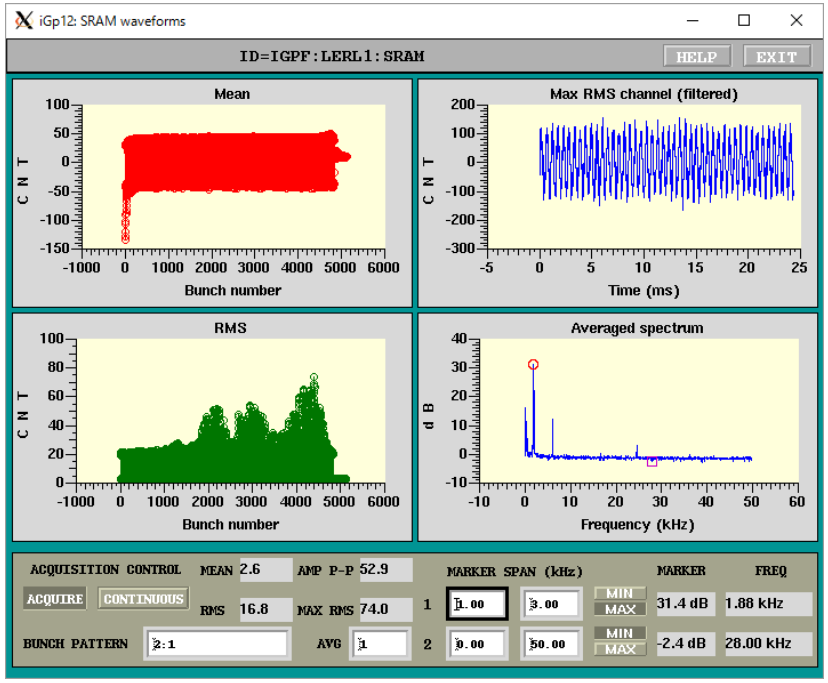
C:¥Users¥tobiyama¥Documents¥Delphi¥KEKB-iGp12¥Win32¥Debug¥2016-05-26-14-28-43.dat Mode

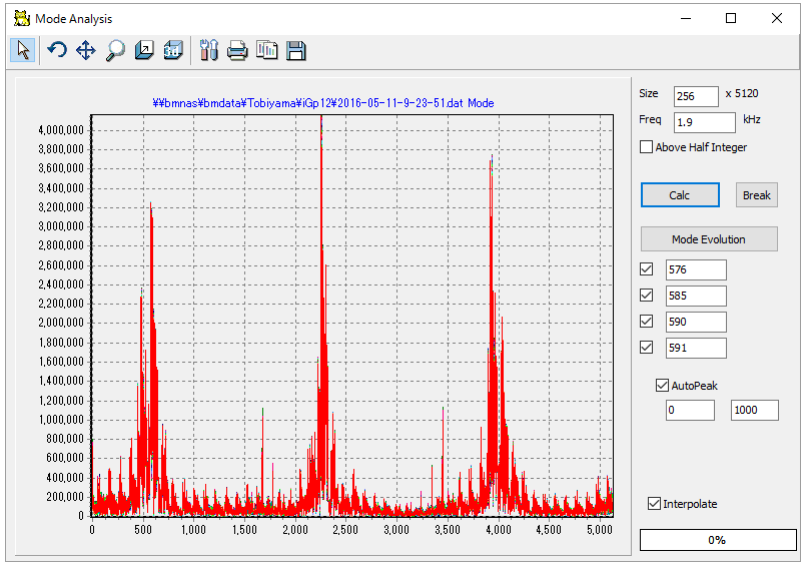

FModeEvo
Mode
3296
3304
1520
1507
t=1.7ms
t=1.9ms
t=2.0ms
t=1.9ms
Fit Ser.1
1.7 ms
Fit Ser.2
1.9 ms
Fit Ser.3
2.0 ms
Fit Ser.4
1.9 ms
Tmin 1 ms
Tmax 11 ms
Time(ms)


FModeEvo
Mode
3296
3304
1520
1507
t=-0.4ms
t=-0.4ms
t=-0.4ms
t=-0.4ms
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
Time(ms)

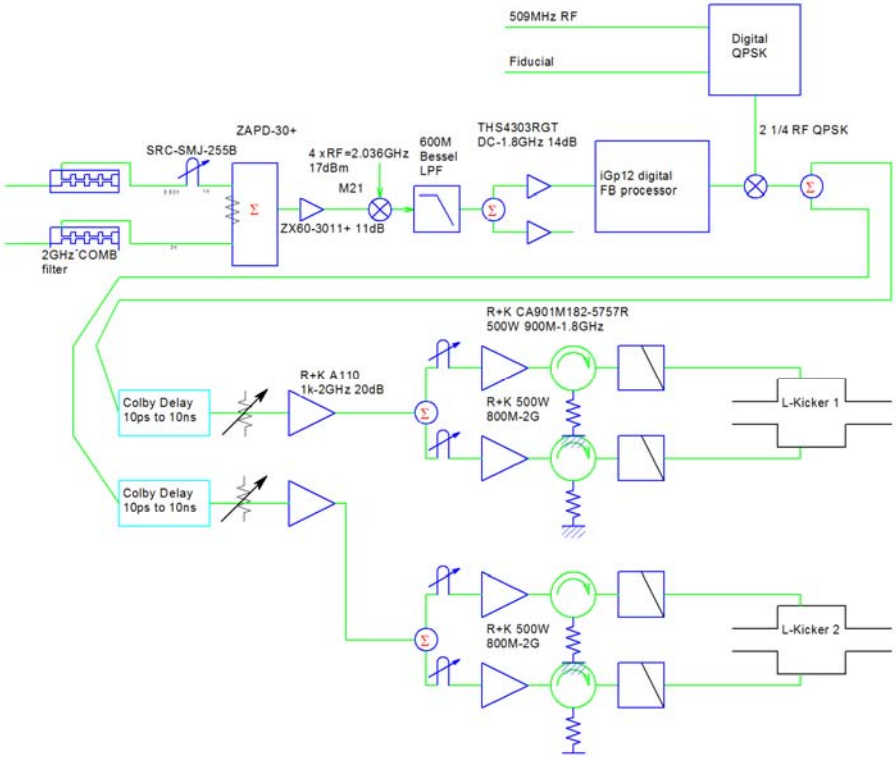
LER longitudinal FB

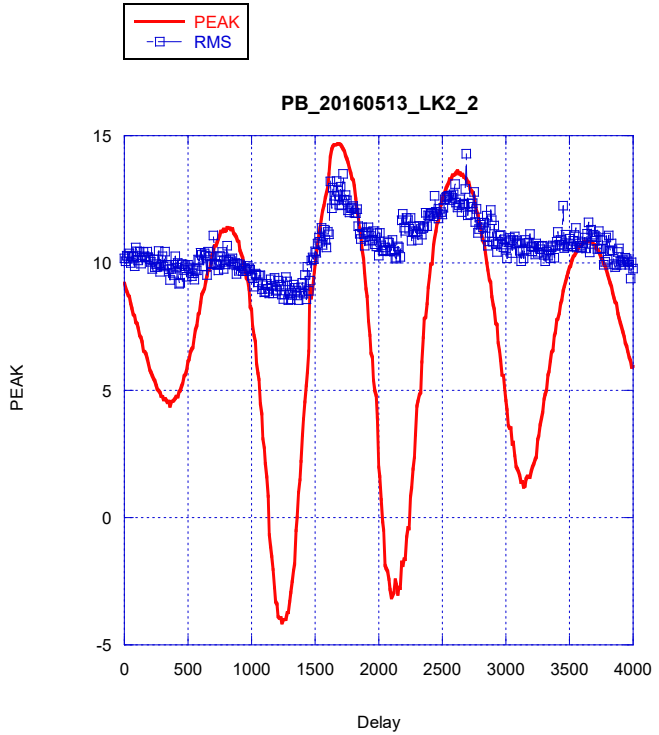
- Longitudinal instability starting with beam current >660mA with by 3 mode.
- Wide modes around 500?



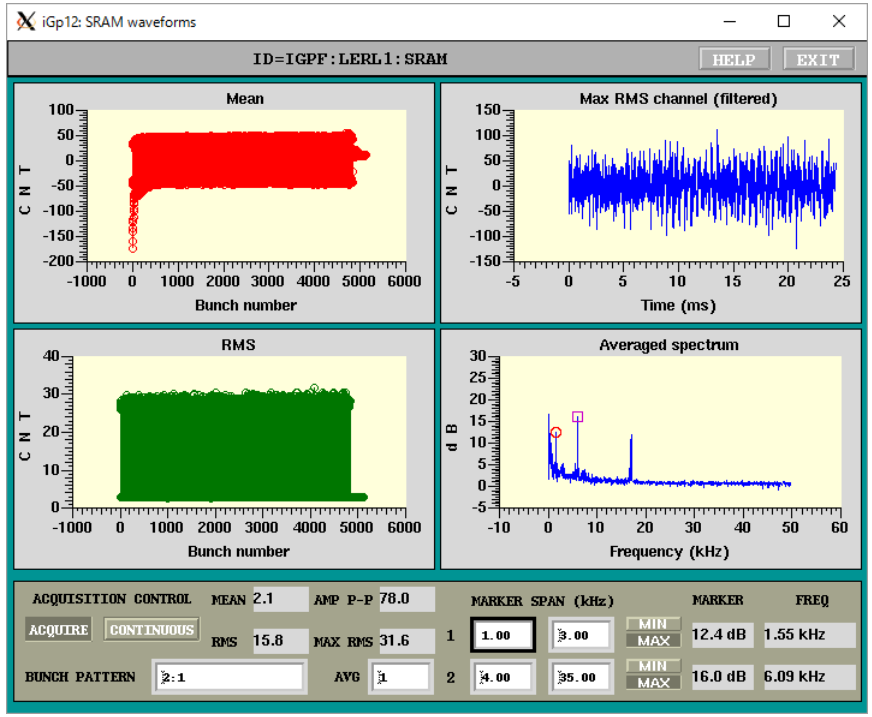


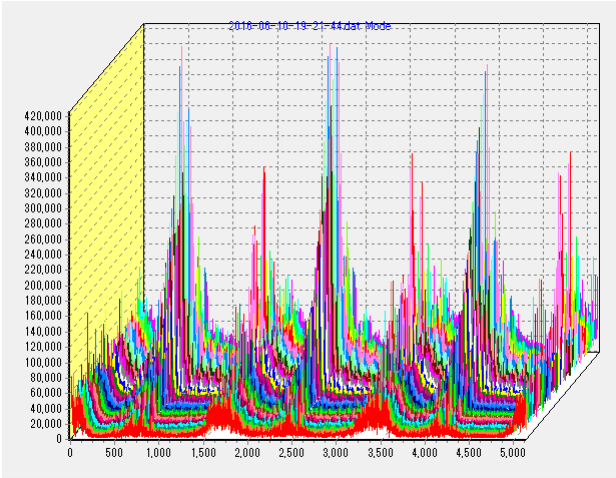
Tuning of LFB

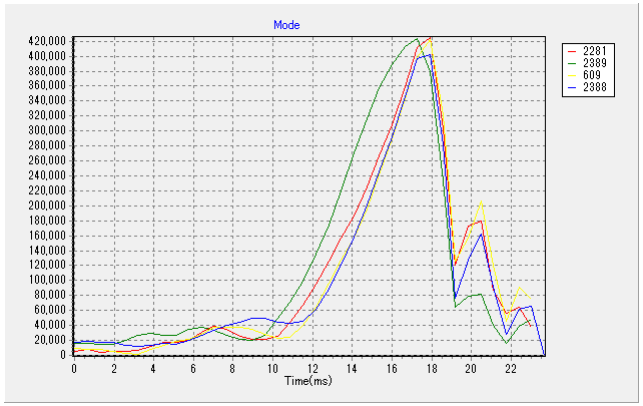




Successfully suppressed instability





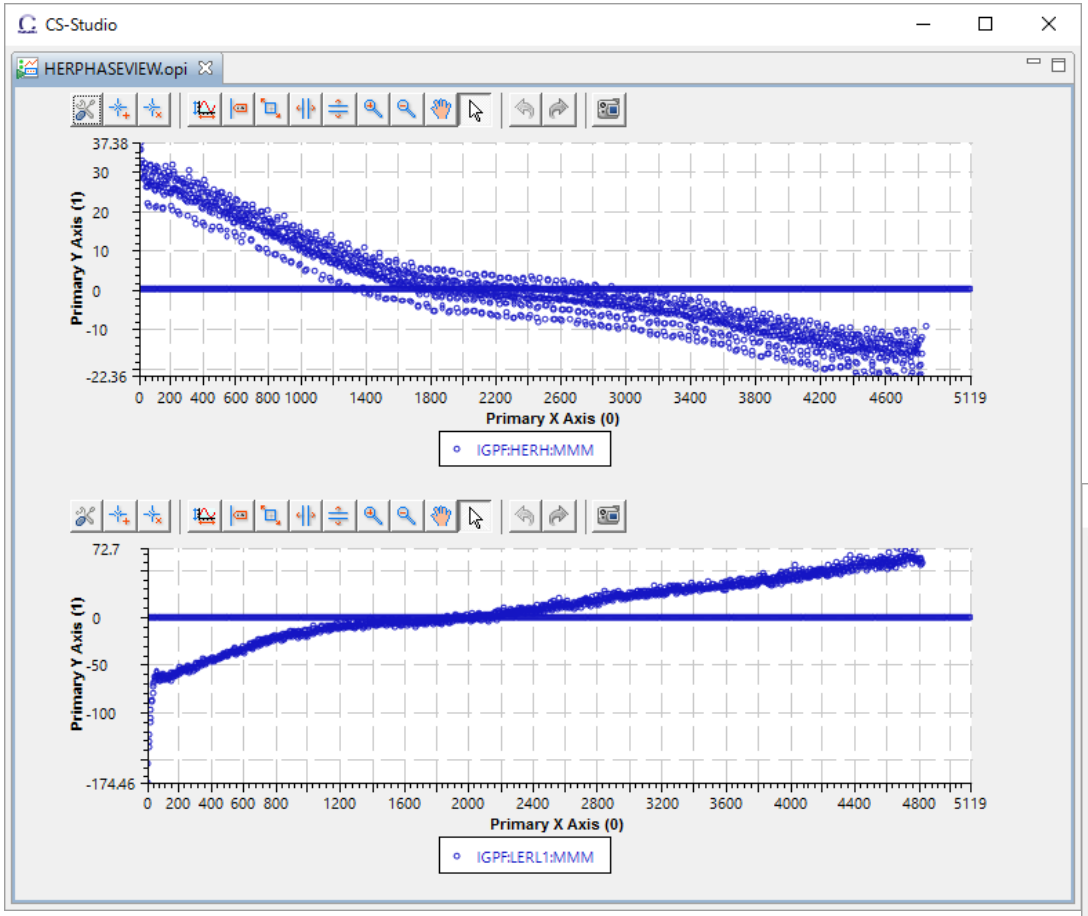


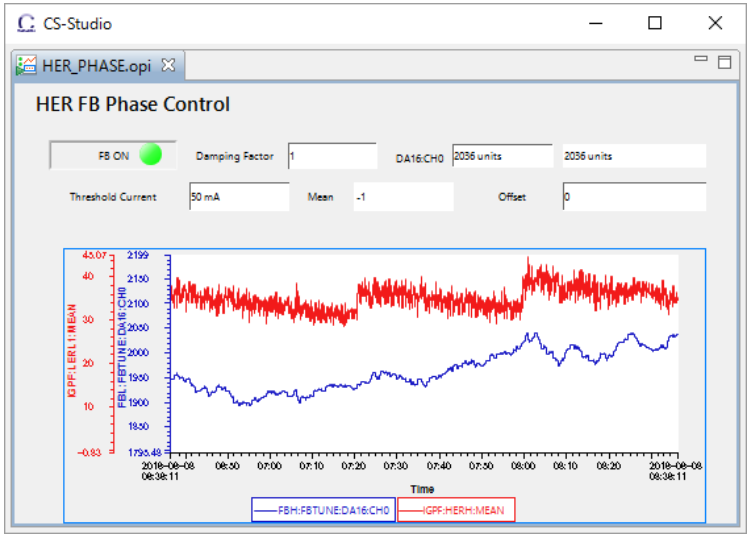
1/16 down sample
Growth~40ms, Damp~25ms

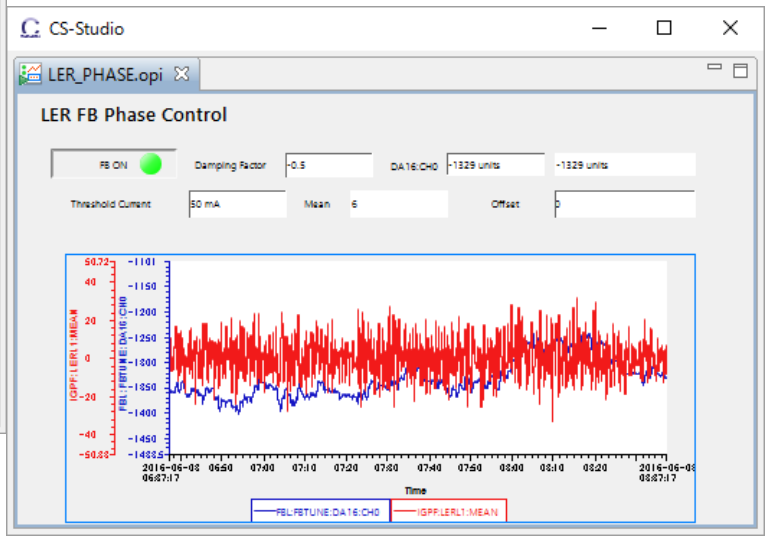
Difficulty in FB systems(1)

- **2GHz(=508MHz x 4) reference stability**
  - Phase of 508MHz clock has changed frequently without correlation of beam.
  - Found broken 508MHz phase shifter at reference line(RF).
  - Also make slow feedback loop by using iGp(L) fast memory.

2GHz feedback loop



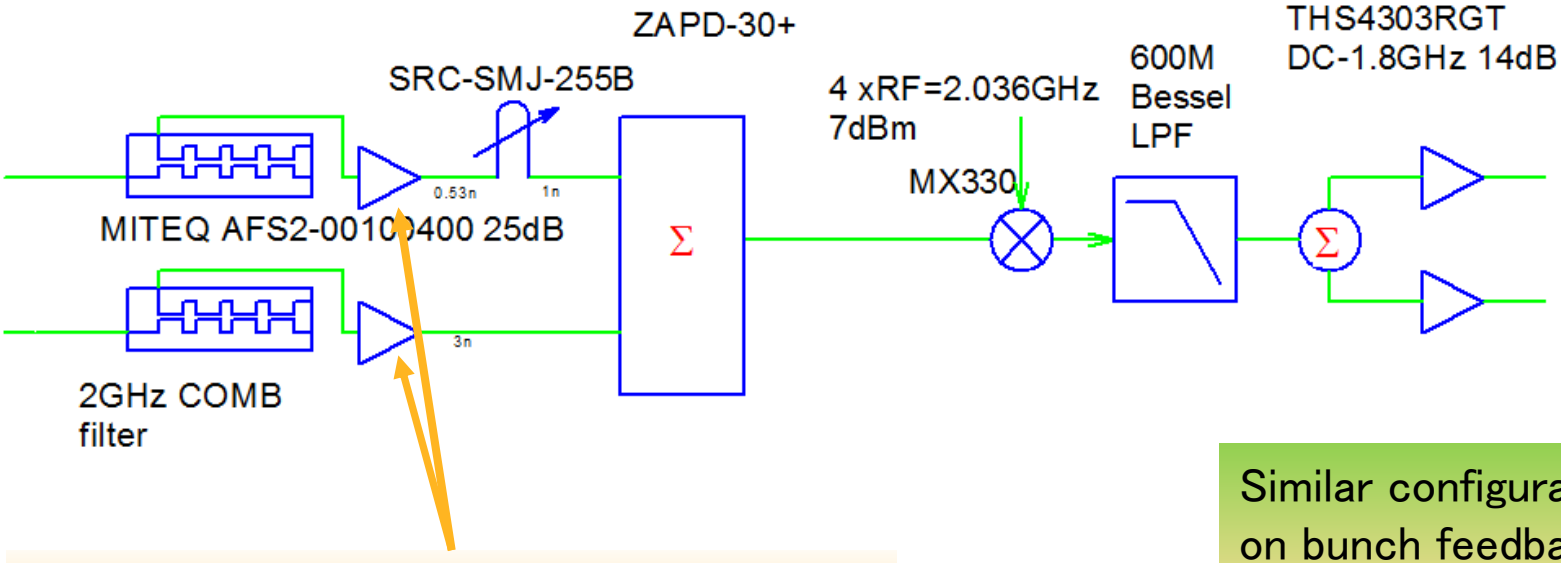




Difficulty in FB systems(2)

- **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

Saturation of FB detector

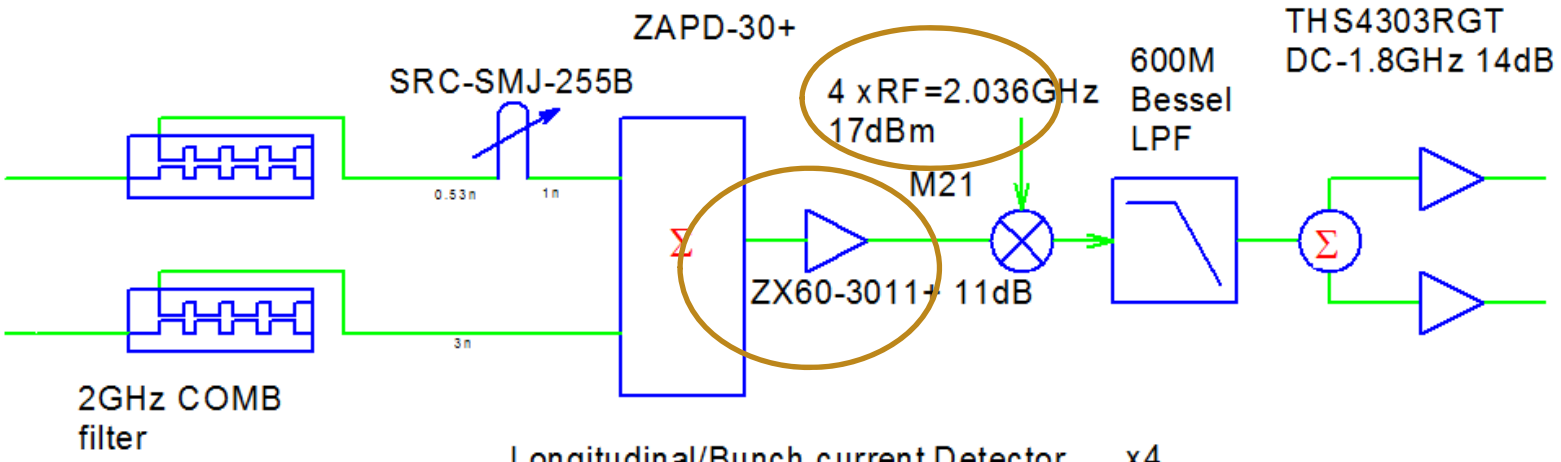


Found MITEQ LNA saturates with bunch current >0.5mA.

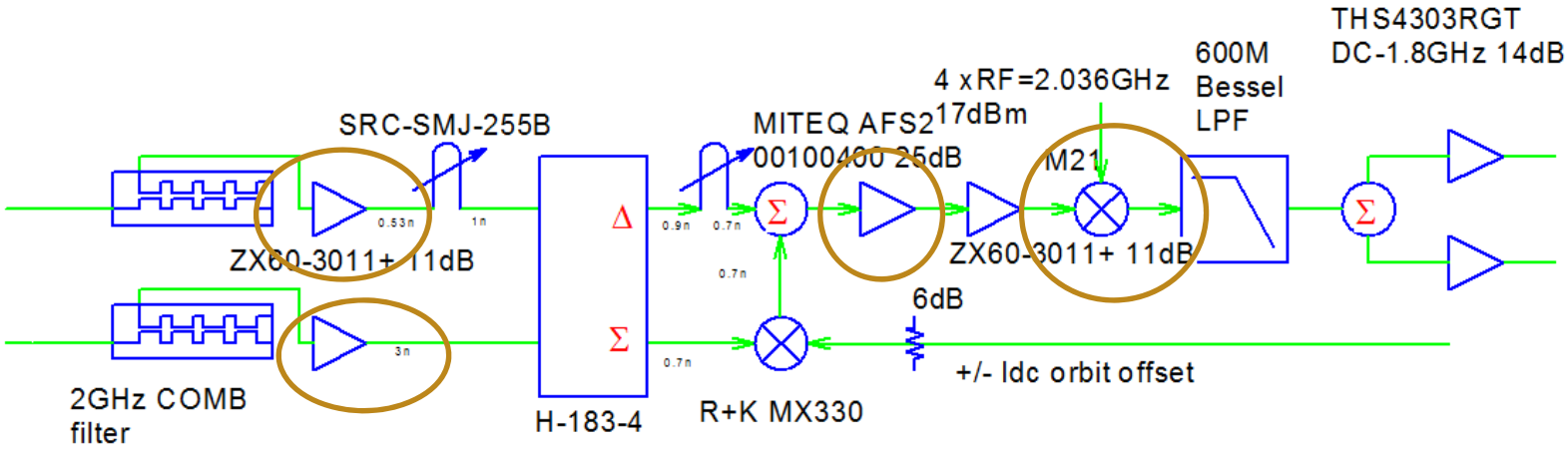
Similar configuration on bunch feedback detectors.
Need modification!

Bunch current alarm did not work with setting of >0.5mA/bunch which caused over current accident at HER (stored ~5mA/bunch).

Revised FB/BCM detector



Longitudinal/Bunch current Detector x4

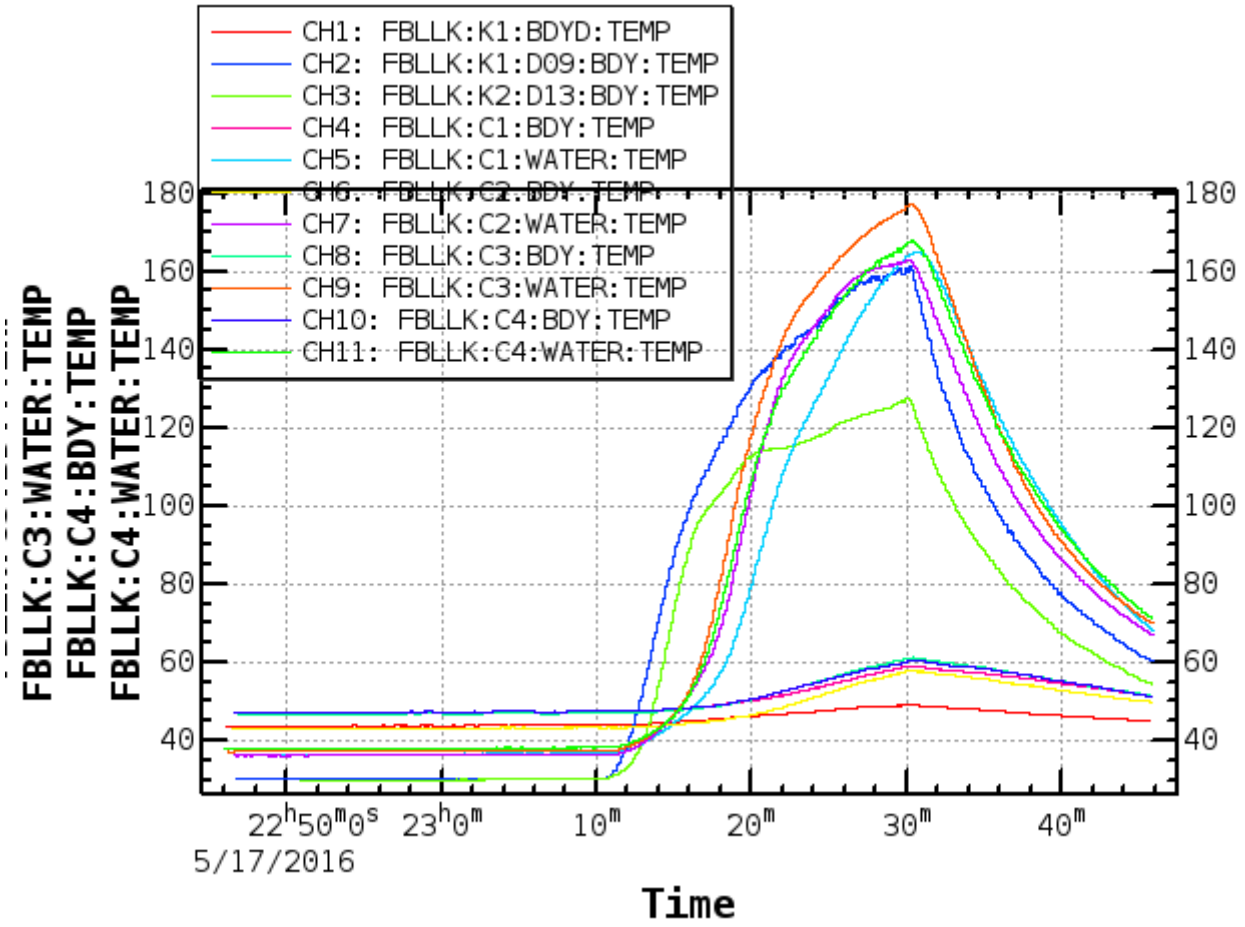


Transverse Detector x8

Difficulty in FB systems(3)

- **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.
- **Automatic beam abort request has been implemented**
  - Chiller stop
  - Temperature increase

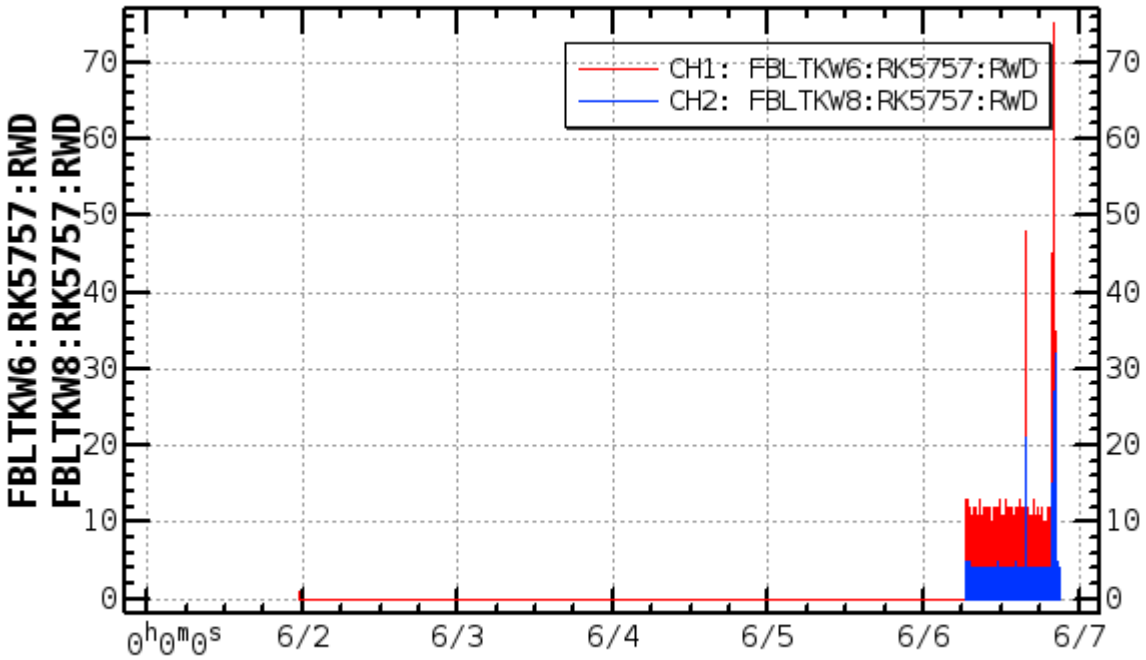
Burning of LFB kicker dummy loads

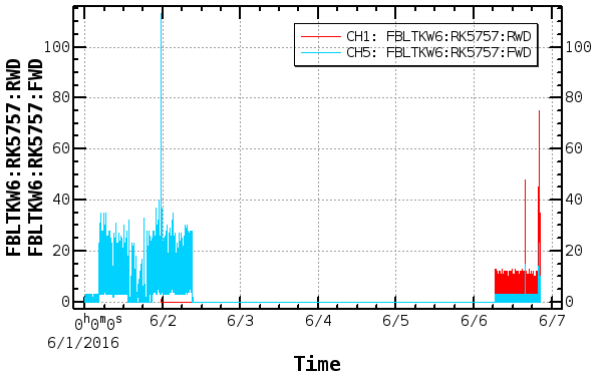


Difficulty in FB systems(3)

- **New transverse FB kicker for LER seems broken?**
  - Completely short-circuit at FT2(?) after short maintenance period.

LER TKW2 trouble





- **No signature observed before trouble**
  - No abnormal temperature rise.
  - No reflection.
  - No vacuum burst.

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
    - IP position monitors
  - Beam current/ bunch current monitor
  - Loss monitor
  - Bunch by bunch feedback systems
    - Tune monitors
    - Transverse FB (HER and LER)
      - LER transverse kicker trouble
    - Longitudinal FB (LER)

For Phase 2 operation

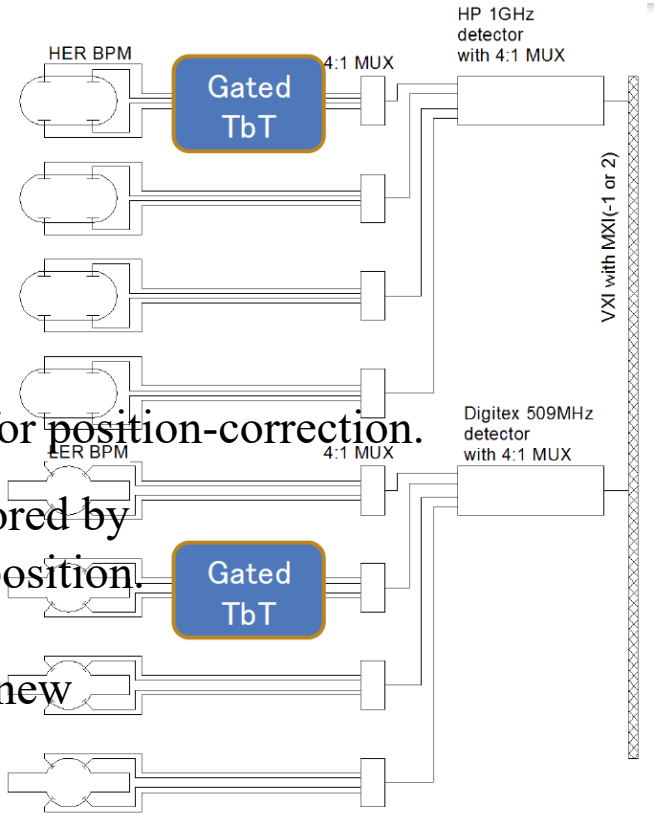
- **Replacement of damaged BPM heads.**
- **Transverse FB kicker**
  - Need to investigate the cause of trouble.
  - High beam power kicker (with collaboration of SLAC)
- **IP feedback systems**
  - Simulation of feedback (with dithering feedback)
  - Implementation of IP feedback algorithm.

Backup slides

Narrowband BPM system

Features

- 1GHz detectors of HER are those used in KEKB.
- Detectors of LER are newly developed 509MHz detectors.
- All VXI main frames in KEKB were replaced with new main frames.
- Gain calibration and beam based alignment are applied instead of BPM mapping at a laboratory and in situ survey of BPM position respectively.
- Rotation angle of BPM was measured prior to operation for position-correction.
- Movement of BPMs against adjacent sextupoles is monitored by displacement sensors, then used for correcting the beam position.
- Data acquisition software of KEKB is modified to fit the new arrangement of the detectors.



Cabling

- Cabling was checked by beam because final cabling check was not done to reduce the cost.
- Wrong cable connection was found at 25 BPMs, then corrected.

Position offset of BPM

- Beam based alignment has been applied to get position offset between a BPM and the center of an adjacent quadrupole.

→ H. Sugimoto's talk ?

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 4um and 4um in LER and HER respectively for most BPMs.

➡ H. Sugimoto's talk ?

Stability of relative gain among four signal paths

- So called "consistency" is continuously monitored.

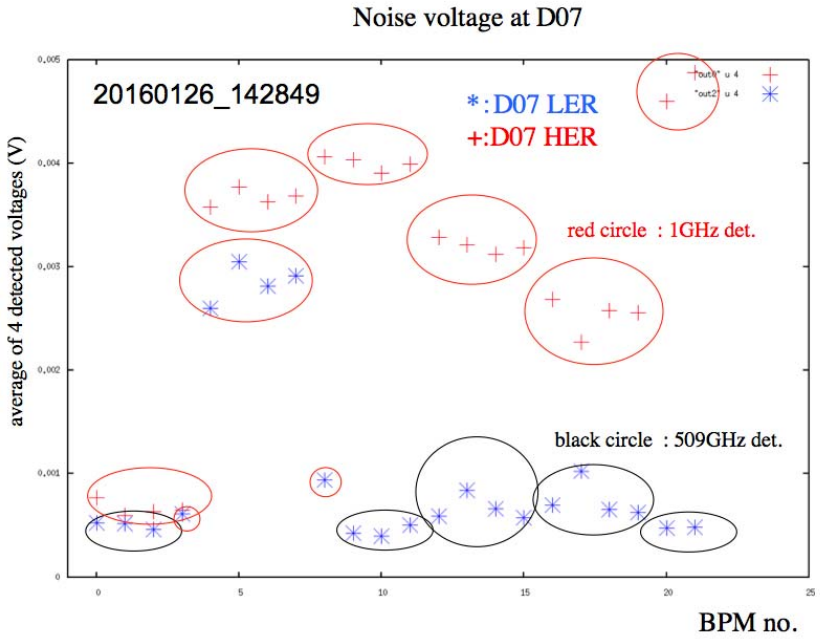
Consistency is defined as an rms value of 4 beam positions obtained by combination of 3 electrodes.

- Consistency is stable in LER where most feedthroughs and their cables are replaced.
- Consistency of some BPMs drifts or suddenly jumps in HER where KEKB hardware is used.

Change of consistency is sometimes cured by cleaning of connectors and/or signal cables. Otherwise, the gain is to be calibrated again.

Noise in 1GHz 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.



Troubles

•Very low signal level was found in two 509MHz detectors.

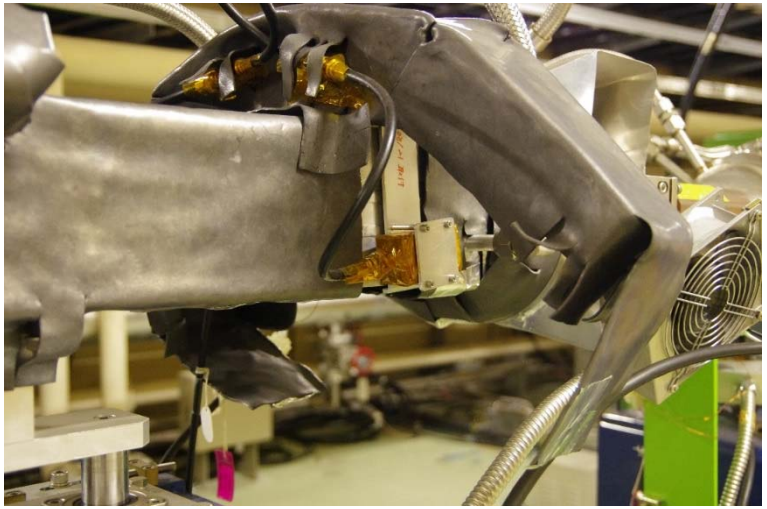
A disconnection was found in signal path in one of the detectors.

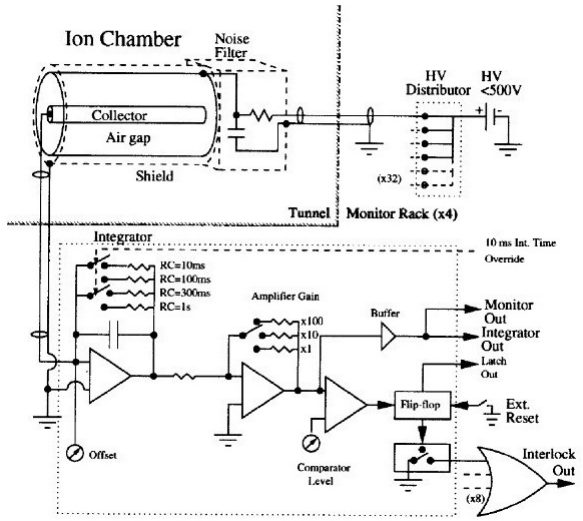
Another detector is being investigated. Probably an attenuator was not controlled correctly.

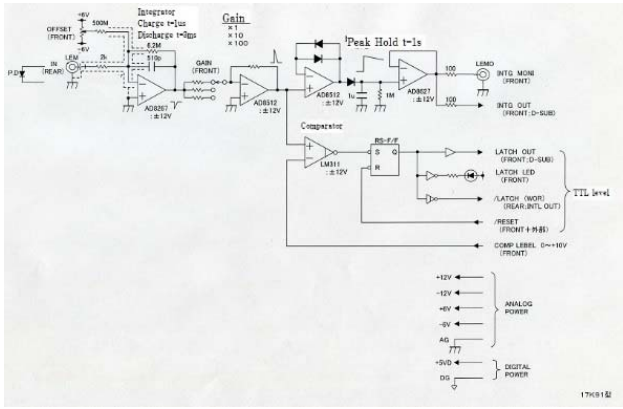
•Set up error of local oscillator's frequency was found at two 509MHz detectors.

•A damaged feed through was found at a LER BPM QD3P4.

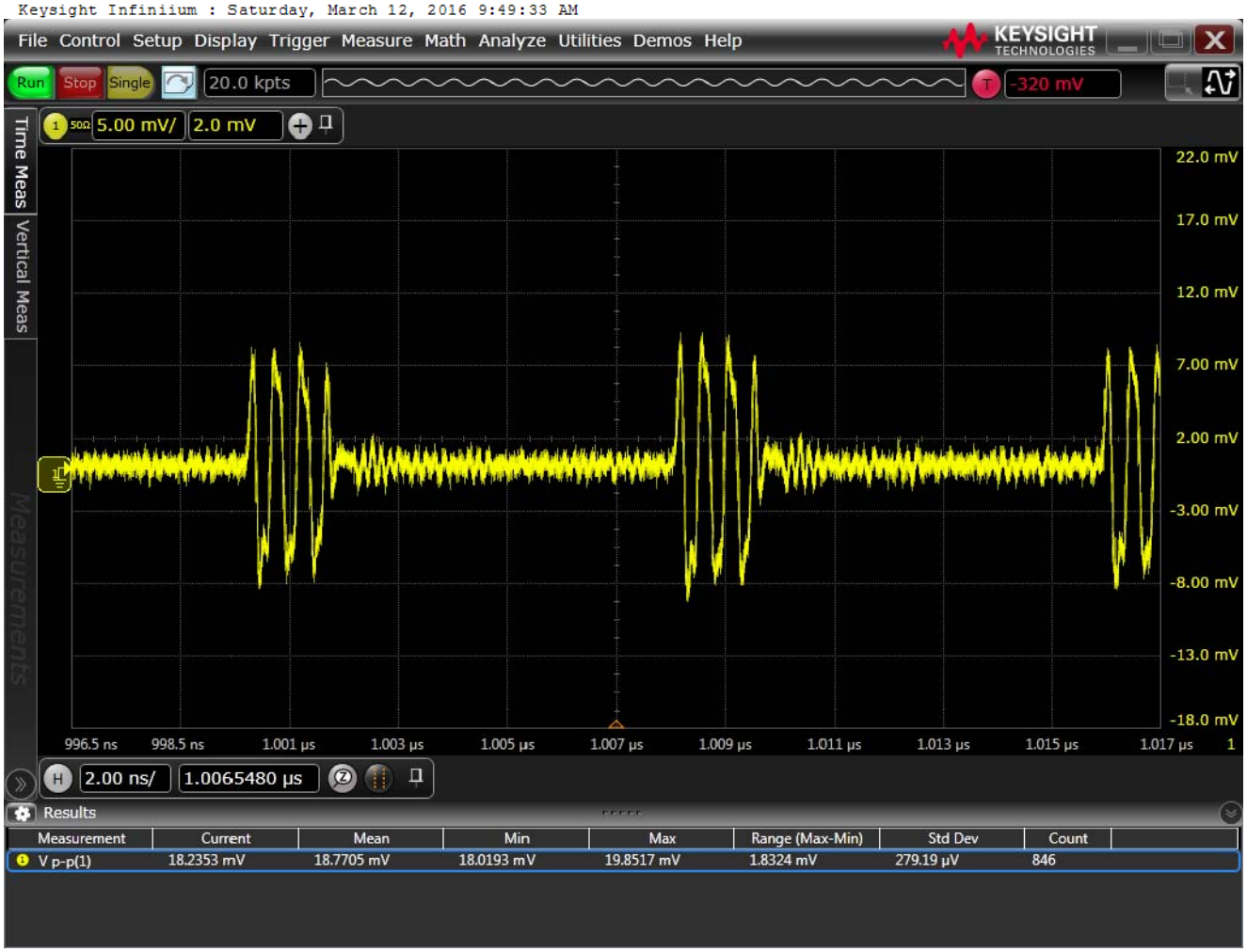
Beam loss monitor & Abort logger





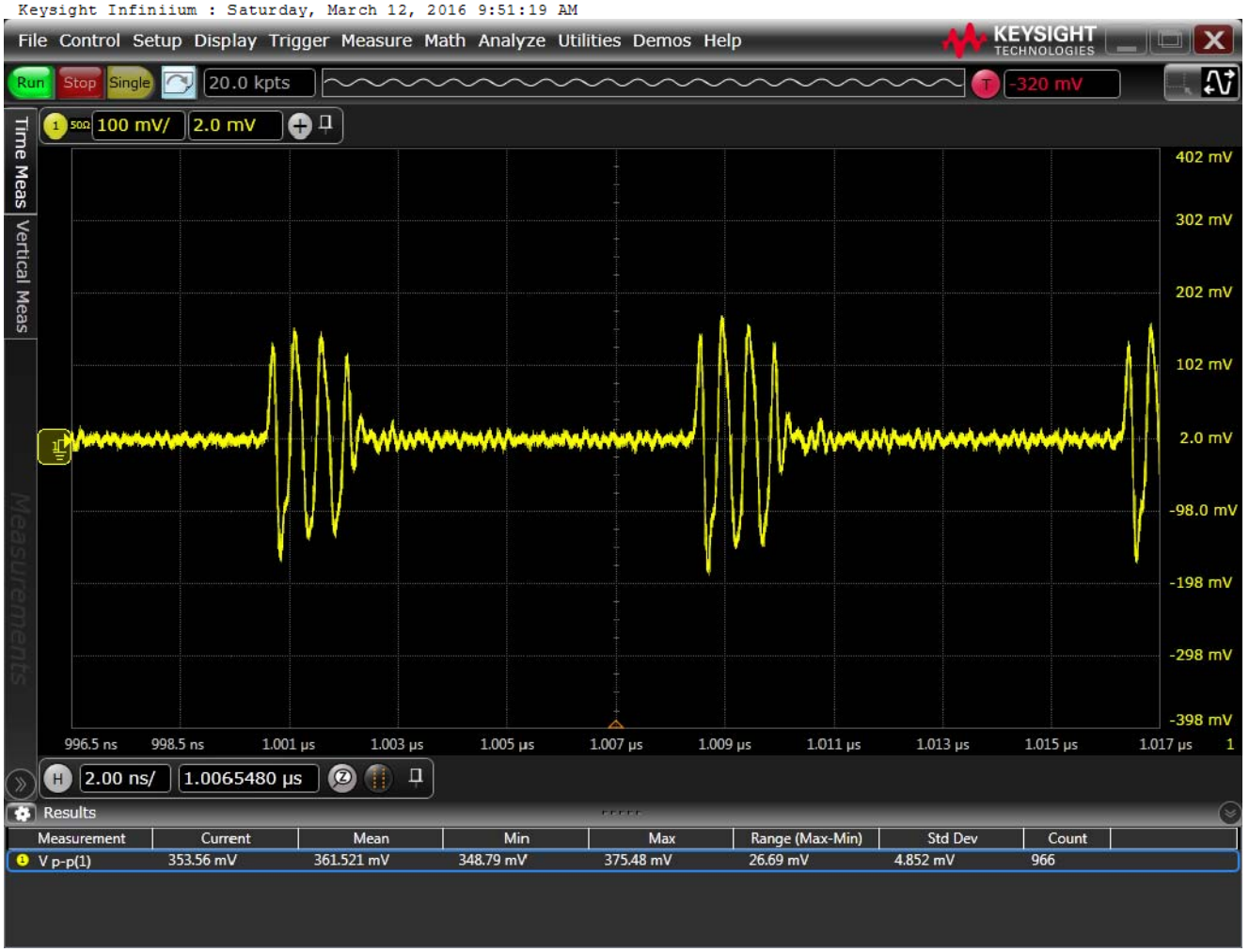


2GHz Comb filter output



LER (DS) 0.12mA/bunch、−30.6dBm

MITEQ LNA output



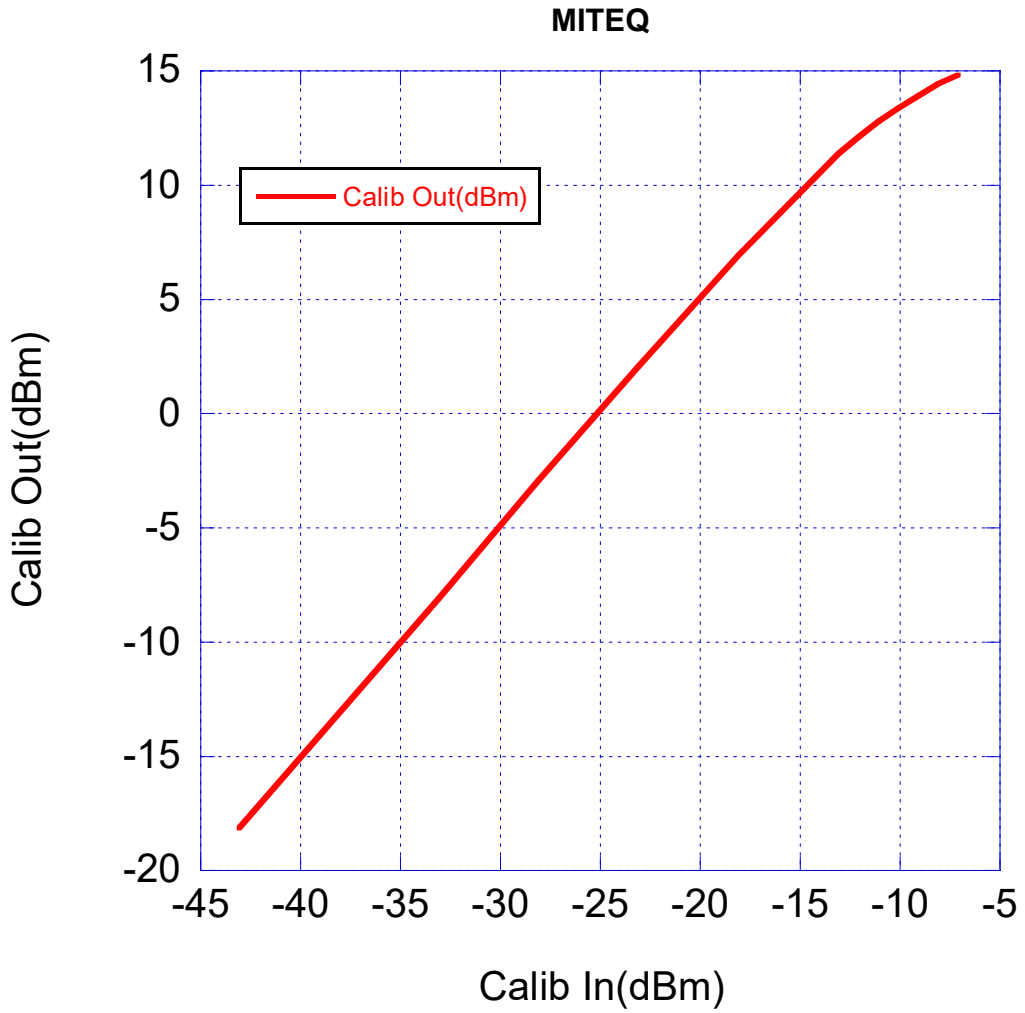
−4.87dBm (G=25dB)

MITEQ LNA

- Low noise amplifier
- G=20dB(Spec)
- NF 1.5dB
- P1 10dBm

- At 2mA/bunch, the output of the comb filter will be -6.16dBm- with 25dB amplifier, the linear output will be 18dBm : Completely saturated!.
  - The BCM has saturated after 0.5mA/bunch

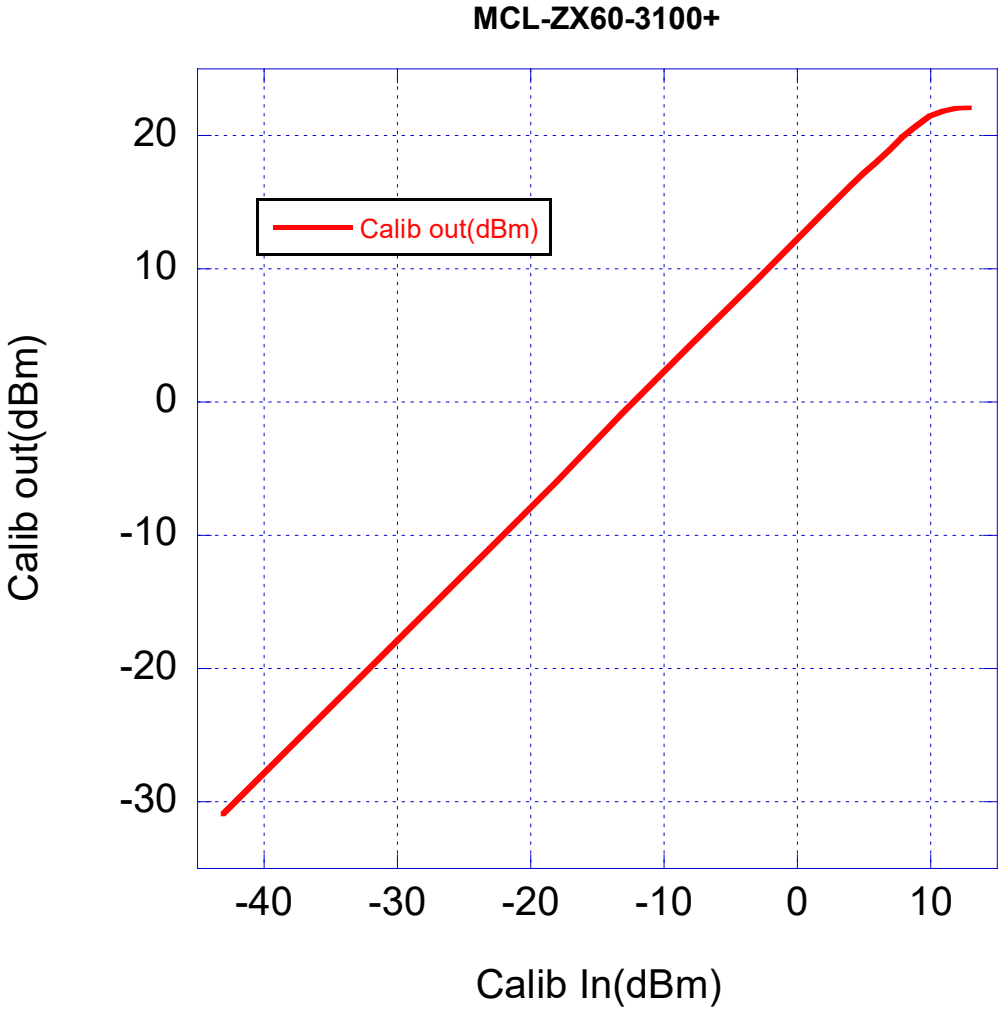
MITEQ LNA response



MCL ZX60-3011+ LNA

- Gain = 11.5dB
- P1dB >21dBm
- NF ~1.7dB

MCL ZX60-3011



Idea 1(bad idea..)

- Remove MITEQ LNA after Comb filter
- Leave original Level7 DBM
- Add DC amplifier (G=14dB) after output

- Large low frequency noise!

HER #0が真ん中


Keysight Infiniium : Friday, March 18, 2016 8:07:34 AM
File Control Setup Display Trigger Measure Math Analyze Utilities Demos Help
KEYSIGHT TECHNOLOGIES
Run Stop Single
32.5 kpts
-870 mV
20.0 mV/ 0.0 V
10.0 mV/ 5.2 mV
500 mV/ -540 mV
Time Meas
Vertical Meas
Measurements
80.0 mV
60.0 mV
40.0 mV
20.0 mV
0.0 V
-20.0 mV
-40.0 mV
-60.0 mV
-80.0 mV
-15.000 mV
914 ns 919 ns 924 ns 929 ns 934 ns 939 ns 944 ns 949 ns 954 ns 959 ns 964 ns
5.00 ns/ 939.2820 ns
Results
Measurement Current Mean Min
V p-p(1) 37.285 mV 30.1417 mV 5.915 mV
Markers
X1 2.50897740 µs
X2 2.51412780 µs
ΔX 5.150400 ns
1/ΔX 194.16 MHz
Y1 21.0000 mV
Y2 6.00000 mV
ΔY -15.0000 mV

LER #0は67.556ns後