

MOCB01

**BEAM INSTRUMENTATION
FOR THE SUPERKEKB RINGS**

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International Beam Instrumentation Conference,
IBIC2012, Tsukuba, Japan, Oct. 1-4, 2012

Introduction

- SuperKEKB is an upgrade of KEKB B-factory.

- Very small vertical beam size with "nano-beam scheme"
 - Doubled beam current of KEKB

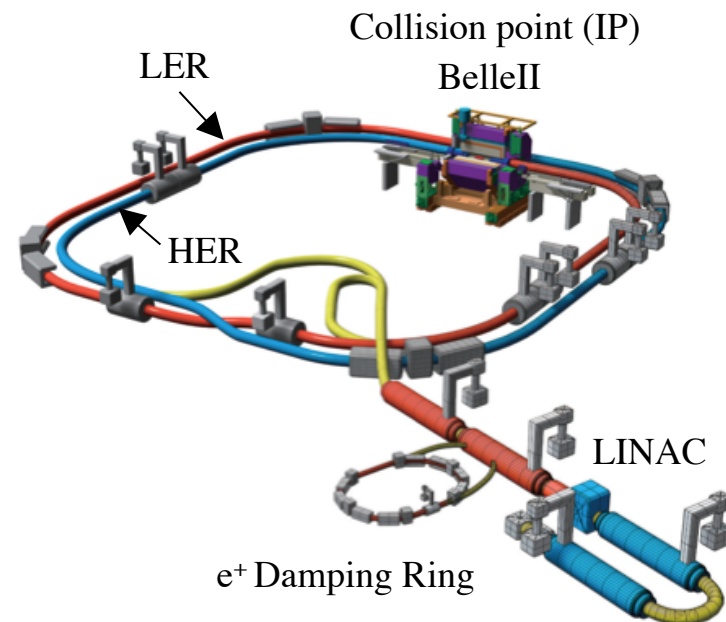
↳ 40 times larger luminosity than KEKB.

- The first beam is expected in the Japanese FY 2014.

Major upgrades

- New LER vacuum chambers (ante-chamber)
- New final focus system in the interaction region (IR)
- New positron damping ring

Ring	HER(e ⁻)	LER(e ⁺)
Energy (GeV)	7	4
Circumference (m)	3016	
Beam current (A)	2.6	3.6
Number of bunches	2500	
Bunch separation (ns)	4	
Bunch length (mm)	5	6
Beta function @IP hor./ver. (mm)	25/0.30	32/0.27
Emittance (nm)	4.6	3.2
x-y Coupling (%)	0.28	0.27
Vertical beam size at IP (nm)	59	48
Damping time trans./long. (ms)	58/29	43/22



Main Ring Instrumentations

System	Quantity		Comments
	LER	HER	
Beam position monitor (BPM)	445	466	Closed orbit correction, slow orbit feedback, IR orbit feedback, optics correction
Displacement sensor	~100	~100	Measurement of displacement between the sextupole and the BPM
Transverse bunch-by-bunch feedback	1	1	Suppression of beam instabilities
Longitudinal bunch-by-bunch feedback	1	0	Suppression of beam instabilities
Visible light monitor	1	1	Horizontal beam size, longitudinal bunch profile
X-ray light monitor	1	1	Vertical beam size measurement
Beamstrahlung monitor	1	1	Beam information at collision point (IP)
Tune monitor	1	1	
Loss monitor	~300	~300	Ion chambers and PIN diodes
DCCT	1	1	Reused from KEKB
Bunch current/fill pattern monitor	1	1	Revised from KEKB

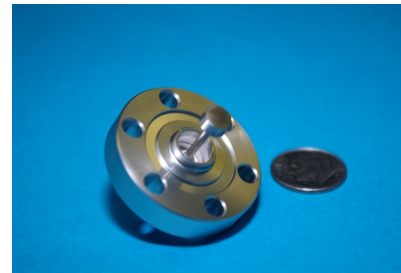
Items colored **orange** are new in SuperKEKB.

A luminosity monitor will be prepared by the Belle II group.

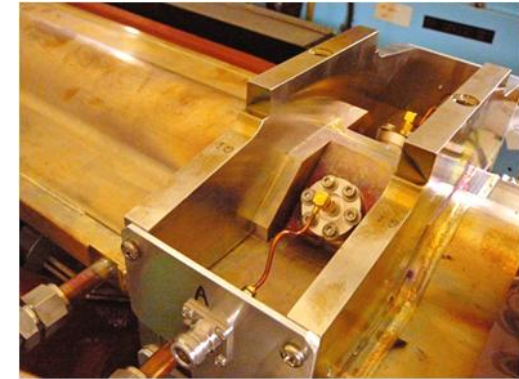
Beam Position Monitor System

Button electrode for the LER

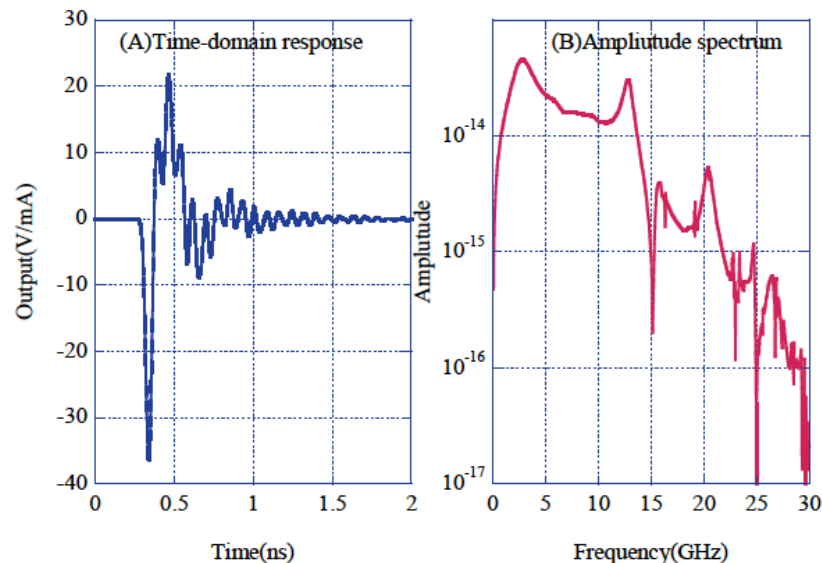
- Diameter : 6mm
- Flange type for easy replacement and for removal during TiN coating of the chamber.
- Pin-type inner conductor for tight electrical connection.
- Prototypes were successfully tested at KEKB.



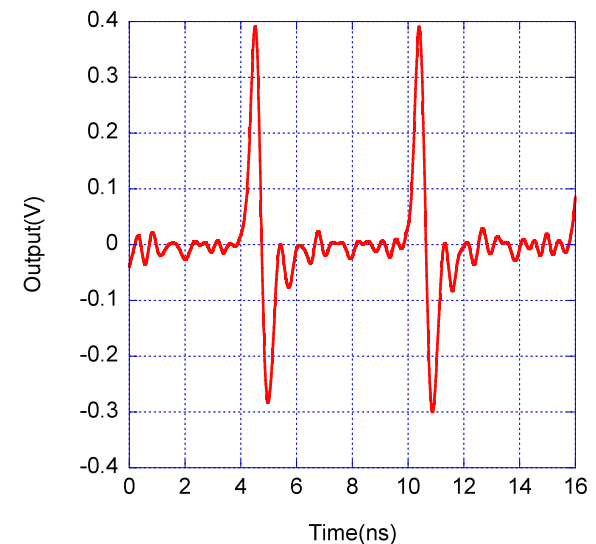
Button electrode



BPM block (ante-chamber)



GdfidL simulation



1mA/bunch, 1.5GHz scope, 50m cable

BPM Detectors

- The KEKB detector was a 1 GHz narrowband superheterodyne detector module (VXI). One narrowband detector covers four BPMs.
- A main detector system of SuperKEKB follows that of KEKB in order to maximally use KEKB system to reduce the cost.
- The narrowband detectors of SuperKEKB HER are reused from KEKB.
A new narrowband detector with a detection frequency of 509 MHz will be used for the LER since the cutoff frequency of a new LER ante-chamber is below 1 GHz.
- Additionally, turn by turn detectors will be installed at selected BPMs to measure the optics during collision.
- Also, a special wideband detector is being installed for the BPMs closest to the collision point (IP) for orbit feedback to maintain stable collision.

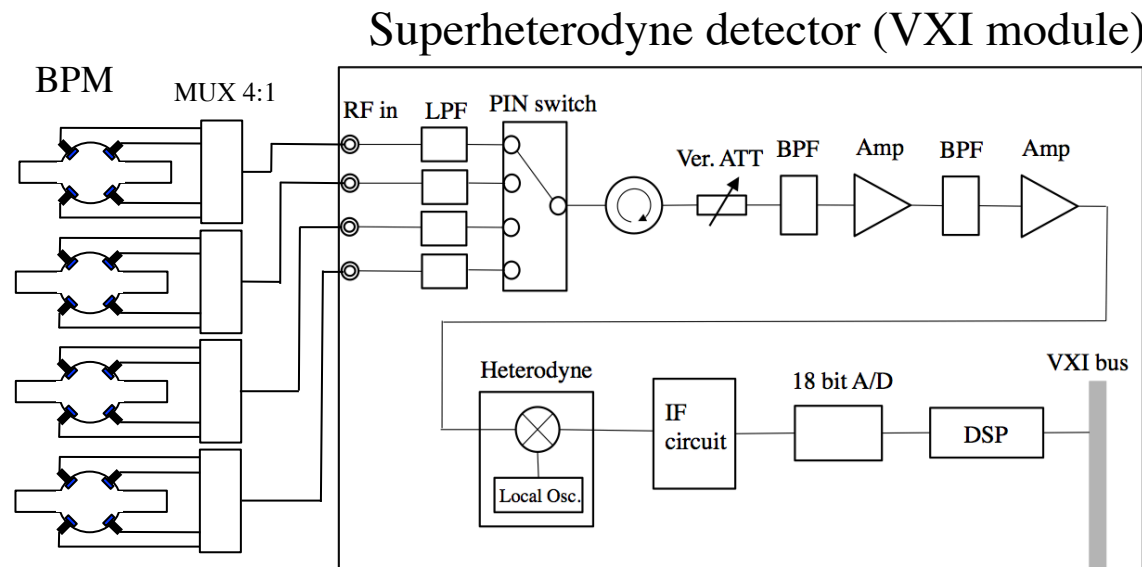
Type	Function	Resolution	Repetition	Quantity
Narrowband KEKB	closed orbit correction, slow orbit feedback, optics measurement	2 μ m	0.25Hz	117 (already we have.)
New narrowband	as above	2 μ m	0.25Hz	127
Turn-by-turn	optics measurement during collision	50 - 100 μ m	100kHz	270
IR feedback	collision feedback	<1 μ m	5kHz	4

509 MHz Narrowband Detector

- Development of the 509 MHz narrowband detector is in final stage.
- Signal to noise ratio larger than 90 dB is achieved by 2048 points FFT and averaging of 8 points with CW signal.

S/N : 90 dB → Resolution : 0.5 μ m

- Final tuning to get better linearity and so on is in progress.
- 20 units will be produced in this FY as a pilot production.
- Mass production of about 110 units is scheduled in the next FY.

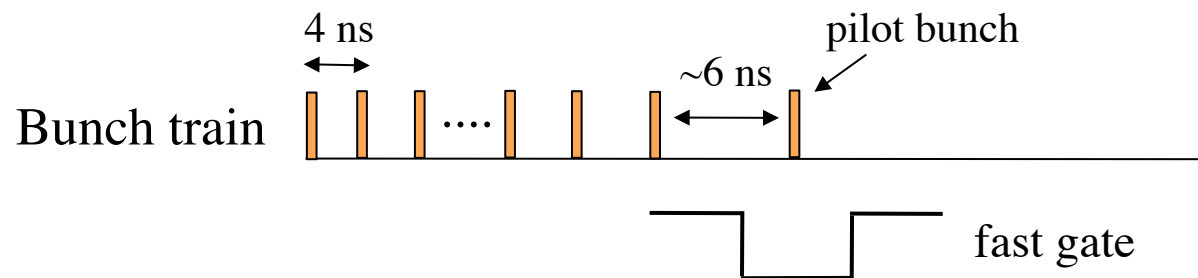


Turn-by-Turn Detector with Fast Gate

Purpose

1) Measurement of optics parameters during collision

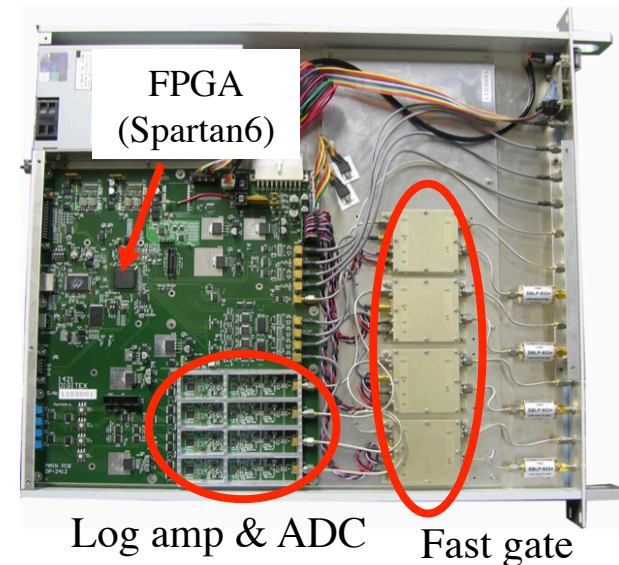
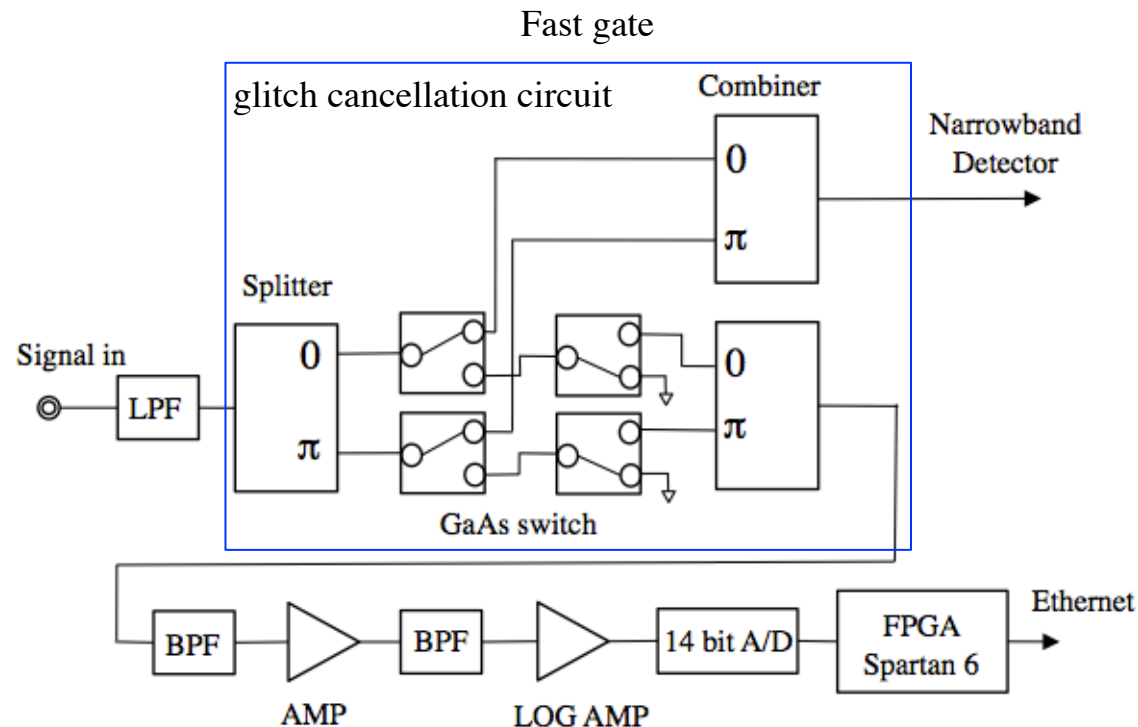
- Detect oscillation of a non-colliding pilot bunch
- Calculate optics parameters such as beta functions and coupling parameters from the bunch oscillation data
- The pilot bunch is kicked by the bunch-by-bunch feedback system.



2) Injection tuning

Block diagram of turn-by-turn detector

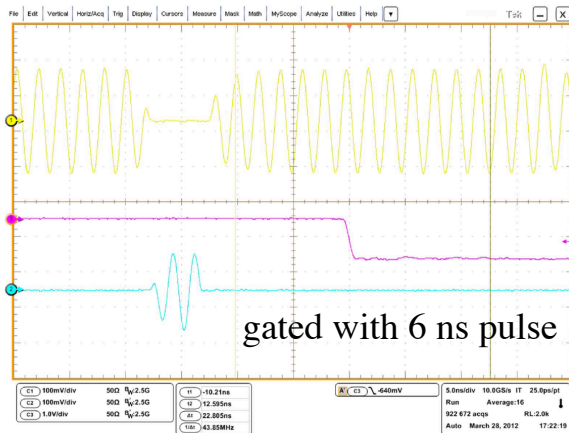
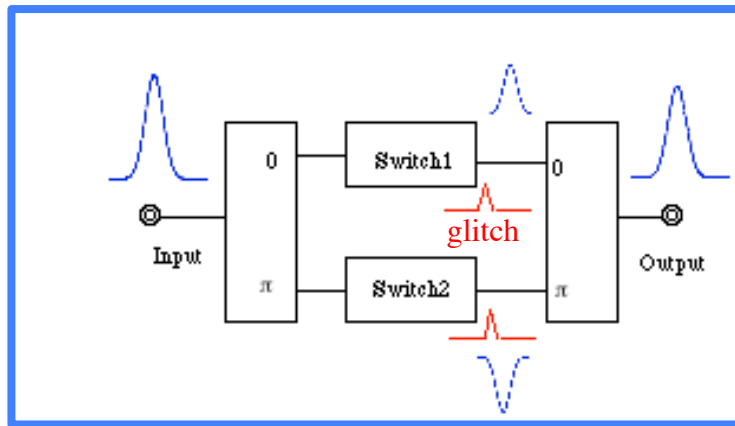
- The detector has GaAs fast gates to select the signal of the pilot bunch. Signals of remaining bunches are sent to the output port of the detector, which is connected to the narrowband detector in order to enable the simultaneous measurement of the narrowband detector and the turn by turn detector.



- Switch : Hittite GaAs MESFET, DC – 12GHz
- Log amp : ADL5513 (AD)
- ADC : ADS850 (TI)

Glitch cancellation circuit (T. Naito)

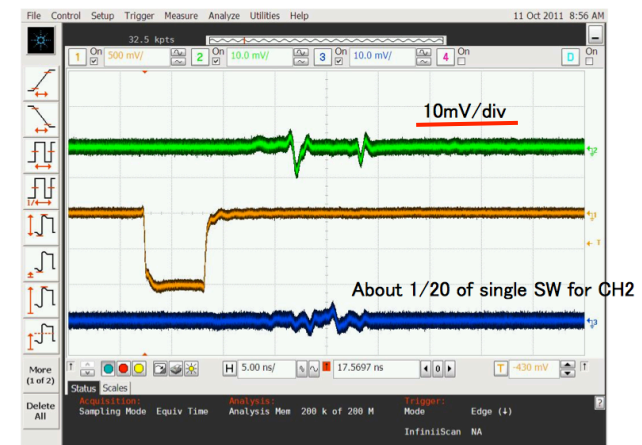
- A $0-\pi$ splitter and a combiner placed before and after the switches, respectively, remove a common mode glitch of the switches.



- A test of the switches shows the isolation larger than 85 dB.
- The detection by the narrowband detector connected to the turn-by-turn detector was not affected by the switches at a laboratory measurement.

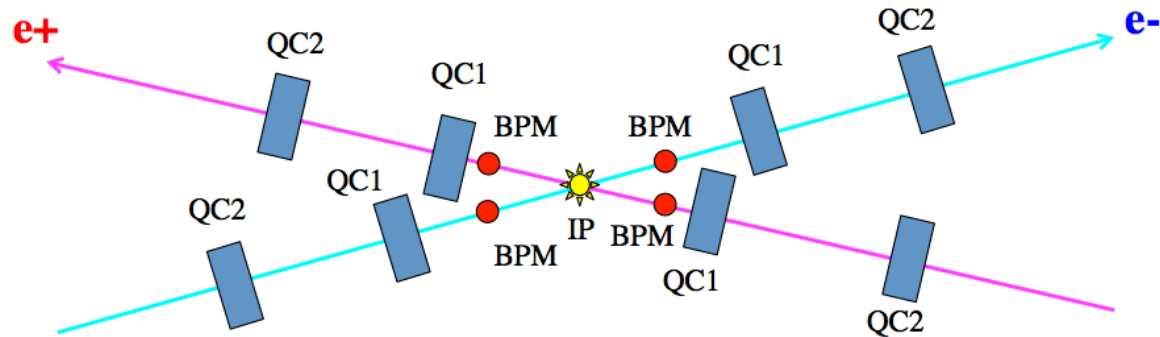


w/o glitch cancellation circuit



with glitch cancellation circuit

IR Feedback Detector



- Detect vertical orbit shift at BPMs by the beam-beam kick when two beams collide with a vertical offset.

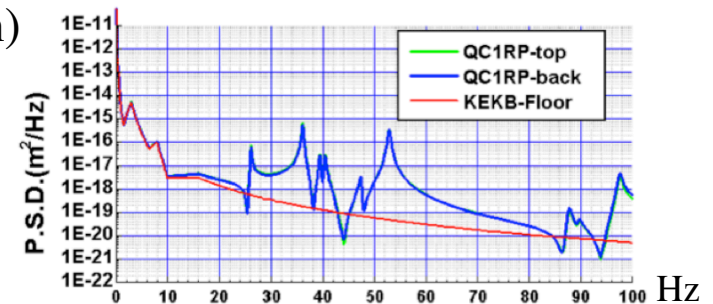
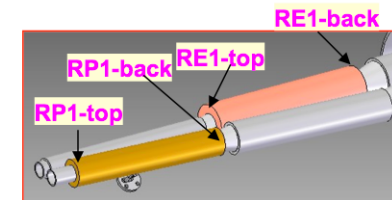
Orbit shift at BPMs : $1.3 \mu\text{m} @ 0.1\sigma_y^*$ offset at IP

- Steer the beam position and angle at IP to reduce the offset.
- Main sources of orbit movement : vibration of quadrupoles closest to IP

Main frequency components : 3, 36, 53Hz (simulation)

- Tentative specification for R&D of the detector

{	Resolution	$< 1 \mu\text{m}$
	Repetition	5kHz
	Bandwidth	1kHz



Movement of QC1RP by a simulation (H. Yamaoka)

a) Detector

- Down-convert 508.8MHz component to intermediate frequency (IF) of 16.9 MHz with an analog mixer to reduce the degradation of the SNR by the clock jitter of ADC.

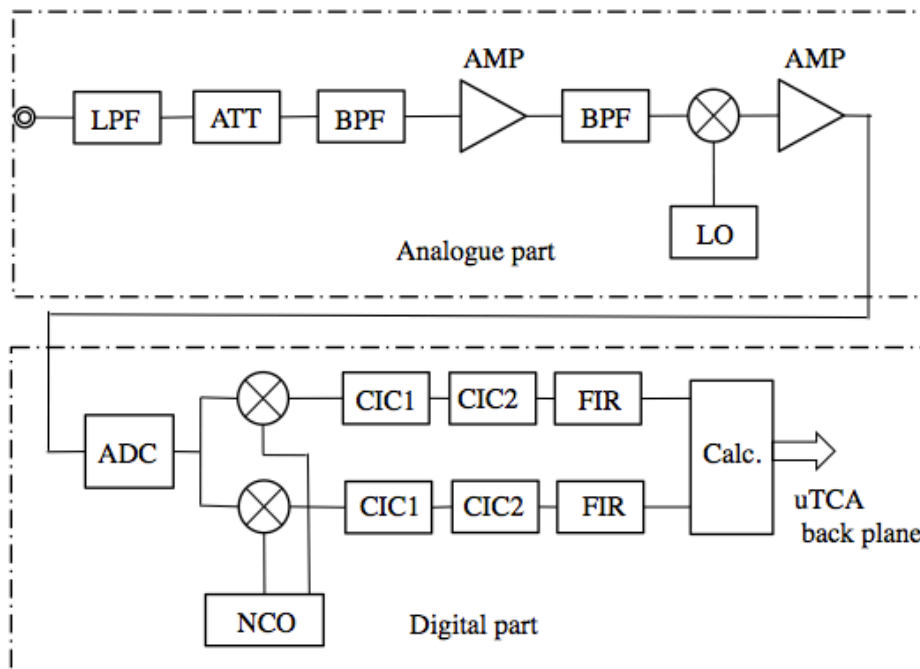
Analogue part

- AD conversion

- Digital filters (2 CICs, 1 FIR)

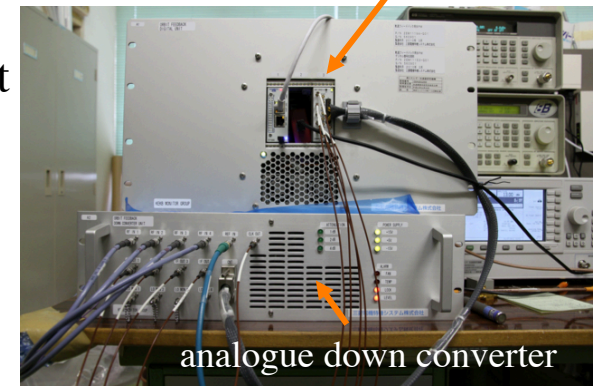
- Position calculation

Digital part



Prototype

μTCA



Digital processor board

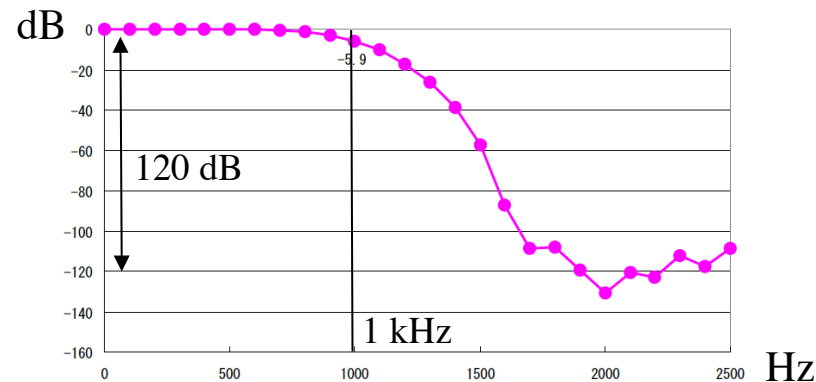
- The digital part is implemented in a μTCA board developed for SuerKEKB LLRF system.
- EPICS is embedded in the board.

b) Performance of the prototype

•Analogue part

- Clock jitter 1.30 ps
- Noise figure 14.3dB @ 16.9MHz
- Temperature coefficient of IF signal -0.03dB/deg.

•Frequency characteristics of the digital filter

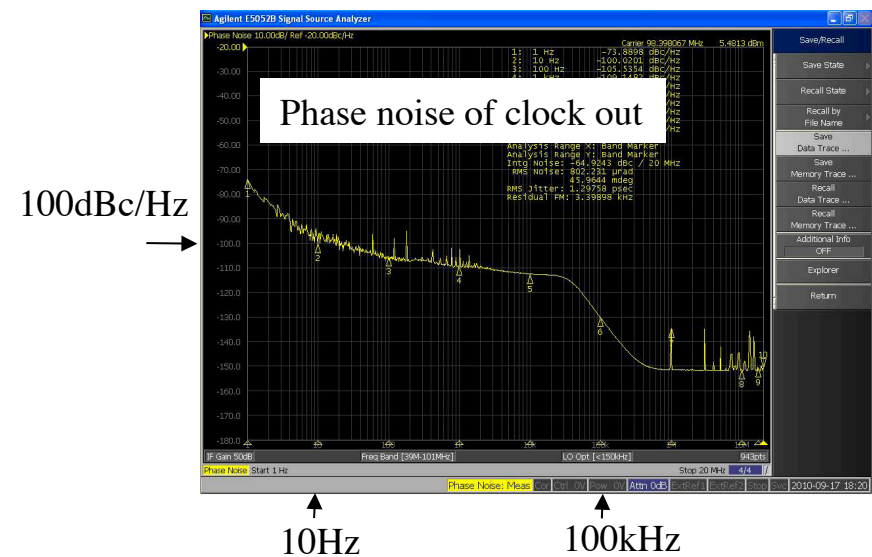


Attenuation is as expected.

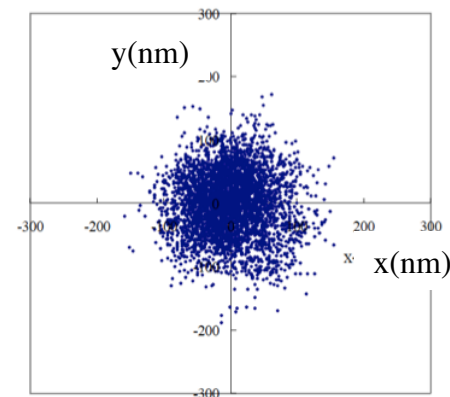
•First prototype had a group delay of 3.3 ms.

A simulation shows that the group delay should be less than 1ms to get enough rejection gain against the disturbance (i.e. 10dB@50Hz).

The group delay will be reduced to less than 1 ms by reducing the taps of the FIR.



•Resolution (CW input)



$$\sigma_x = 47 \text{ nm}$$

$$\sigma_y = 60 \text{ nm}$$

Chamber radius 10mm

Synchrotron Radiation Monitor

We will install three kinds of synchrotron radiation monitor.

1)Visible Light Monitor

- Streak camera :longitudinal profile
- Interferometer :horizontal beam size, (vertical beam size)
Vertical beam size at source point: $16\mu\text{m}$ (LER), $19\mu\text{m}$ (HER)
A vertical beam size measurement is near the limit of the interferometer resolution.

2)X-ray Monitor

- Coded aperture imaging and pin hole : vertical beam size

3)Large Angle Beamstrahlung Monitor

- Measure relative offsets and size ratios of the beams at the collision point.

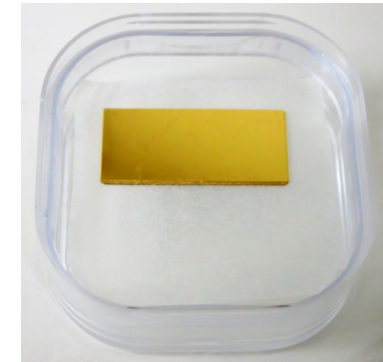
Visible Light Monitor

a) Diamond mirrors

- Incident power on the extraction mirror : 280 W ~ KEKB HER.
- Since the heat deformation was already a problem at KEKB, we are developing a diamond mirror that would not deform as much under the same heat load.

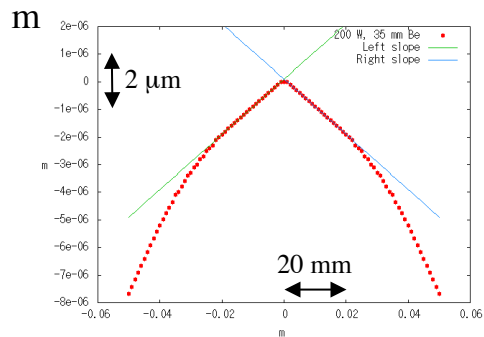
Quasi-monocrystalline diamond

- Diamond surface is nearly a single crystal. Good surface smoothness is expected ($R_a \sim 2 \text{ nm}$, $< \sim \lambda/50$).
- 10 mm x 20 mm x 0.5 mm and 20 mm x 20 mm x 1 mm prototype completed.
- Very good heat conductance and low thermal expansion coefficient make apparent change in magnification smaller than that of Be mirrors used at KEKB.

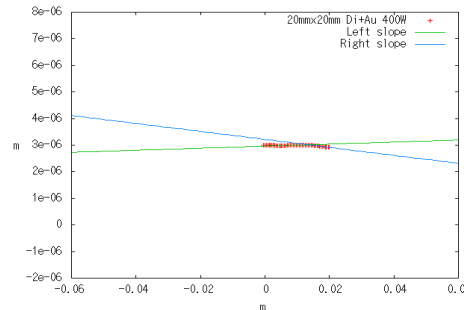


Diamond mirror
(Surface: 3 μm Au)

Surface Deformation (ANSYS simulation)

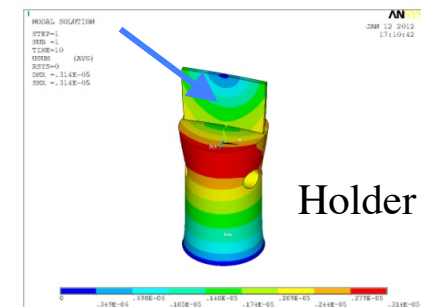


Be mirror
(200W SR power)



Diamond mirror
(400W SR power)

Mirror



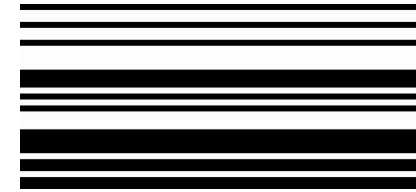
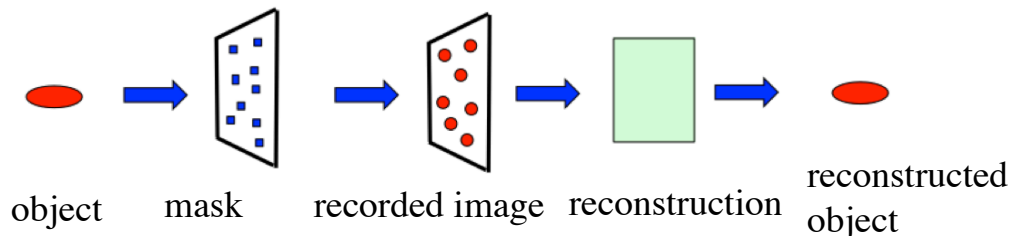
- Heat deformation is being measured.

To be presented in TUPB74.

X-ray monitor

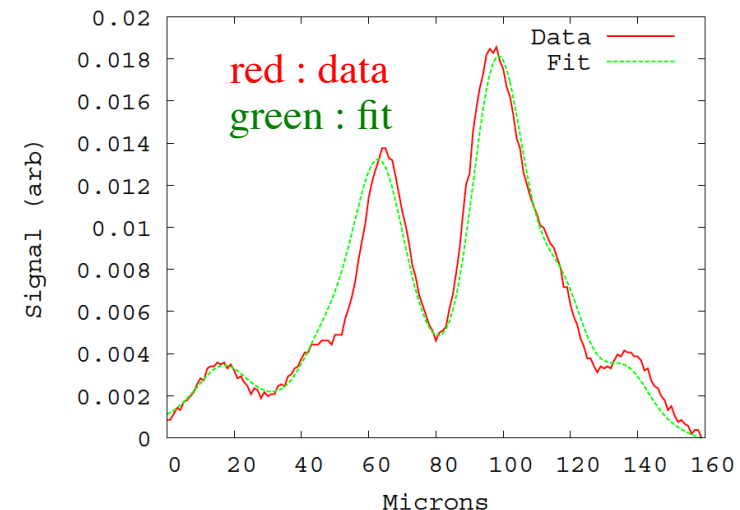
a) Coded aperture imaging

- Developed by X-ray astronomers.
- Light from an object is modulated by a mask.
- The resulting image must be deconvolved through mask response including diffraction and spectral width by Kirchhoff integral over mask to reconstruct the object.
- Large open aperture of 50 % gives high flux throughput for bunch-by-bunch measurements which will likely be needed for low-emittance tuning.
- A heat-sensitive and flux-limiting monochromator is not needed.



1D Uniformly Redundant Array (URA) mask

- The method has been successfully tested at CsrTA.

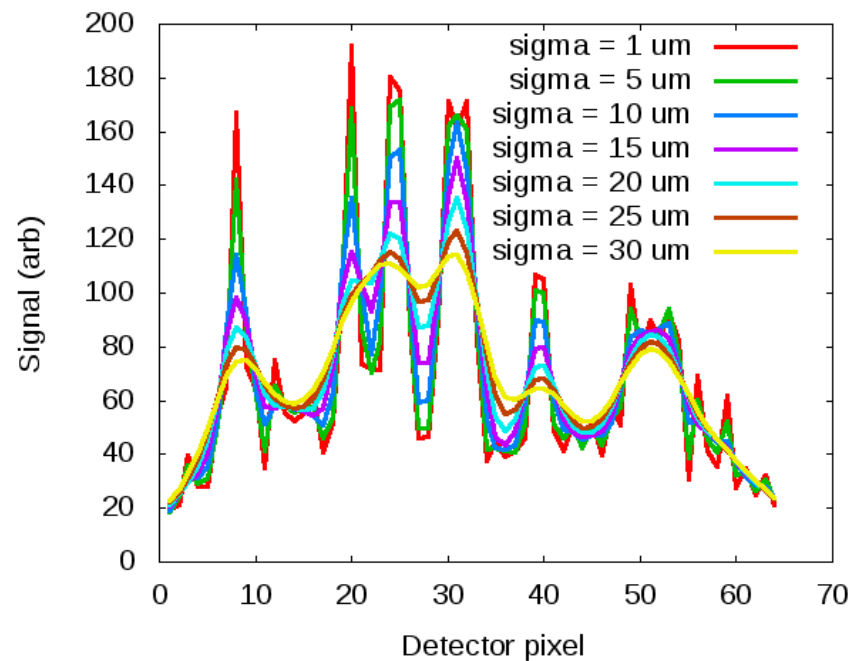


Measured and simulated image at CsrTA ($\sigma_y \approx 25 \mu\text{m}$)

(J. W. Flanagan et al., IPAC'10)

b) Simulation in SuperKEKB

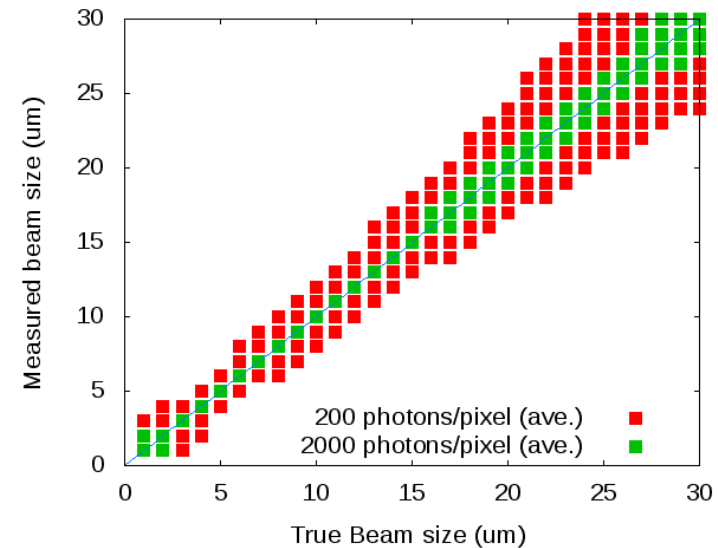
- Vertical beam size at source point: $21\mu\text{m}$ (LER), $11\mu\text{m}$ (HER)



Detected image or pattern in SuperKEKB

Red points : using a 64-pixel Fermionics detector

Green points : using a hypothetical detector with improved photon detection efficiency at higher x-ray energies.

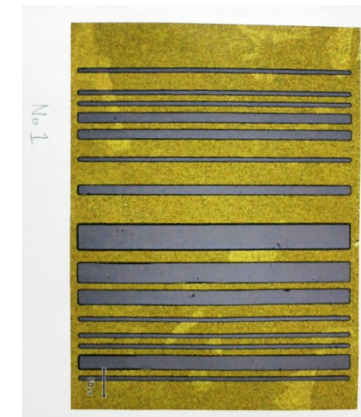


Estimated single-shot resolutions
limited by photon statistics

Resolution at true beam size of $10\mu\text{m}$ is $\pm 2.5\mu\text{m}$ with the Fermionics detector.

c) Mask

- Tests at CEsrTA show the URA mask gives predicted single-shot resolution.
- A Si mask was successfully tested at SuperKEKB full current power load in CEsrTA.
- A diamond substrate mask was also fabricated and installed at CEsrTA, and ready to be tested.

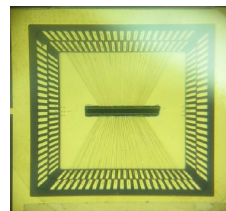


Diamond+Au mask
Minimum slit width 10 μ m

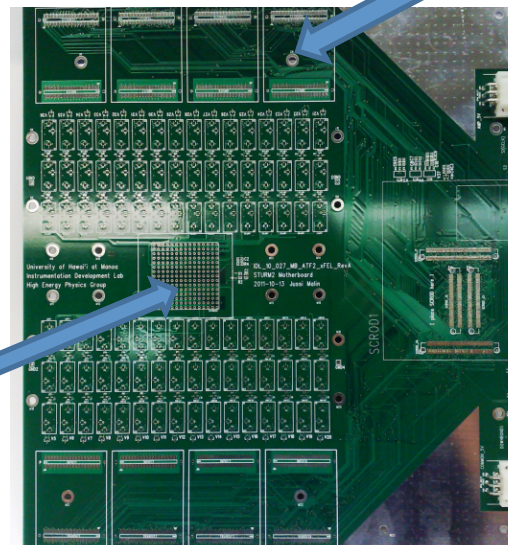
d) Detector and readout

- The base line detector is the Fermionics photon detector.
- A digitizer is STURM (Sampler of Transients for Uniformly Redundant Mask) ASIC for high-speed readout developed at U. Hawaii.
- A 64-channel system where a Fermionics detector, a preamp board and a STURM digitizer board are integrated on a motherboard is being developed for testing at ATF2.

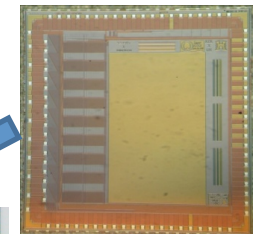
➡ To be presented in MOPB72.



Detector



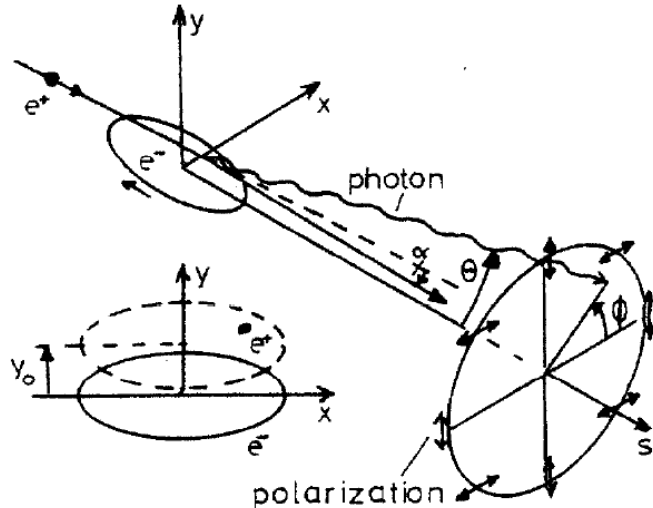
64-channel system



Digitizer ASIC
(STURM2)

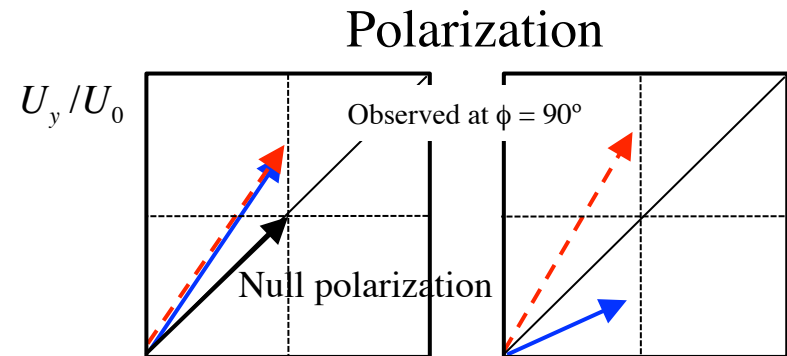
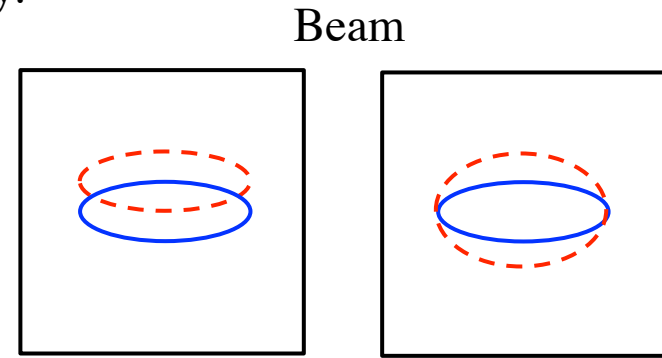
Large Angle Beamstrahlung Monitor(LABM)

- Proposed by G. Bonvicini, then tested at CESR.
- Beamstrahlung is the radiation of the particles of one beam due to the bending force of the electromagnetic field of the other beam.
- Beamstrahlung polarization at specific azimuthal points provides unique information about the beam-beam geometry.
- The LABM for the SuperKEKB is being built in the US, mostly at Wayne State University.



A positron is vertically deflected by the electron beam.

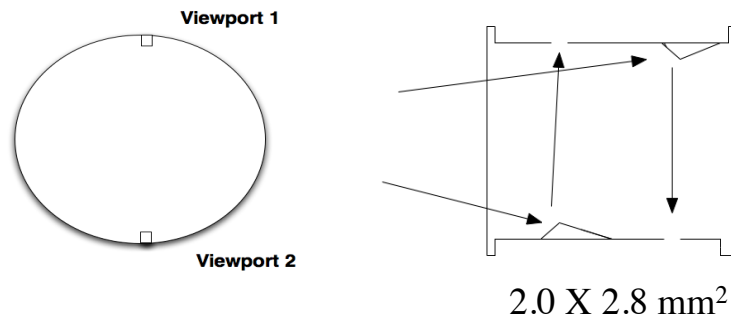
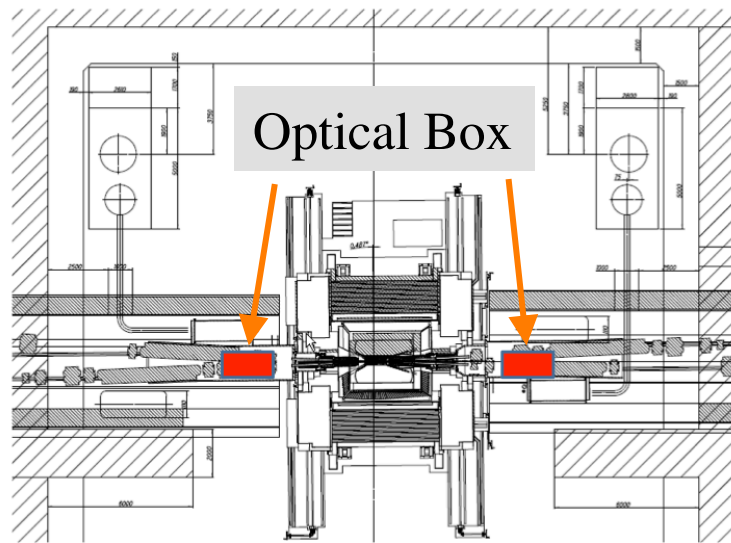
M. Bassetti et al., PAC1983



U : Polarization vector U_x/U_0

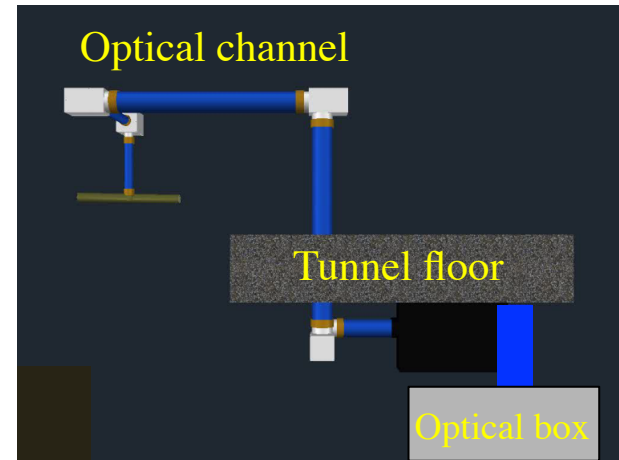
G. Bonvicini et al., PRE 59 (1999).

a) Setups

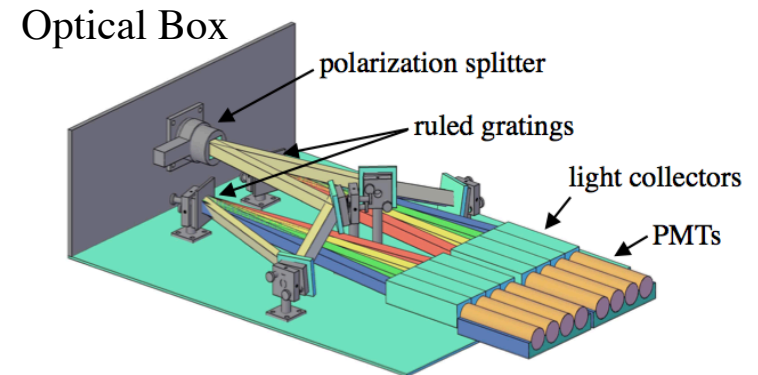


- The monitor consists of four viewports.

- At full SuperKEKB luminosity, the photon flux at the primary mirror is of the order 10^{12} Hz, and a factor of 50-500 lower for each individual electronic channel.



- Light is transported through an optical channel to an Optical Box.



- Light is separated into two transverse polarizations and four different wavelength bands.

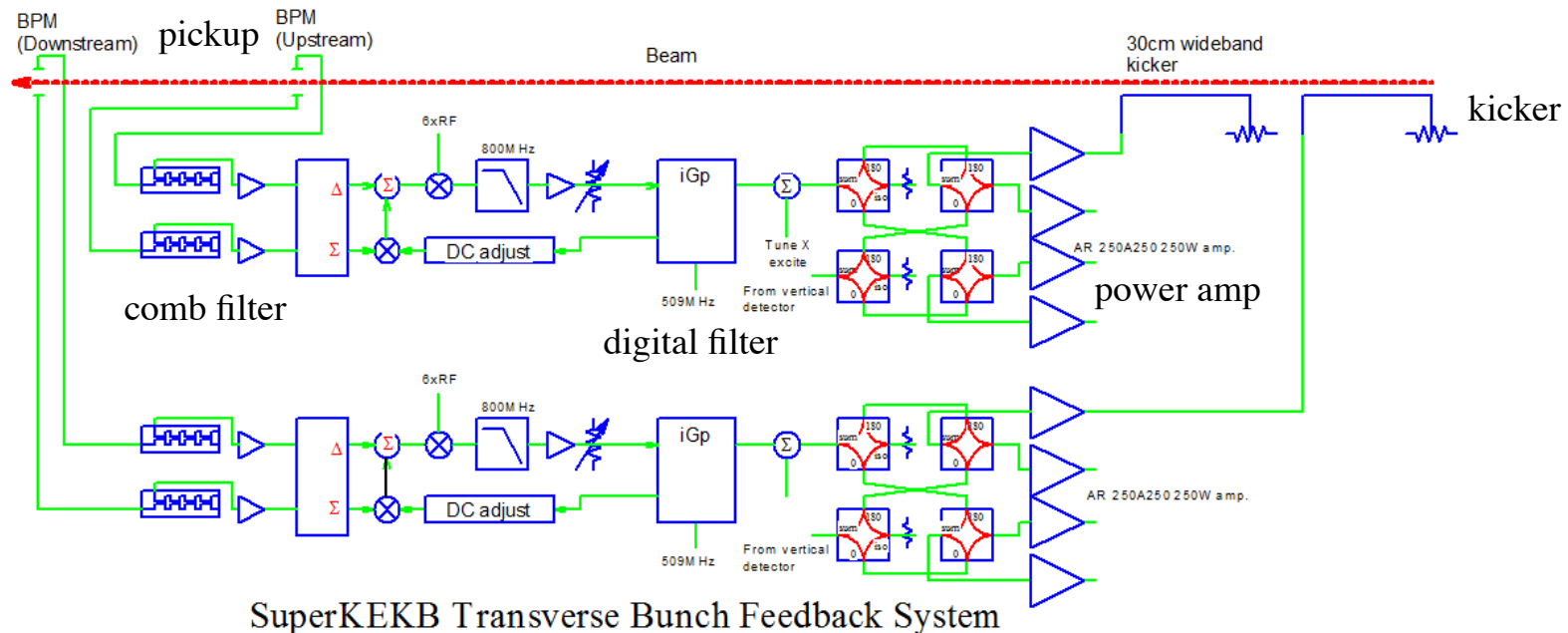
Bunch-by-Bunch Feedback System

Transverse feedback system

- Since the horizontal tune is near the half integer, several turns are needed to observe the orbit change at the monitor if the phase relation between the source of the kick and the monitor is not suitable.

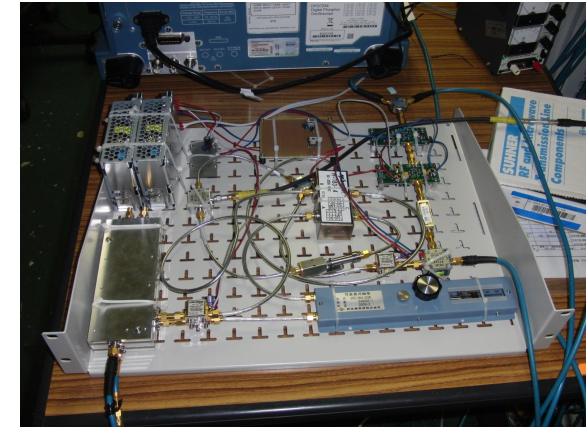
➔ Two sets of short stripline kickers which cover two feedback loops with 90 degrees phase difference will be installed in each ring.

- The design of the kicker is similar to that of a present KEKB kicker. The shunt impedance of 10k ohm per kicker is expected.
- Power amps are old four 250W-amps and new four 500W-amps in each ring.

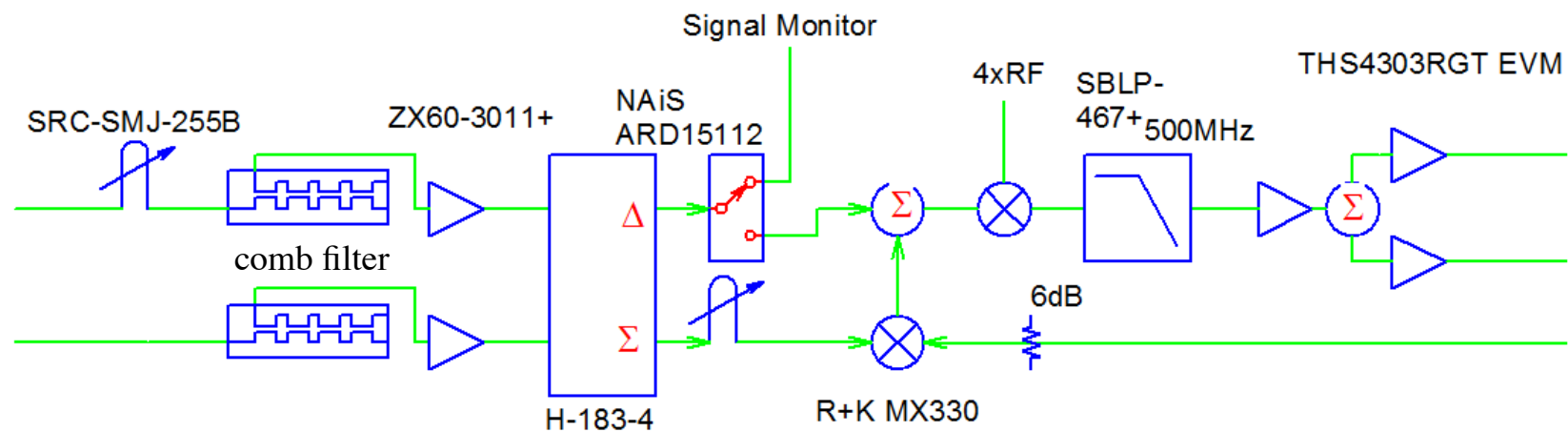


a) Pickup and Low noise front-end

- The button electrode has a glass feedthrough sealing with low relative dielectric constant of about 4 which has good time and frequency response.
- The detection frequency is 2 GHz.
- A 2 GHz comb filter is used to cut low frequency noise and to improve isolation between bunch signals.
- A difference signal is mixed with LO with frequency of $4 \times \text{RF}$ frequency, amplified to increase gain, fed to 600 MHz Bessel LPF then amplified by a DC amp.



Test circuit

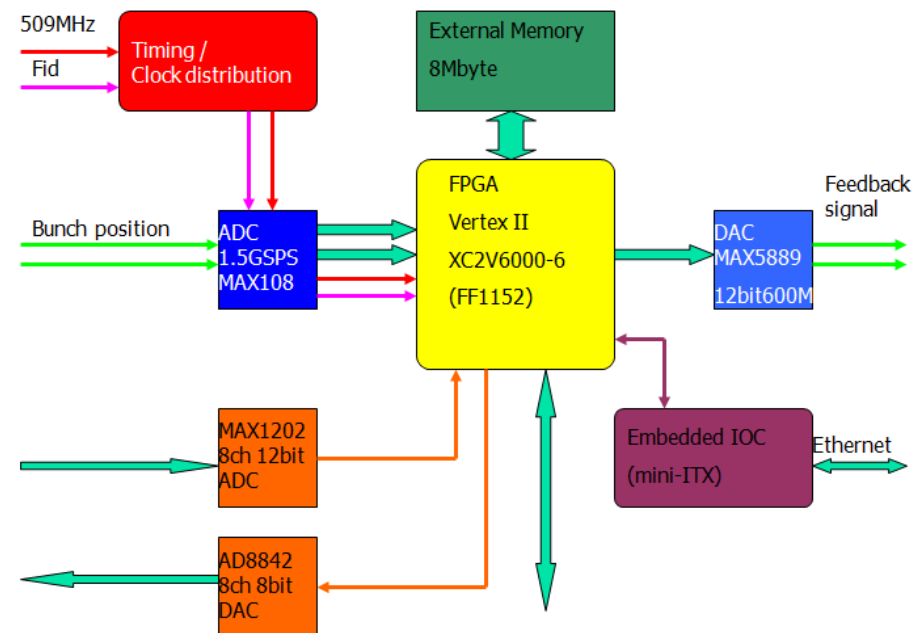


b) Digital filter

- The iGp processor is a baseline system.
- It was developed under US-Japan collaboration (KEK-SLAC-INFN-LNF).
1.5GSPS 8 bit ADC, 600MSPS 12 bit DAC
FPGA Vertex II
- Successfully tested for the transverse and longitudinal system at KEKB and routinely used in longitudinal feedback at KEK-PF.
- The ADC is upgraded to 12 bits system to extend dynamic range in order to capture large offset signal due to the beam-beam kick.



iGp processor



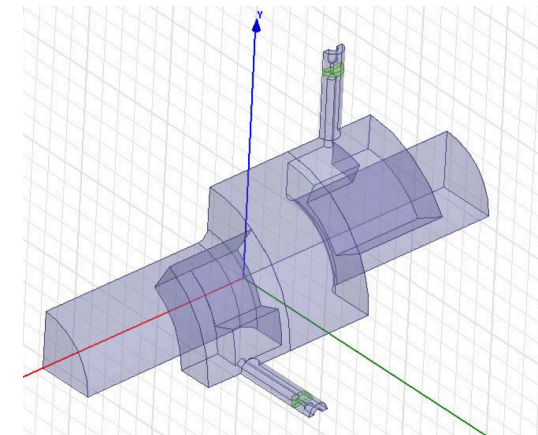
Longitudinal feedback system

- A growth rate of the longitudinal coupled bunch instability due to the impedance of ARES cavities in LER is 15 ms which is shorter than the longitudinal radiation damping time of 22 ms.

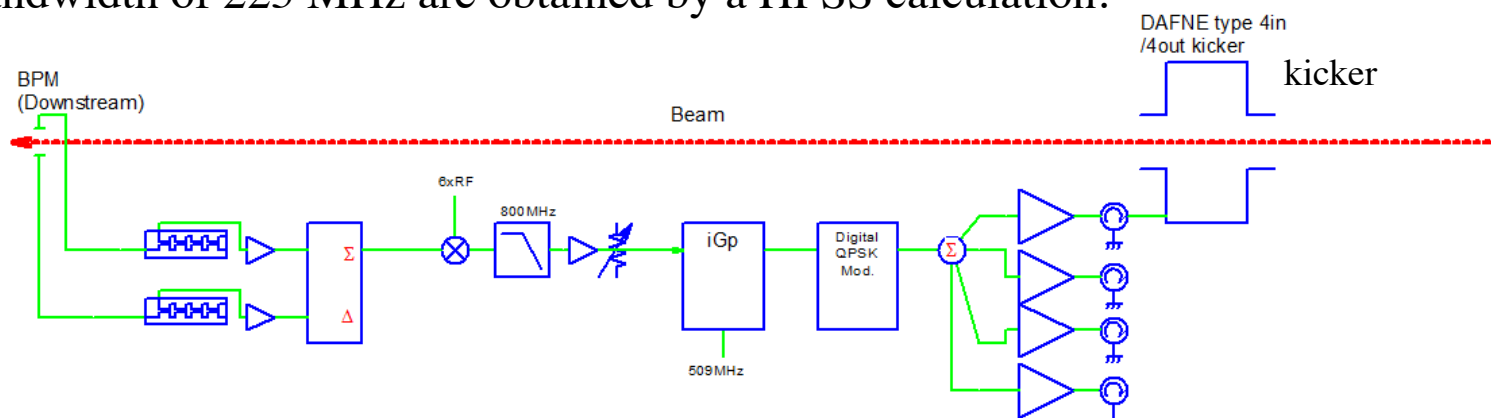
➔ The longitudinal feedback system is indispensable in LER.

- Four DAFNE type kickers, with 2-input, 2-output ports will be used to get larger capture range.
- Two 500W- amps per kicker are used.
- The frontend electronics and the digital filters are same as those of transverse system.
- The design of cavity has started.

So far the shunt impedance of 1k ohm at 1.15GHz and the bandwidth of 225 MHz are obtained by a HFSS calculation.



HFSS model of the kicker



SuperKEKB Longitudinal Bunch Feedback System

Summary

- The electron-positron collider KEKB B-factory is currently being upgraded to SuperKEKB. The first beam is expected in the Japanese FY 2014.
- The BPM system will be equipped with the super-heterodyne detectors, the turn-by-turn log ratio detectors and the IR orbit feedback detectors.
- New X-ray beam profile monitor based on the coded aperture imaging method will be installed.
The large angle beamstrahlung monitor detecting polarization of the synchrotron radiation generated by beam-beam interaction will be installed near IP.
The diamond mirror for the visible light monitor is being developed.
- The bunch-by-bunch feedback system will be upgraded using low noise frontend electronics and new 12 bits iGp digital filters.
- The beam current monitor, the tune monitor and the loss monitor are mostly reused from KEKB.

Acknowledgments

- The authors would like to thank the [KEKB vacuum group](#) for manufacturing BPM chambers.
- They also thank [Prof. J. Fox](#) for valuable advices for the instrumentation system of SuperKEKB.
- The authors thank [staffs at Cornell University](#) for their assistance and efforts for development of the X-ray monitor at CesrTA.
- They also thank [Prof. T. Mitsuhashi](#) for cooperation to test the X-ray monitor at ATF2.