IP feedback for SuperKEKB

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KEK Accelerator Laboratory

Machine parameters for SuperKEKB

Machine Design Parameters

parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7.007	GeV
Half crossing angle	φ	11		41.5		mrad
# of Bunches	N	1584		2500		
Horizontal emittance	ε_x	18	24	3.2	5.3	nm
Emittance ratio	κ	0.88	0.66	0.27	0.24	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
Beam currents	I_b	1.64	1.19	3.6	2.6	A
beam-beam param.	ξ_y	0.129	0.090	0.0886	0.081	
Bunch Length	σ_z	6.0	6.0	6.0	5.0	mm
Horizontal Beam Size	σ_x^*	150	150	10	11	um
Vertical Beam Size	σ_y^*	0.94		0.048	0.062	um
Luminosity	**L**	**2.1×10^{34}**		**8×10^{35}**		$cm^{-2}s^{-1}$

SuperKEKB status update

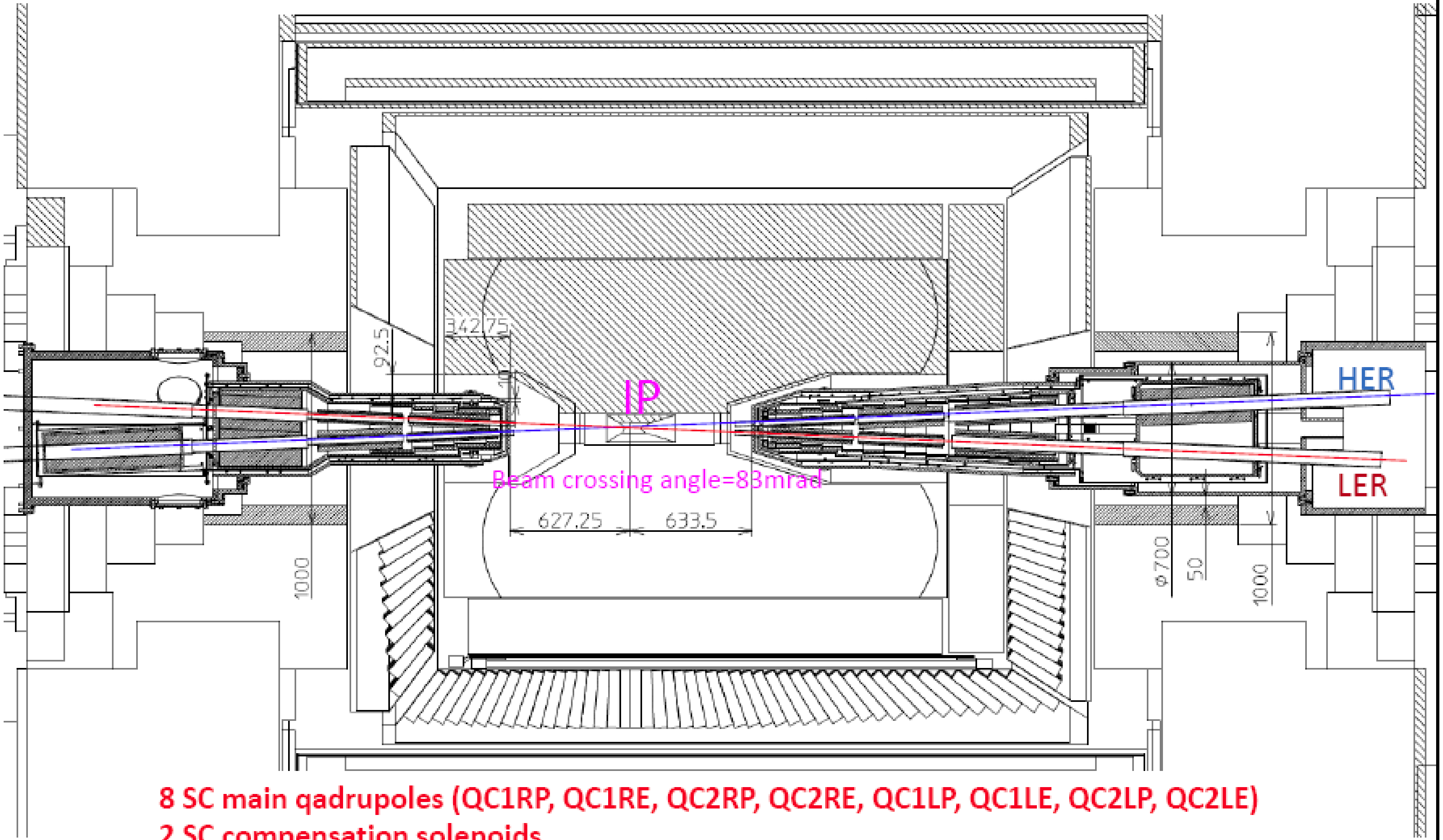
- **Construction works**
  - Finished removing LER arc vacuum chambers.
  - Finished removing LER arc bends.
  - Almost finished removing LER wigglers.
  - Removing Tsukuba straights will start on Apr..

  - Arrived LER wiggler chambers
  - Will arrive Damping ring magnets soon
- **FY2011 construction budget has been approved.**
- **We will have groundbreaking ceremony on 8/Apr.**

Less crowded & much lighter tunnel and much more crowded storage area.

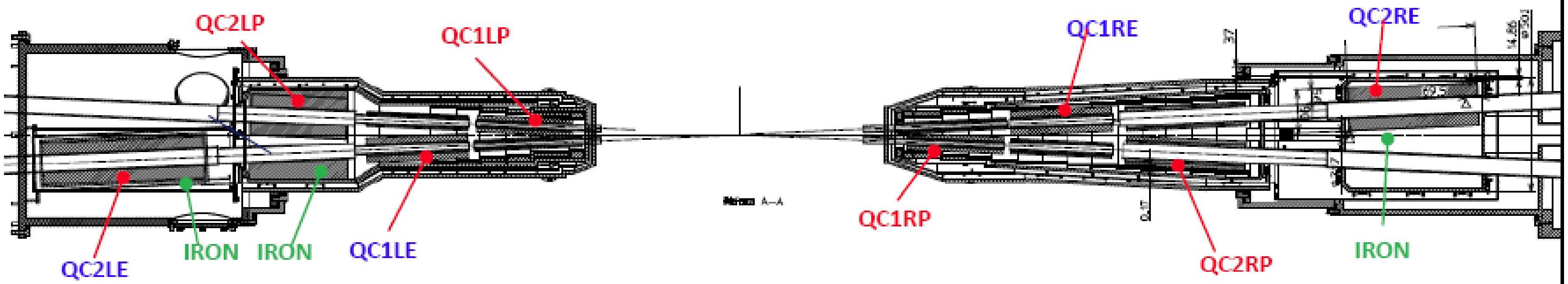
Magnet type	# of Mag. removed from KEKB so far	Mag Weight (t)	Net Weight (t)	comments
LER B	107	~3	~320	~30 magnets will be reused at SuperKEKB. Looking for someone who can use them.
Steering	860	~0.4	~340	~60% of them will be reused with some modification. Looking for someone who can use them.
Wiggler	134	~3	~400	~20 still remains in the tunnel. All wigglers will be reused at SuperKEKB.
			>1000	Vacuum pipes (& the solenoid coils) are not included.

IR SC magnets, cryostat and Belle



8 SC main qadrupoles (QC1RP, QC1RE, QC2RP, QC2RE, QC1LP, QC1LE, QC2LP, QC2LE)
2 SC compensation solenoids
52 SC correction coils

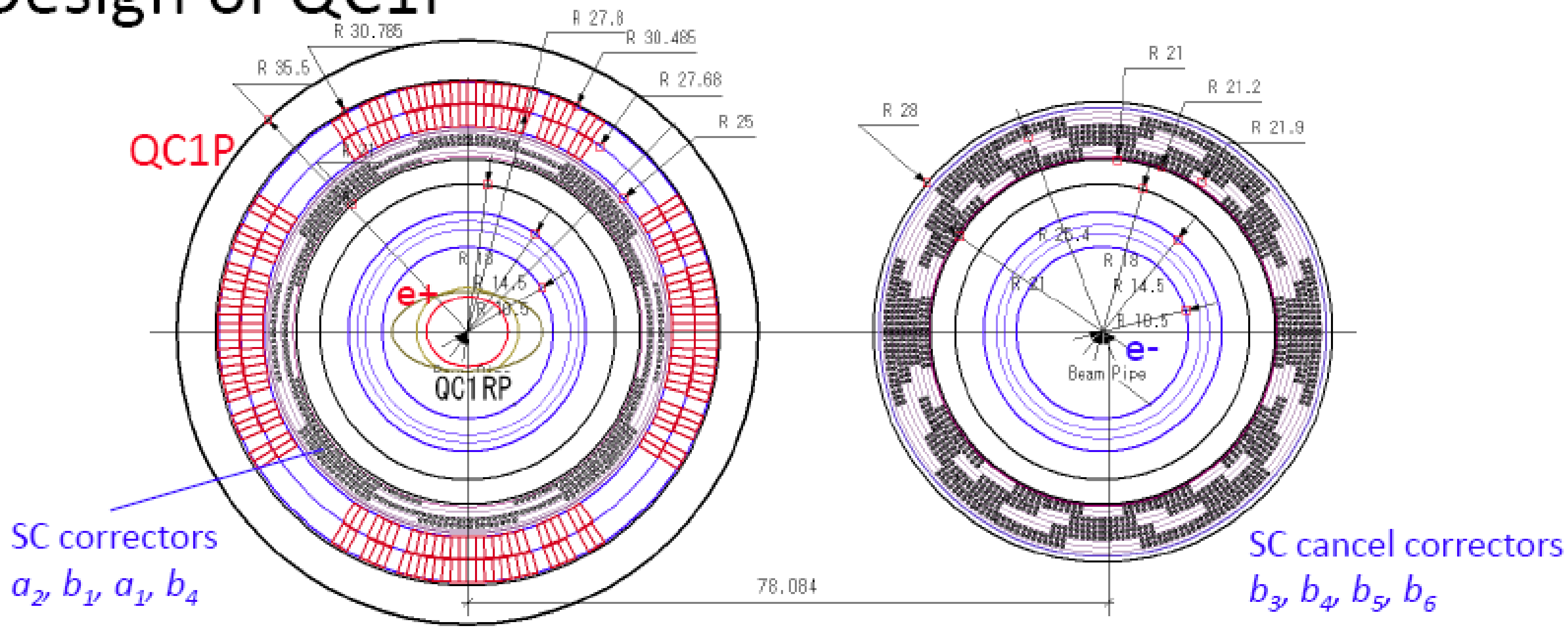
IR magnets



	Integral field gradient (T/m)･m	Position from IP mm	Magnet type	Corrector	Leak field cancel coil
QC2RE	12.91	2925	S.C. + Iron Yoke	a_1, b_1, a_2, b_4	
QC2RP	10.92 [31.21T/m×0.350m]	1956	S.C.	a_1, b_1, a_2, b_4	b_3, b_4, b_5, b_6
QC1RE	26.22 [79.03×0.360]	1410	S.C.	a_1, b_1, a_2, b_4	b_3, b_4, b_5, b_6
QC1RP	22.43 [66.52×0.3372]	932	S.C.	a_1, b_1, a_2, b_4	b_3, b_4, b_5, b_6
QC1LP	22.91 [67.94×0.3372]	-932	S.C.	a_1, b_1, a_2, b_4	b_3, b_4, b_5, b_6
QC1LE	26.03 [82.75×0.360]	-1410	S.C.	a_1, b_1, a_2, b_4	b_3, b_4, b_5, b_6
QC2LP	10.96	-1930	S.C. + Iron Yoke	a_1, b_1, a_2, b_4	
QC2LE	14.13	-2700	S.C. + Iron Yoke	a_1, b_1, a_2, b_4	

2. IR SC magnets

Design of QC1P



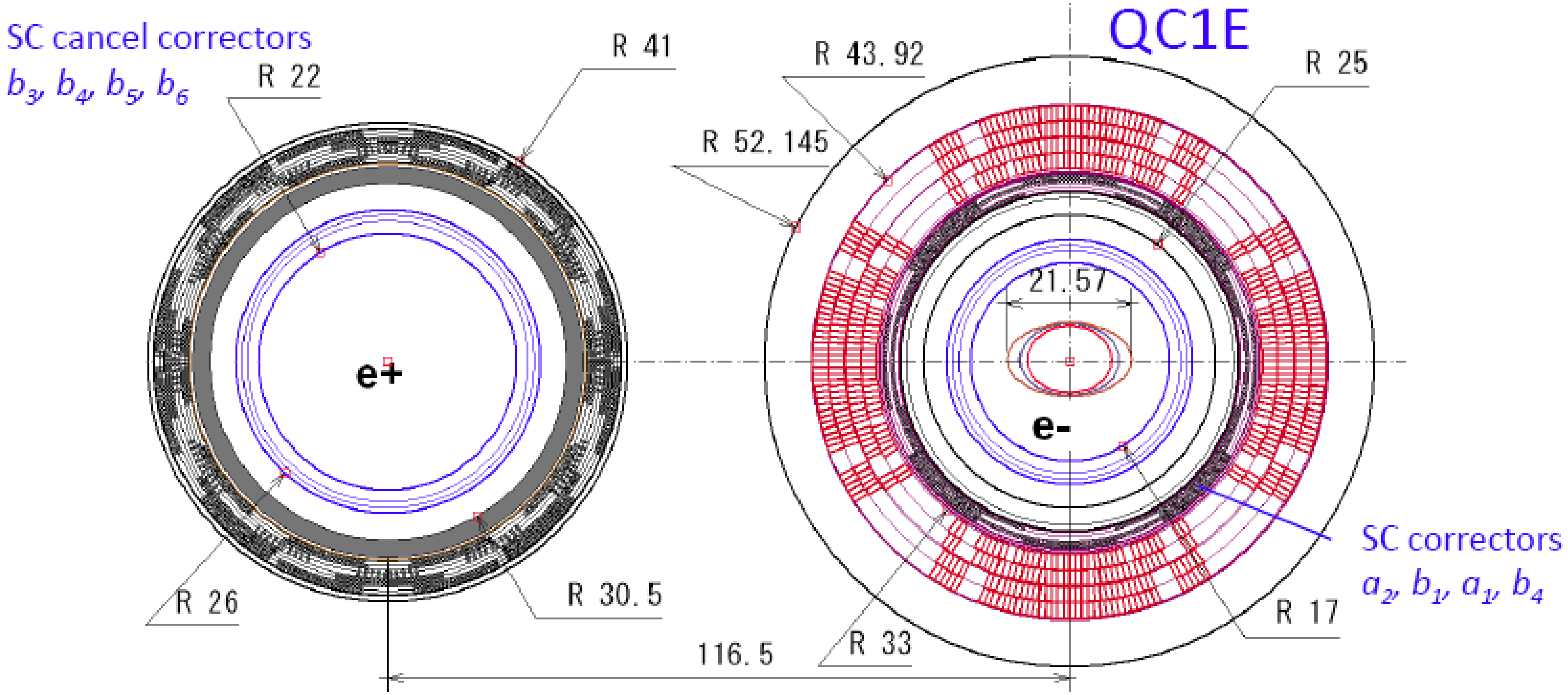
QC1P magnet design (QC1RP, QC1LP)

- Same cross section and longitudinal design for QC1RP and QC1LP
- 2 layer coils [double pancake]
- Designed SC cable
  - Cable size : 2.5 mm in height, and 0.93 mm in width
  - SC strand cable : ϕ 0.5 mm, 10 wires in the cable
- SC correctors inside of the magnet bore
  - a_2, b_1, a_1, b_4 from the inside, single layer coil
- Cryostat inner bore radius=18.0 mm
- Beam pipe (warm tube)
  - inner radius=10.5 mm, outer radius=14.5 mm

SC cancel coils against the leak field from QC1P

- b_5, b_6, b_4 , b_3 from the inside
- Cryostat inner bore radius=18.0 mm
- Beam pipe(warm tube)
  - inner radius=10.5 mm, outer radius=14.5 mm

Design of QC1E



SC cancel coils against the leak field from QC1E

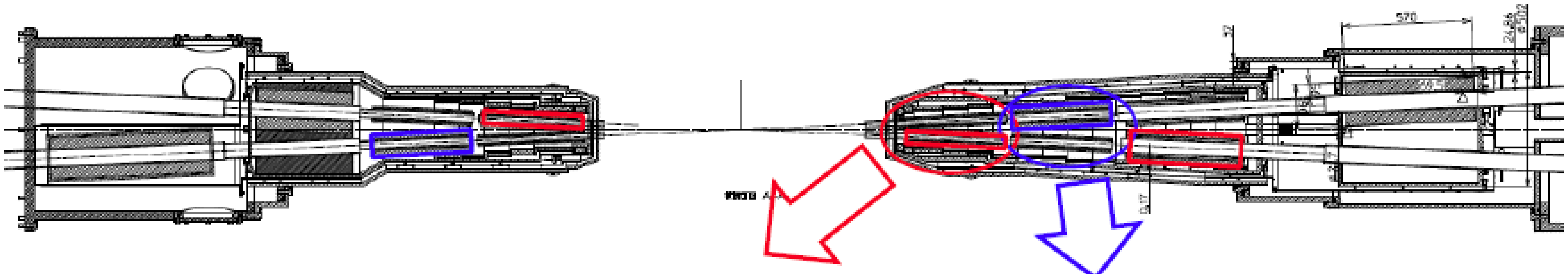
- b_5, b_6, b_4, b_3 from the inside
- Cryostat inner bore radius=30.5 mm
- Beam pipe(warm tube)
  - inner radius=22.0 mm, outer radius=26.0 mm

QC1E magnet design (QC1RE, QC1LE)

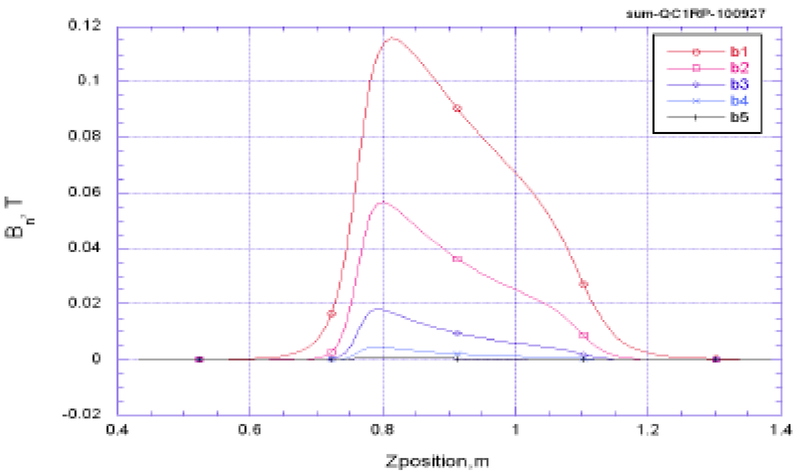
- Same cross section and longitudinal design for QC1RE and QC1LE
- 4 layer coils [double pancake]
- Cryostat inner bore radius=25.0 mm
- Beam pipe (warm tube)
  - inner radius=17.0 mm, outer radius=21.0 mm
- G_R = 79.03 T/m at I_{op}=1242.1 A, I_{op}/I_c= 72.7 %
- G_L = 82.75 T/m at I_{op}=1300.6 A, I_{op}/I_c= 75.8 %

Cancel coils for the leak field of QC1P/E and QC2RP

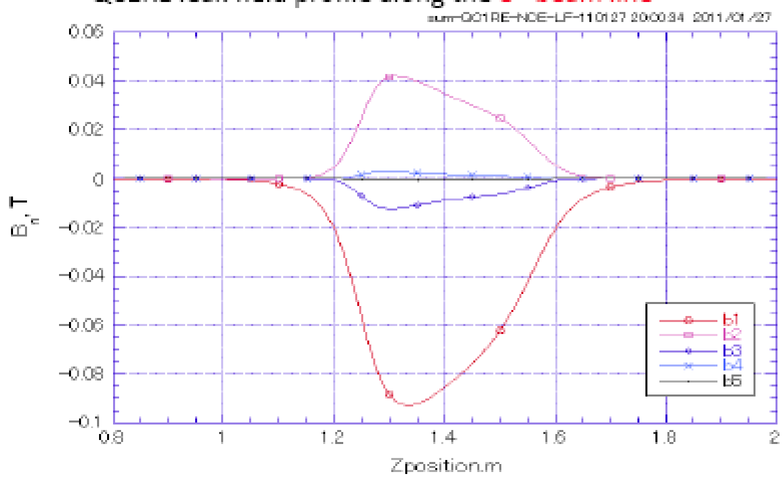
- The leak field profiles along the opposite lines are calculated.
- The leak magnetic fields of the main quadrupoles on the opposite beams are designed to be canceled with the SC correctors of $\boldsymbol{b_3}$, $\boldsymbol{b_4}$, $\boldsymbol{b_5}$ and $\boldsymbol{b_6}$.
- B_1 and B_2 components in the leak field are not canceled, and they are included in the optics calculation.
  - B_2 component is used for focusing and defocusing e-/e+ beams.



QC1RP leak field profile along the e- beam line



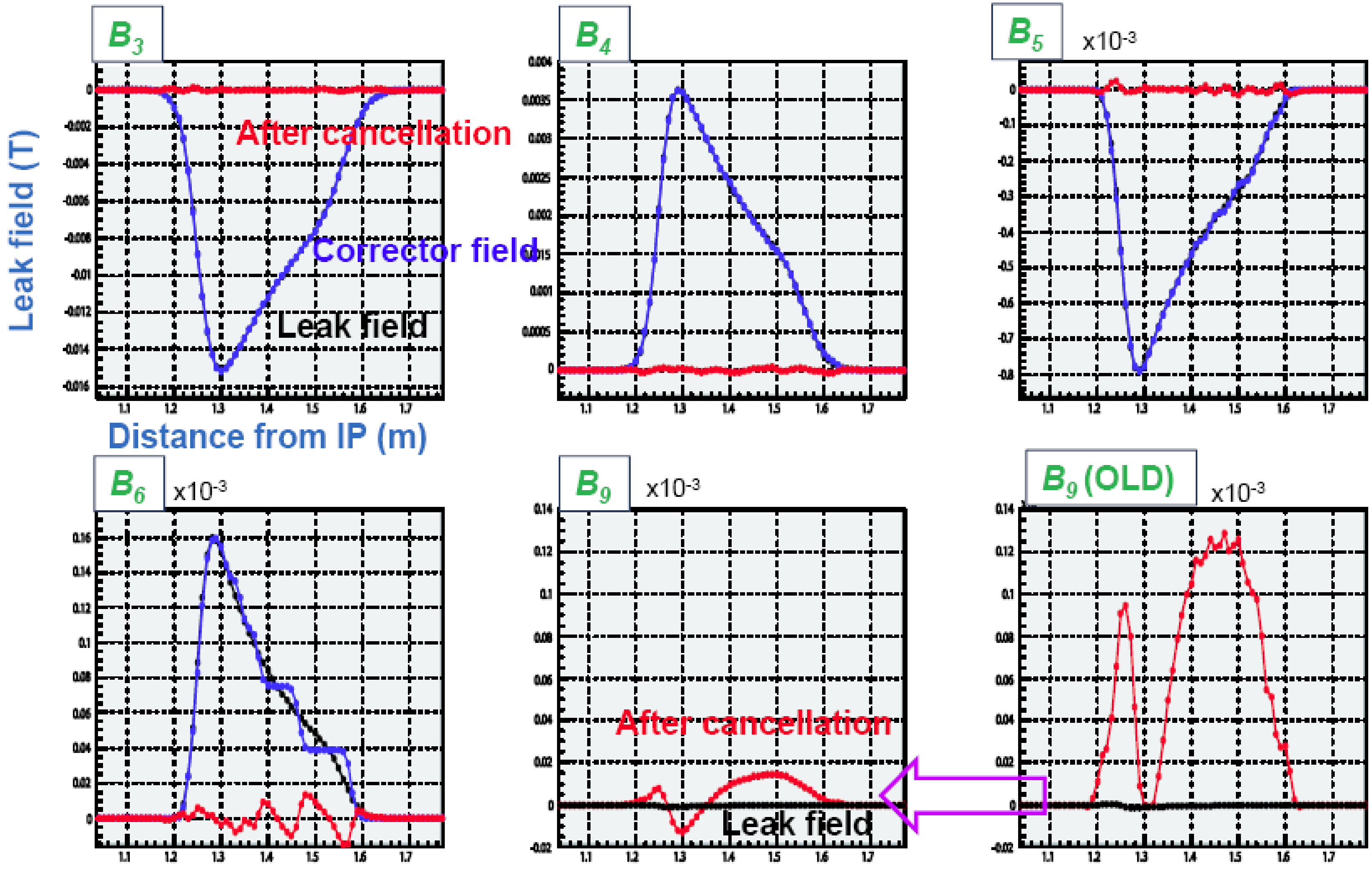
QC1RE leak field profile along the e+ beam line



QC1RE leak field profile and cancellation along LER beam line

No cancellation of dipole and quadrupole fields

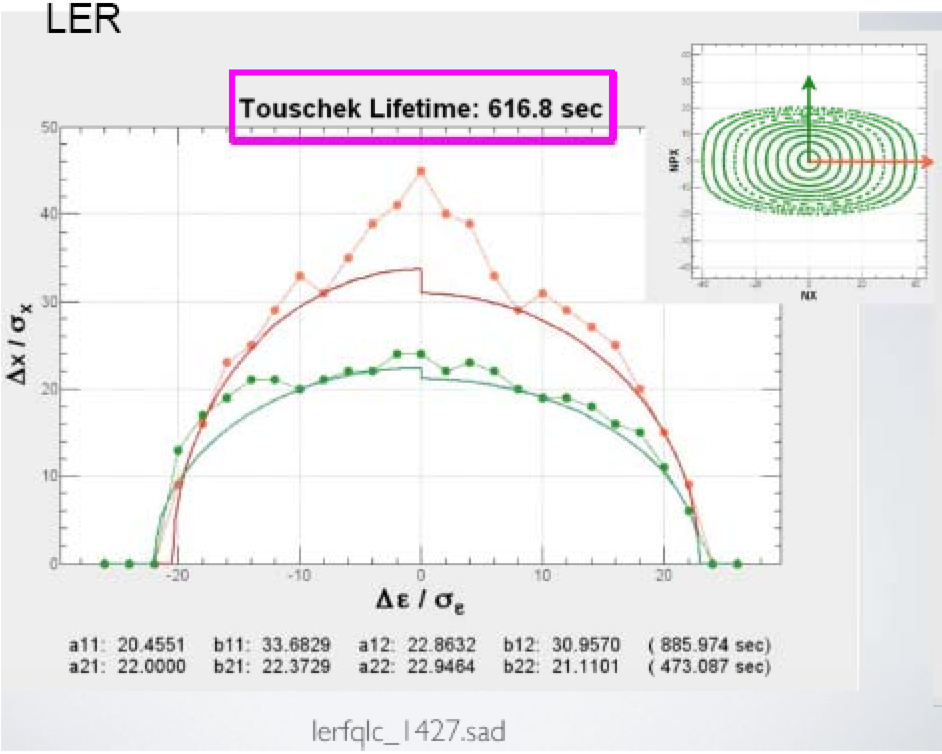
Calculation by M. Iwasaki



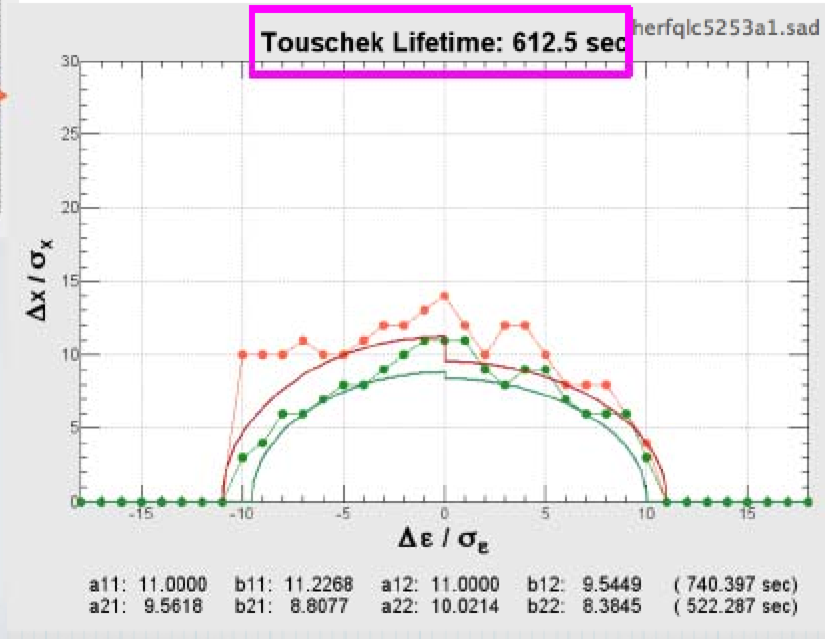
力学口径

まだ改善中の値
724sec程度可能か

LER



HER



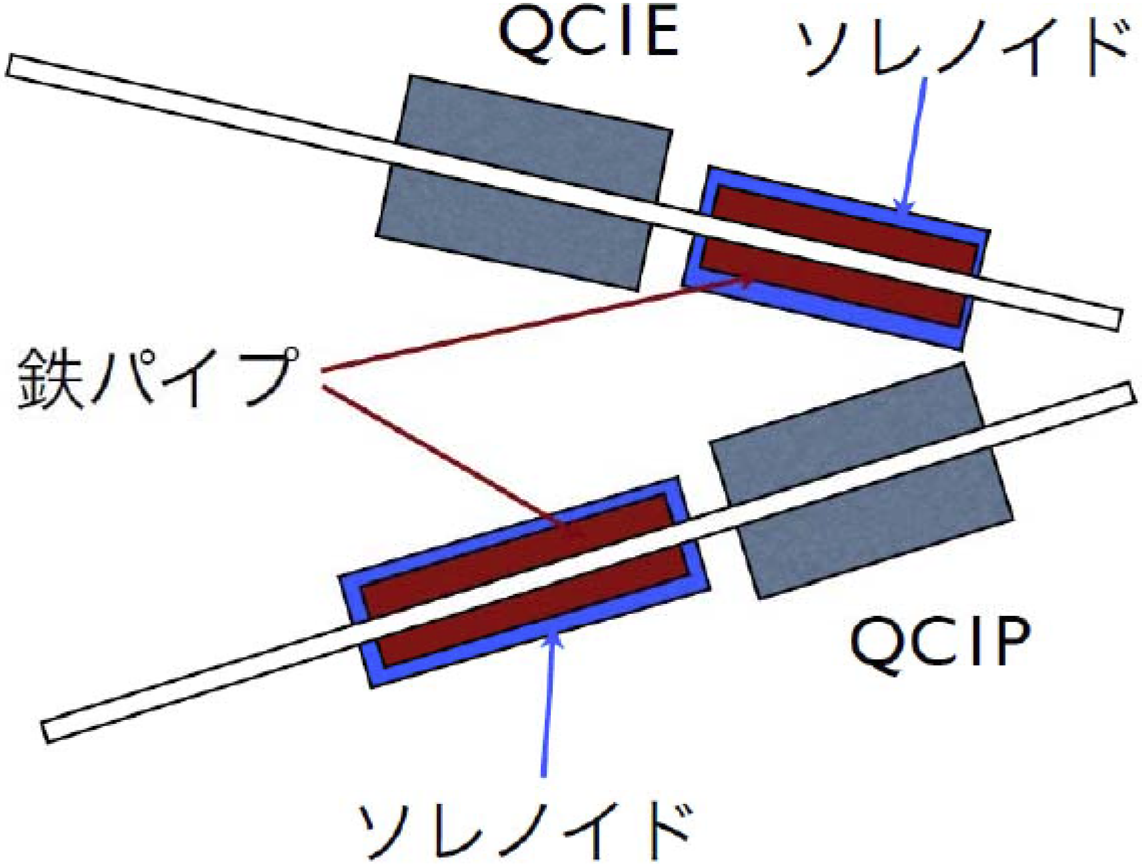
最大入射率：
LER: 4 nC/bunch, 2 bunches/pulse, 25 Hz
HER: 5 nC/bunch, 2 bunches/pulse, 25 Hz

最大入射率と釣り合うビーム寿命は
LER >181 sec, HER > 105 sec

ビーム寿命要求値は >600 sec

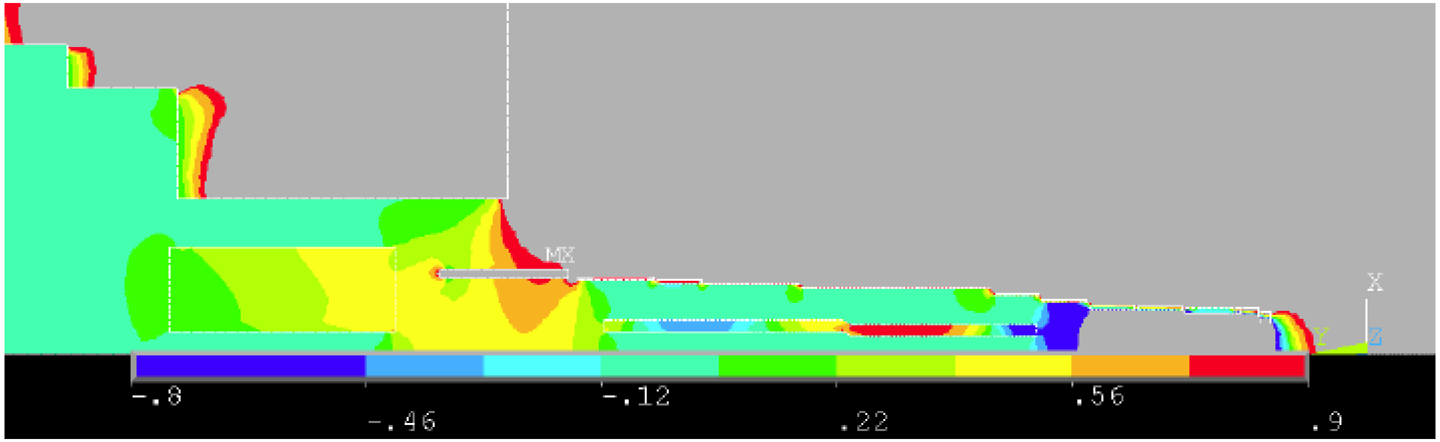
K. Oide, Y. Ohnishi, A. Morita

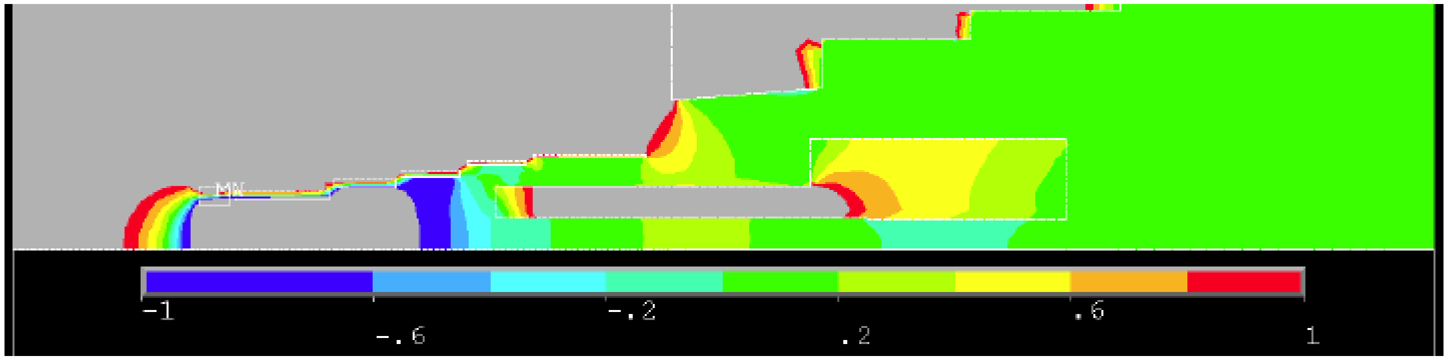
生出案



漏れ磁場の影響を除く為に、QC1E/Pの対向ビームラインに磁気シールドを付ける。

補償ソレノイド磁場





Tunability of Parameters

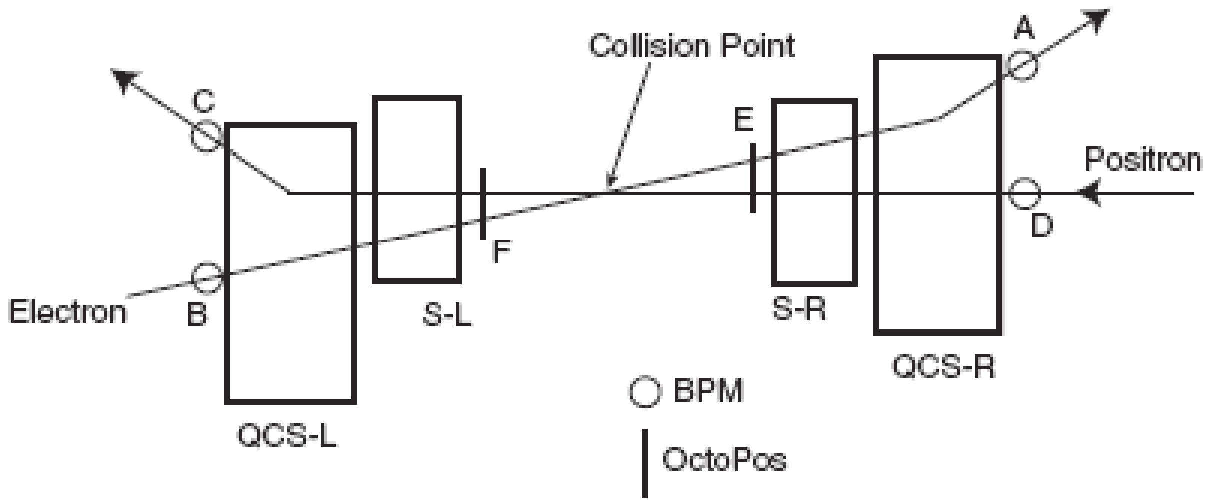
	SuperKEKB	Case I	Case II
Energy (GeV) (LER/HER)	4.0/7.0	4.0/7.0	4.0/7.0
β_y^* (mm)	0.27/0.30	0.27/0.347	0.26/0.30
β_x^* (mm)	32/25	32/25	40/25
ε_x (nm)	3.2/5.3	3.2/4.6	3.2/4.3
$\varepsilon_y/\varepsilon_x$ (%)	0.27/0.24	0.28/0.25	0.48/0.41
σ_y(μm)	0.048/0.062	0.049/0.063	0.063/0.073
ξ_y	0.09/0.081	0.087/0.09	0.09/.078
σ_z (mm)	6/5	6/5	6/5
I_{beam} (A)	3.6/2.6	3.6/2.6	3.6/2.6
$N_{bunches}$	2500	2500	2000
Luminosity (10^{34} cm^{-2} s^{-1})	80	80	80

Machine parameters are tunable to some extent.

US-Japan collaboration

- Since JFY2003
- KEK, SLAC, FNAL, BNL, Cronell U., U. Hawaii, etc.
  - Development of BxB feedback systems
  - Study of E-cloud instability and its cure
  - Development of X-ray beam size monitor
  - Study of beam-beam interactions
- From JFY2011 we will start following programs with SLAC
  - Development of RF gun
  - Design study of the IR masking and shielding
  - Mechanical design of collimators
  - Accelerator physics
- About $609k will be approved

IP orbit feedback for KEKB (iBump)



- **Calculate beam-beam deflection (H and V) using position data from BPM outside QCS magnets.**
  - Repetition~1Hz.
  - LER beam size feedback (Horizontal)
- **Change the HER orbit with fast correctors**
- **Slow orbit corrector (CCC) corrects the residual orbit distortion keeping local bump by the iBump FB.**

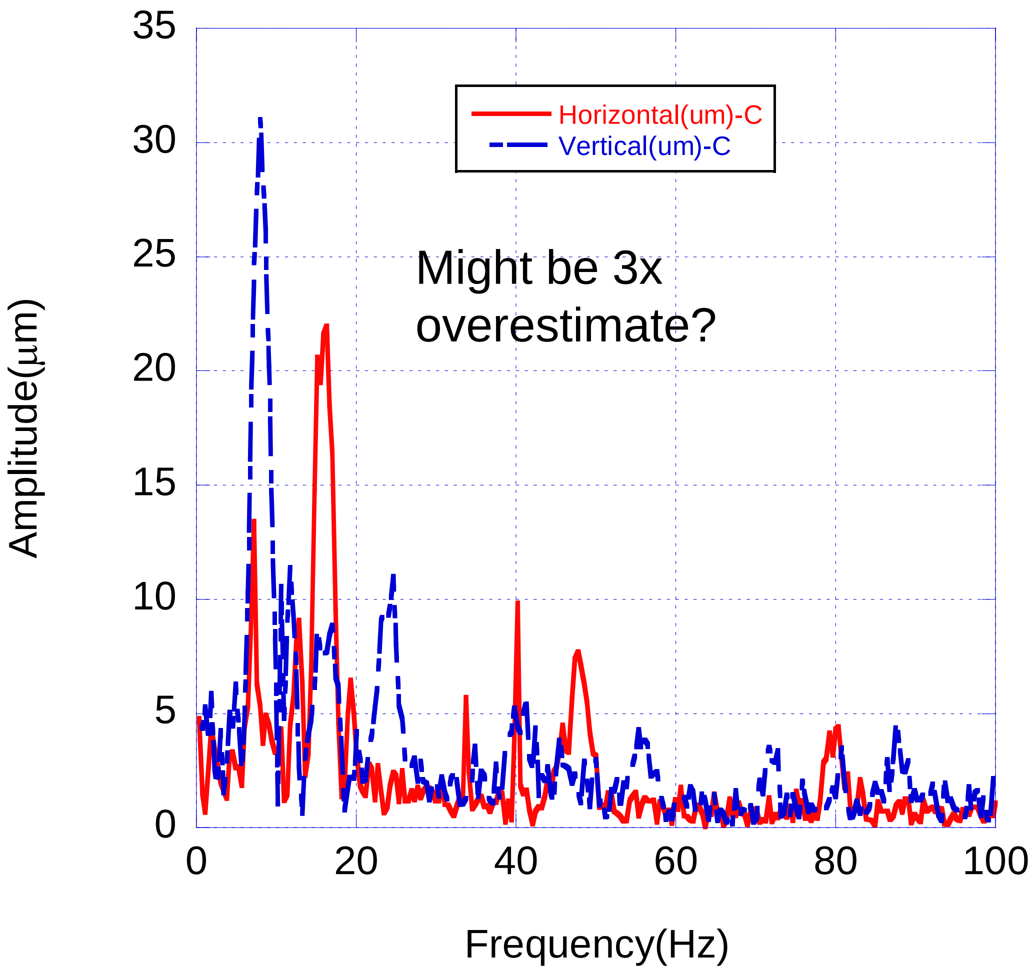
Difficulty of IP orbit control at SuperKEKB

- **SuperKEKB(Nano-Beam Scheme)**
  - Low emittance, low-beta
    - Low emittance -> Orbit drift relative to the IP beam size becomes large.
    - Low-beta -> No difficulty arises, since the orbit change at IP is also smaller.
      But there is an exception. The beta functions at the IR quadrupoles become large.
      -> Position oscillation of these quadurpoles becomes problem.

IP machine parameters

	KEKB		SuperKEKB		
	LER	HER	LER	HER	
ε_x	18nm	24nm	3.2	5.0	
ε_y	0.15nm	0.15nm	8.6pm	13.5pm	~1/4
κ	0.83 %	0.62%	0.27%	0.25%	
β_x*	120cm	120cm	32mm	25mm	
β_y*	5.9mm	5.9mm	0.27mm	0.31mm	~1/4.5
σ_x*	150μm	150μm	10μm	11μm	
σ_x'*	120μrad	120μrad	450μrad	320μrad	
σ_y*	0.94 μm	0.94μm	48nm	56nm	~1/20
σ_y'*	0.16mrad	0.16mrad	0.18mrad	0.22mrad	
iBump horizontal offset		+/- 500μm		+/- 30μm?	
iBump vertical offset		+/- 150μm		+/- 7.5μm?	
iBump vertical angle		+/- 0.4mrad		+/- 0.4mrad?	

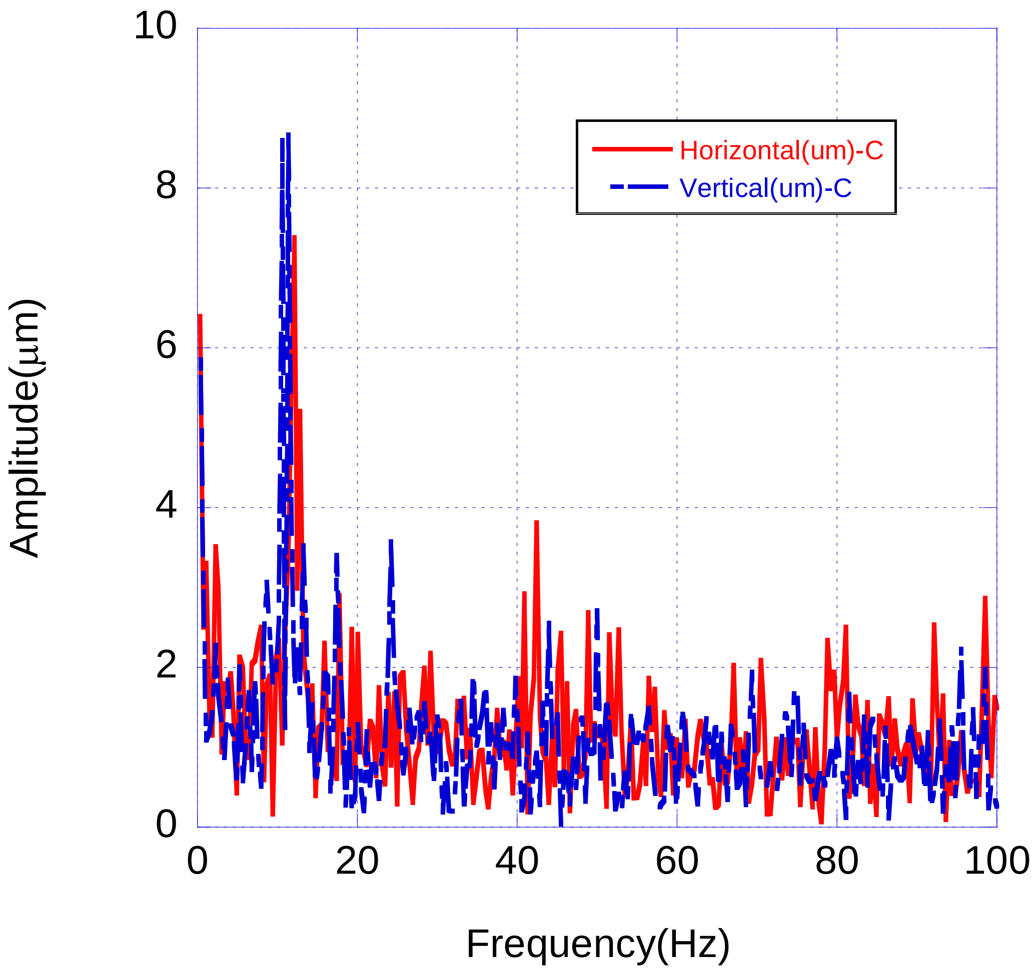
Measured oscillation (KEKB-HER)



Bx~11.4m
By~12.7m

Bx*~1.2m
By*~6mm

Measured oscillation (KEKB-LER)



Bx~21.8m
By~6.4m

Bx*~1.2m
By*~6mm

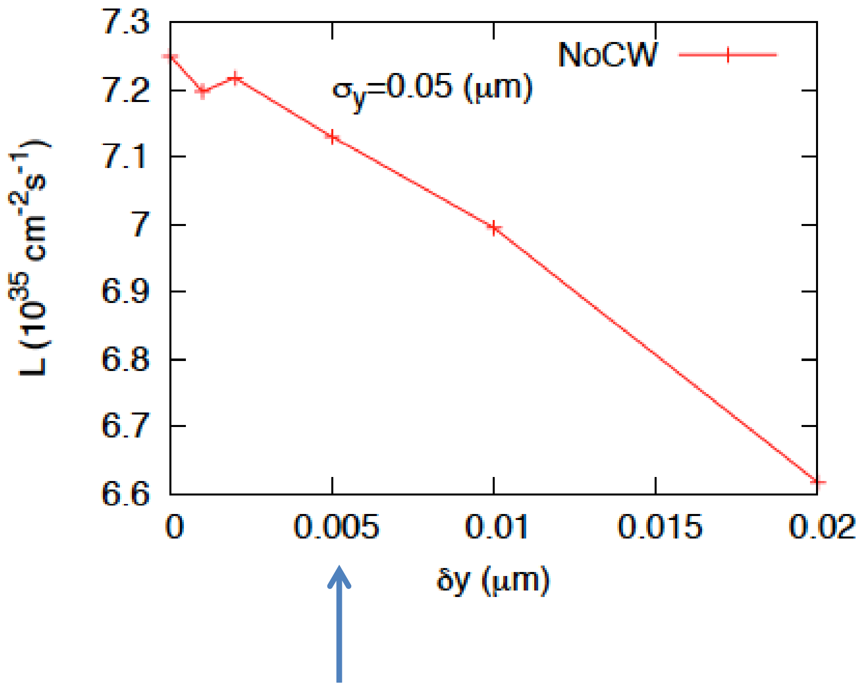
Mechanism of luminosity degradation due to orbit offsets at IP and their tolerance

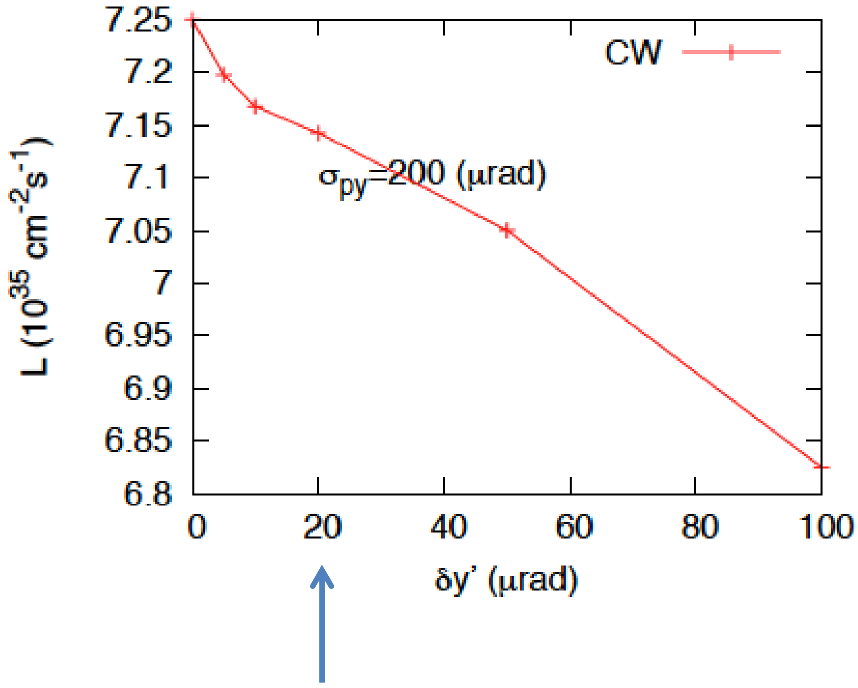
- Mechanism of performance degradation
  - The luminosity degradation due to beam-beam blowup is much larger than geometrical loss.
  - In the horizontal direction, shift of the collision point from the waist point is problem.
- Tolerance
  - Verical offset: Luminosity loss ~ 2% with v-offset of $1/10\sigma_y$
  - Horizontal offset: Shift of CP from waist: < 1/10 β_y* (~30μm) -> h-offset: < ~2.5μm

K. Ohmi

Vertical offset (new)

- tolerance ~0.5σ_i
- toleranceにたいして甘いパラメータ





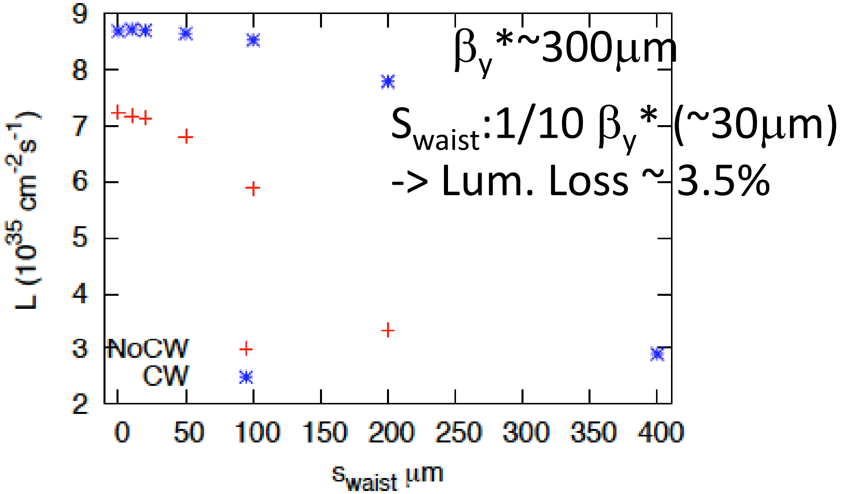
1/10 σ_y*(~5nm) -> Luminosity ~2% loss

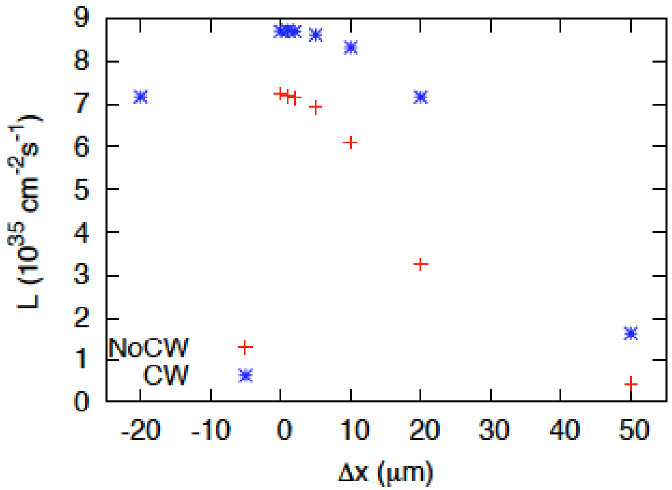
1/10 σ_y' * (~20μrad)-> Luminosity ~1.4% loss

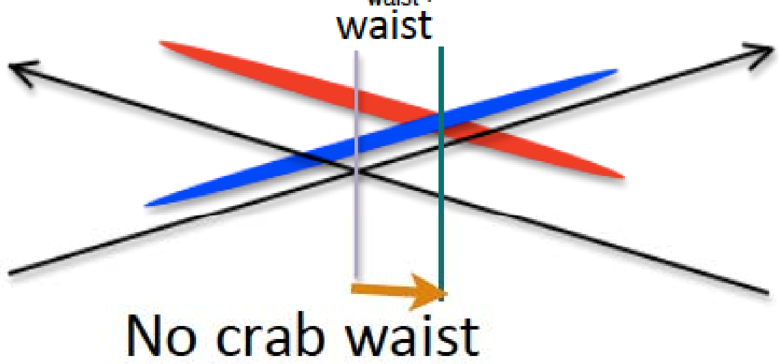
K. Ohmi

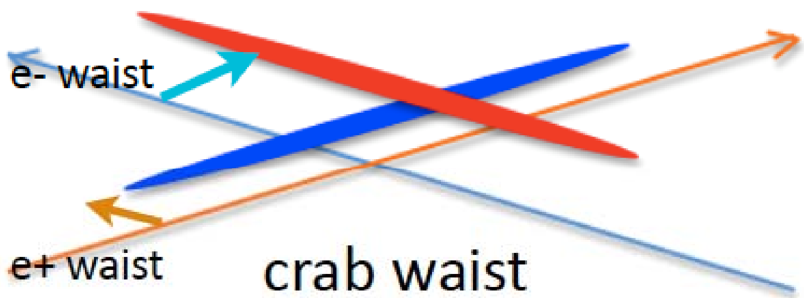
Tolerance of collision condition
Horizontal collision offset and waist

- Horizontal offset and waist are related to each other.
- The cross point of the waist is only one in x-z plane for the crab waist scheme.







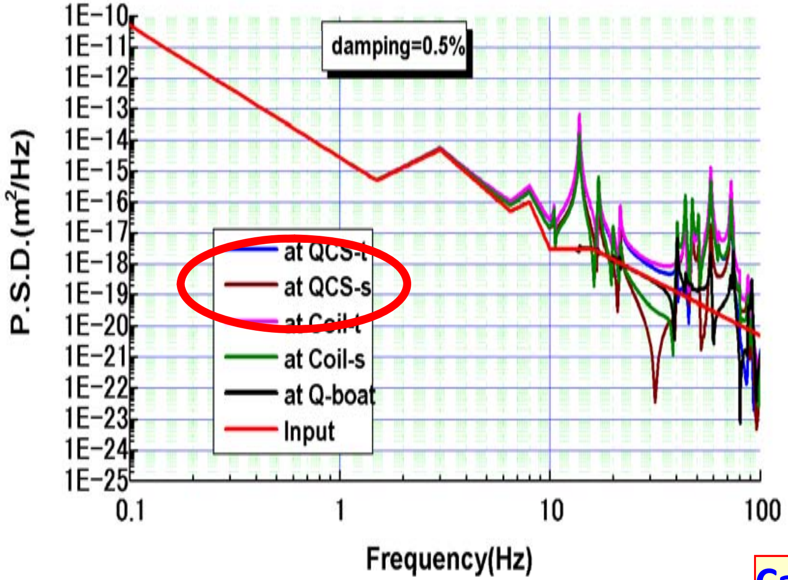


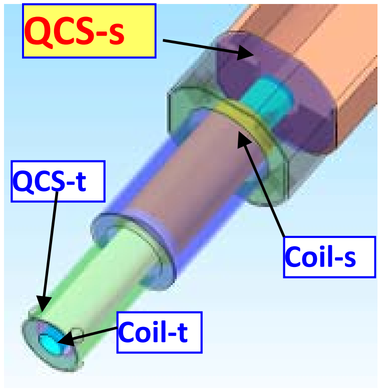
How fast and how largely does the orbit change?

Response amplitude (*Vertical direction*)

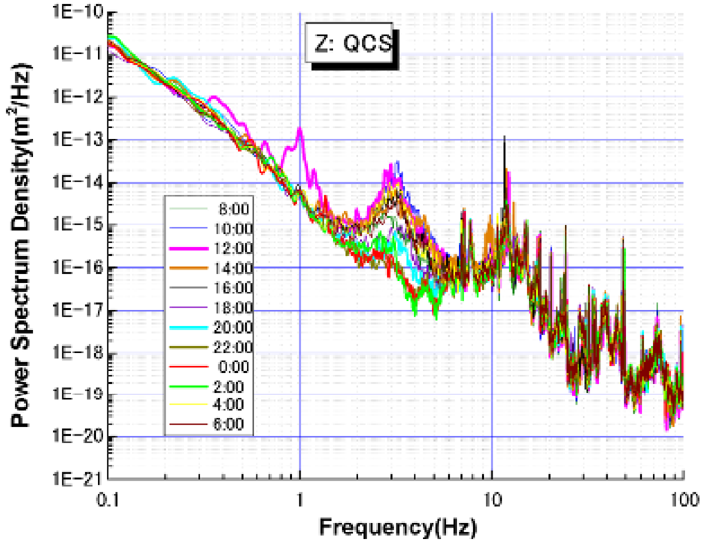
H. Yamaoka

Calculation: ***damp=0.5%***

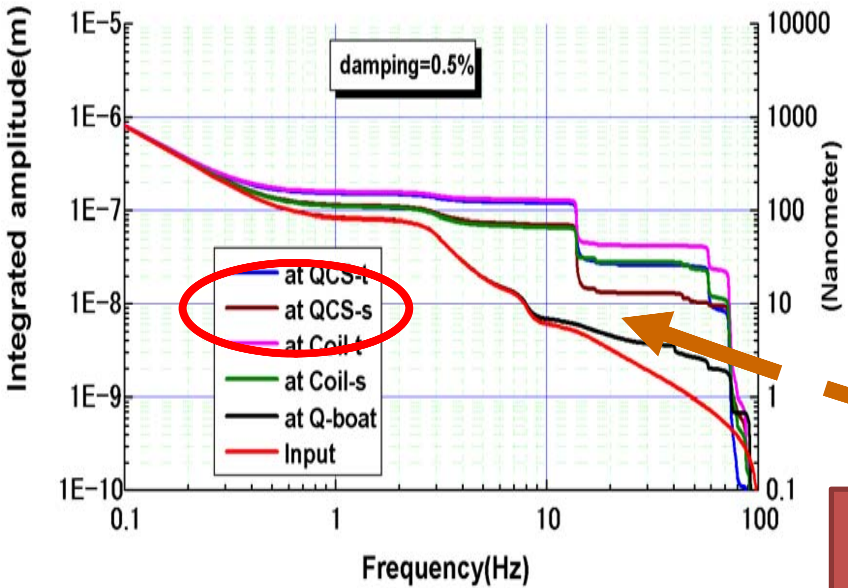


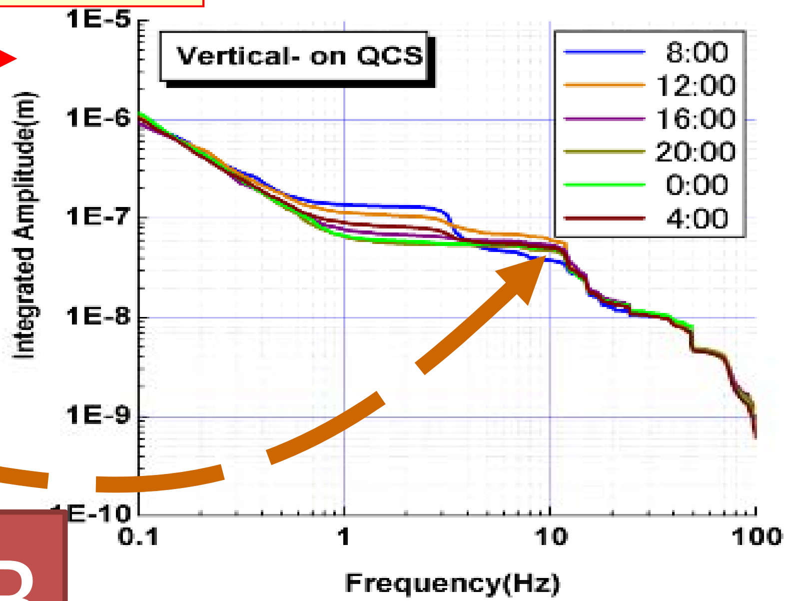


Measurements@QCS-s



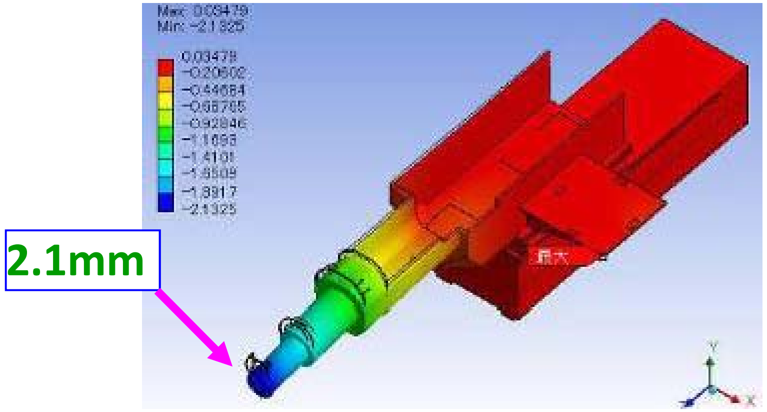
Calculation: | **Measurement**



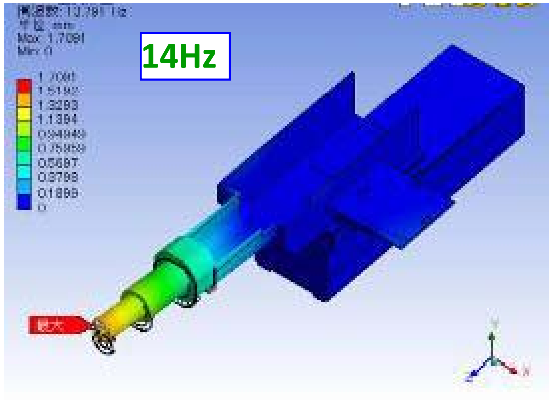


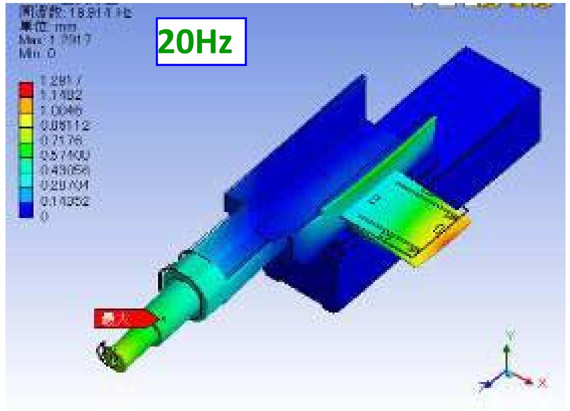
KEKB

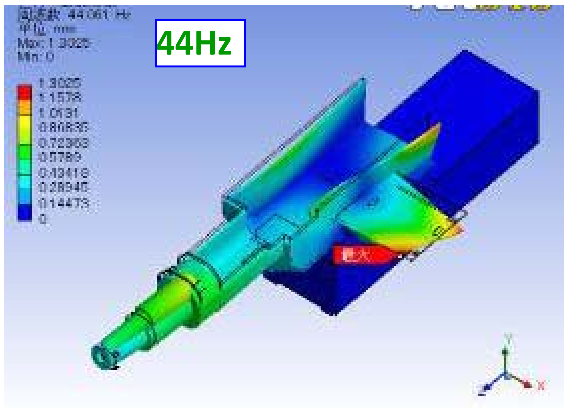
Deformation

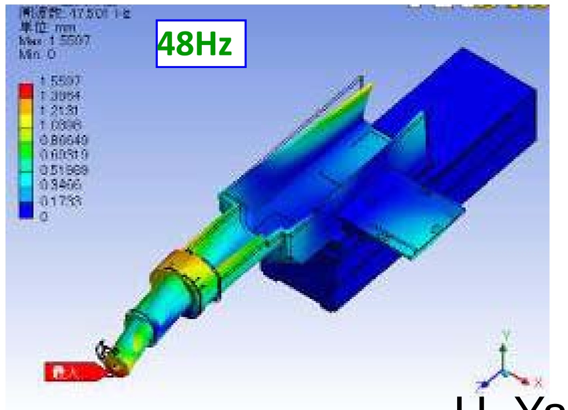


Modal calculation





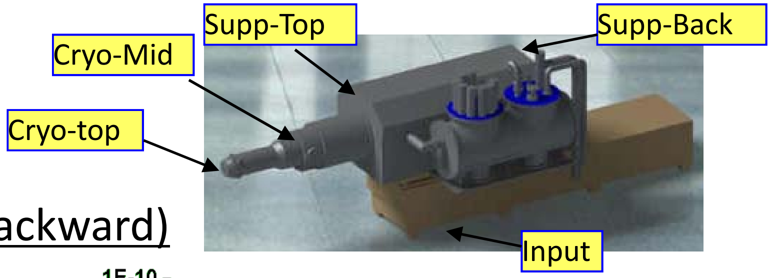


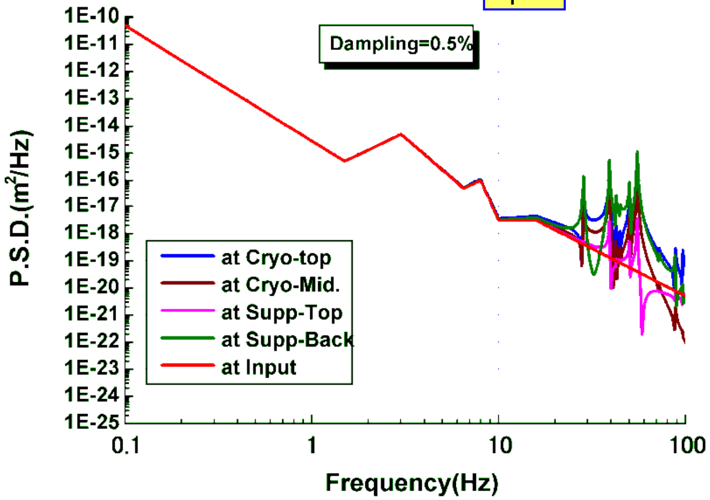


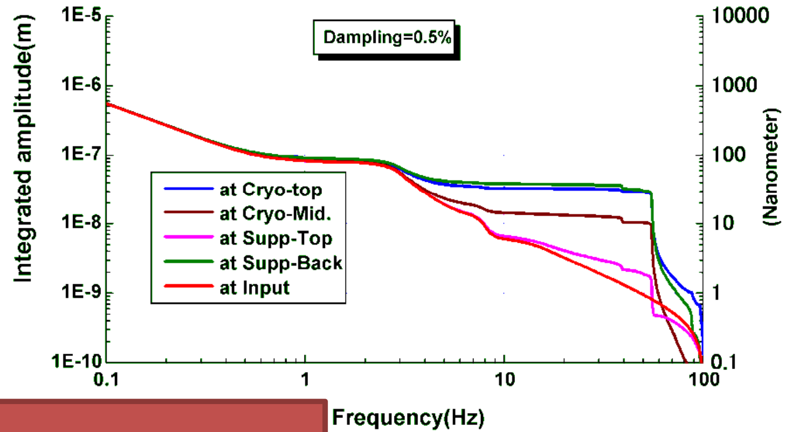
H. Yamaoka

Results(*Vertical direction*)

(Backward)







SuperKEKB

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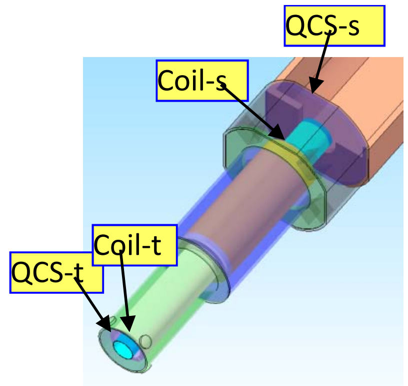
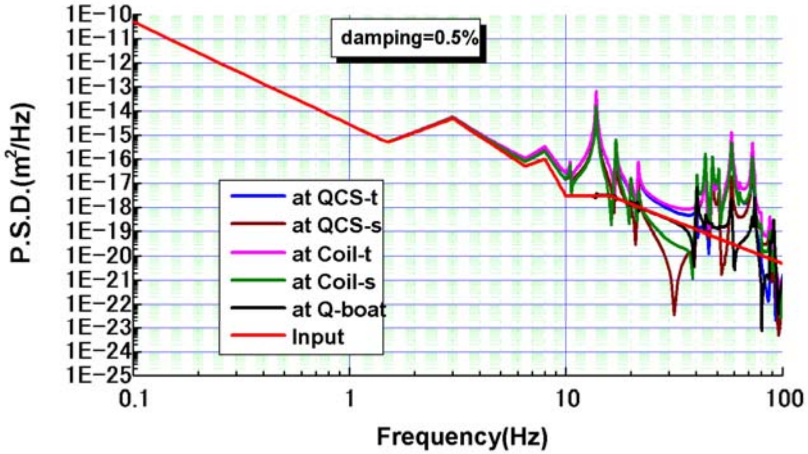
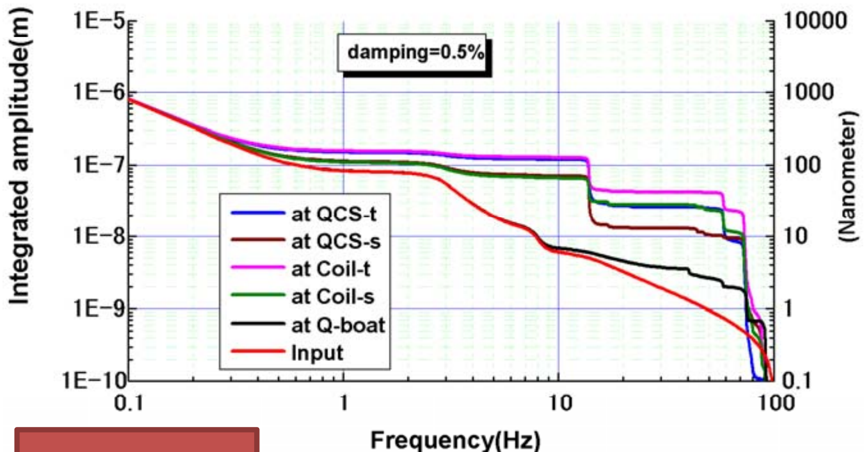


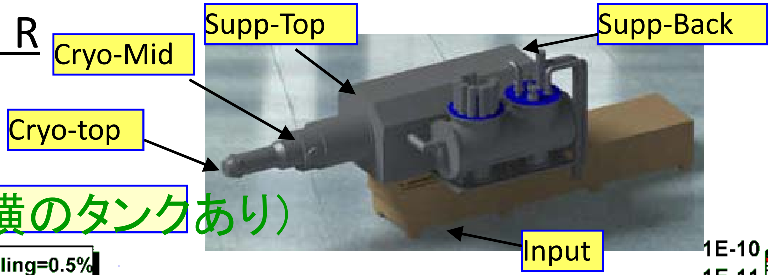




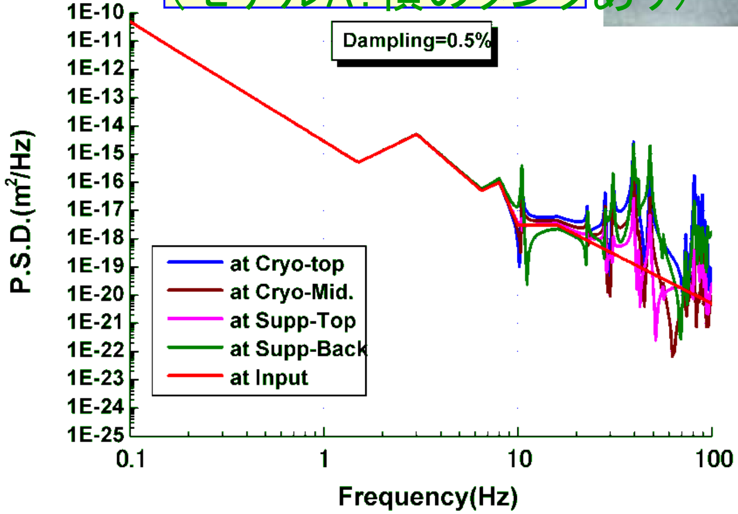
KEKB

床振動に対する影響: R

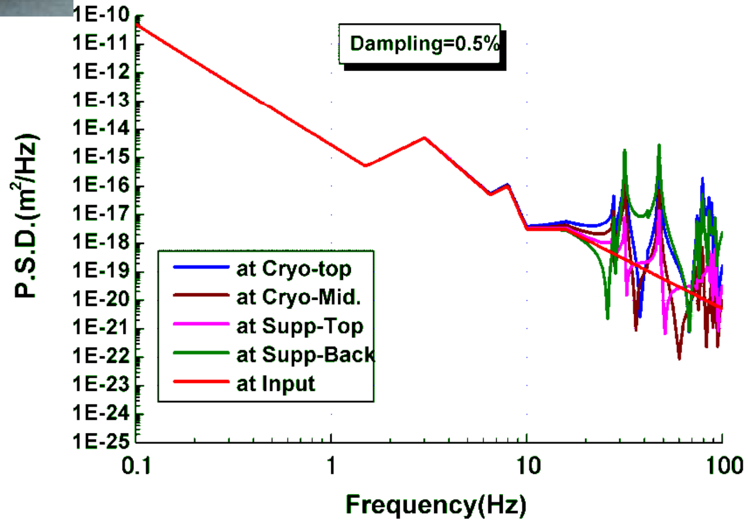
H. Yamaoka

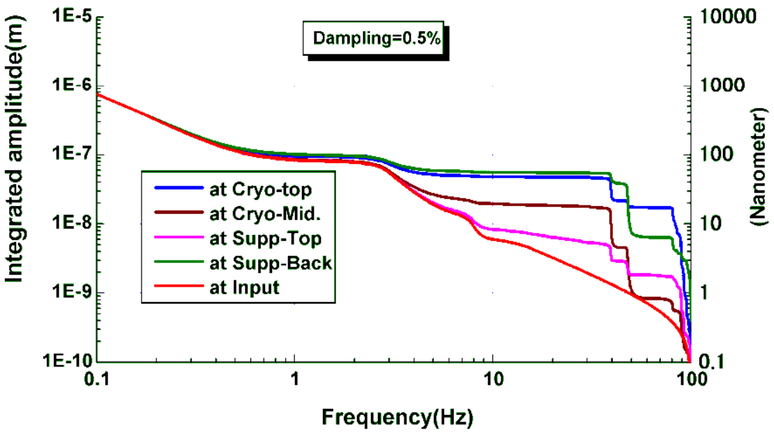


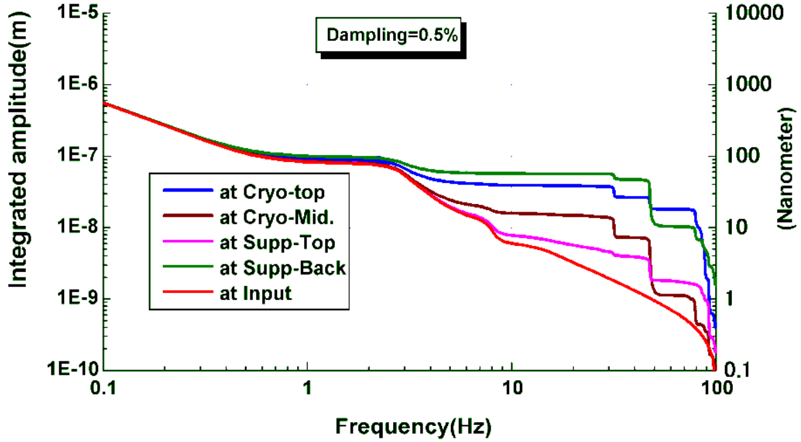
（モデルA：横のタンクあり）



（モデルB：横のタンクなし）





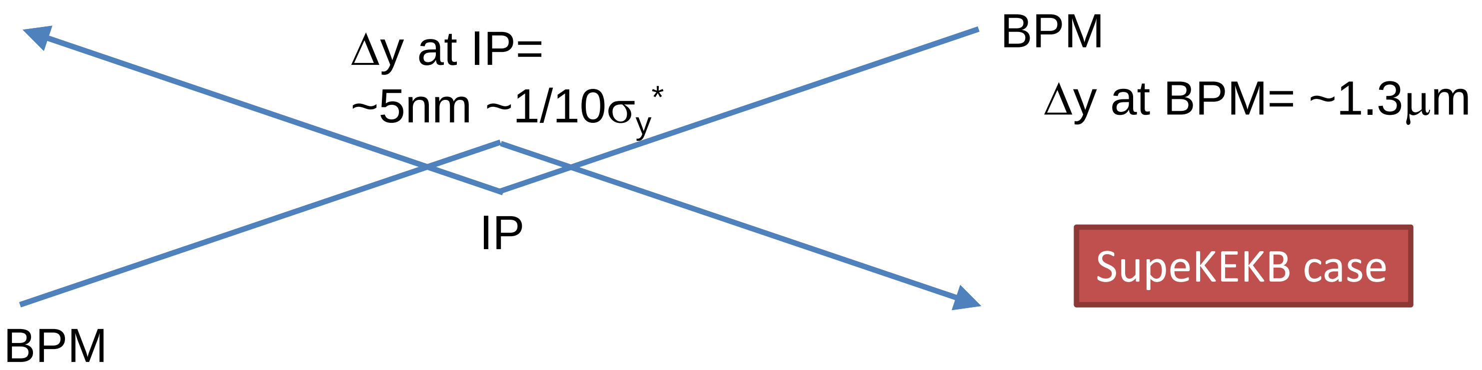


Latest simulation result (SuperKEKB)

How to detect orbit offset at IP

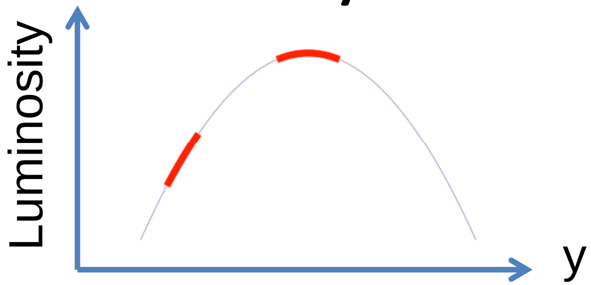
Orbit feedback at IP :Algorism

- Beam-beam deflection (SLC, KEKB vertical)



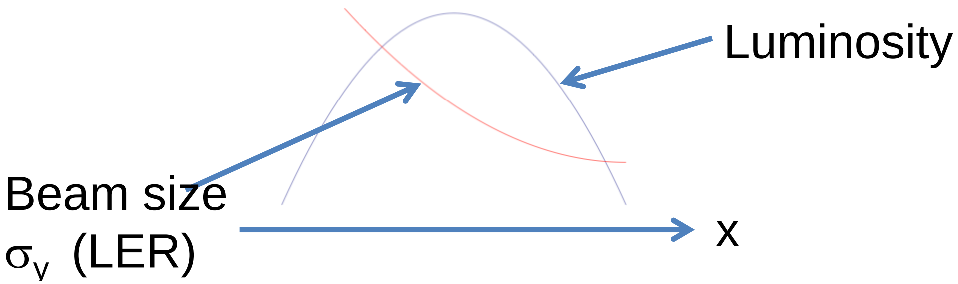
SupeKEKB case

- Luminosity feedback (dithering)(PEP-II)



When we shake the beam at around the peak c
the luminosity, there appears twice of the
frequency of the dithering frequency.

- Beam size feedback (KEKB horizontal)



At KEKB before installation of crab cavitie
the vertical beam of LER was used for the
horizontal orbit feedback at IP.

Sensitivity of detection of beam-beam kick

- Comparison between KEKB and SuperKEKB

$$k_y = \frac{4\pi}{\beta_y^*}\xi_y$$

$$\Delta y' = -\frac{k_y}{2}\Delta y$$

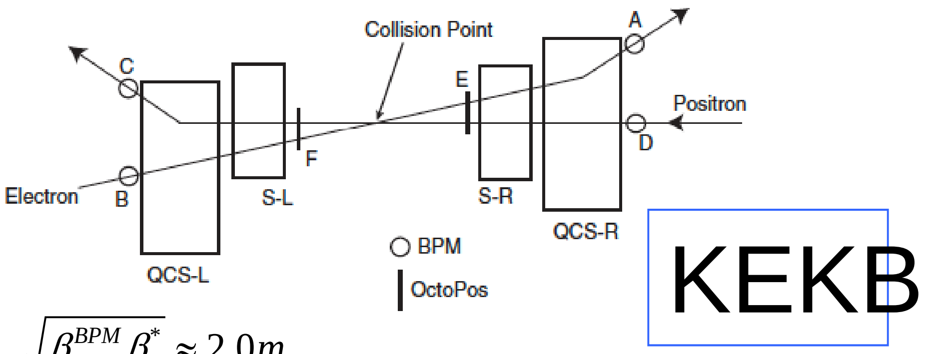
$$\Delta y = \frac{\sigma_y^*}{D} = \frac{\sqrt{\beta_y^* \varepsilon_y}}{D}$$

$$\Delta y' = -\frac{2\pi}{D}\sqrt{\frac{\varepsilon_y}{\beta_y^*}}\xi_y$$

BPMs at SuperKEKB should have 4 times higher sensitivity than KEKB.
-> ~1μm resolution with 1kHz

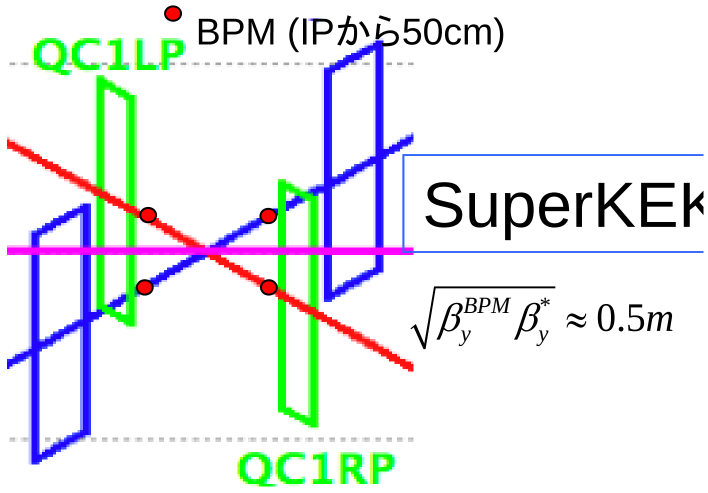
$$\Delta y^{BPM} \approx \frac{\sqrt{\beta_y^{BPM}\beta_y^*}}{2}\Delta y'$$

	KEKB	SuperKEKB
β_y^*	5.9mm	0.27mm
ε_y	0.15nm	8.6pm
$\sqrt{\varepsilon_y / \beta_y^*}$	1.59 x 10^{-4}	1.78 x 10^{-4}
$\sqrt{\beta_y^{BPM}\beta_y^*}$	2.0m	0.5m



$\sqrt{\beta_y^{BPM}\beta_y^*} \approx 2.0m$

A,B,C,D: BPM ~2.4m fromIP



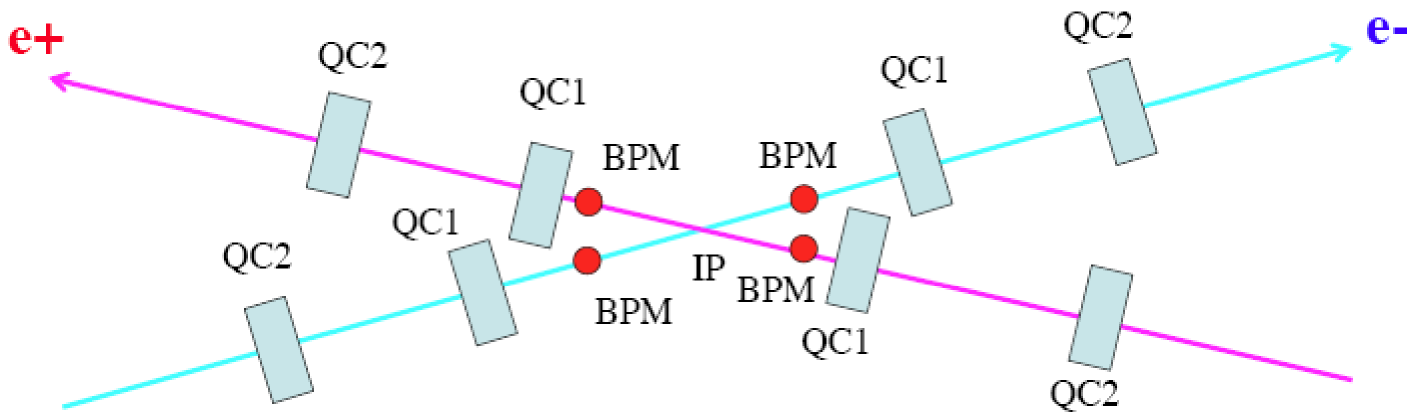
$\sqrt{\beta_y^{BPM}\beta_y^*} \approx 0.5m$

About horizontal orbit feedback

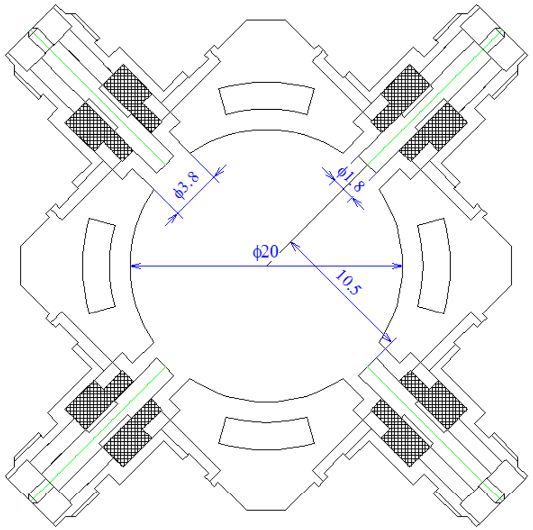
- Difficulty to develop based on the beam-beam defection like the vertical case
  - Small ξx
    - $\xi x \sim 0.0028(e+), 0.0017(e-)$
  - Two sources of horizontal beam-beam kick
    - Horizontal offset and shift of collision timing
- Maybe we need a different method for the Hor. feedback.
  - Luminosity feedback (dithering)? (like PEP-II)
  - Beam size feedback (like KEKB Hor. feedback before crab)
- Effect of horizontal offset
  - Due to Hor. offset, the two beams collide at the position which is shifted from the waist point.
  - The crab waist seems to compensate this shift of waist.
  - However, actually the situation becomes worse with the crab waist, since we have to keep the both beams at the design collision point with this scheme.
- Feedback speed
  - Fast vibration of IR quads is tolerable. We do not need very fast feedback

BPM for IP orbit feedback

- Vertical positions of both beams are monitored for orbit feedback to maintain stable beam collision. For horizontal feedback, BPMs might not be used.
- Resolution:1 μm (tentative)
- Repetition: 1 kHz (tentative)

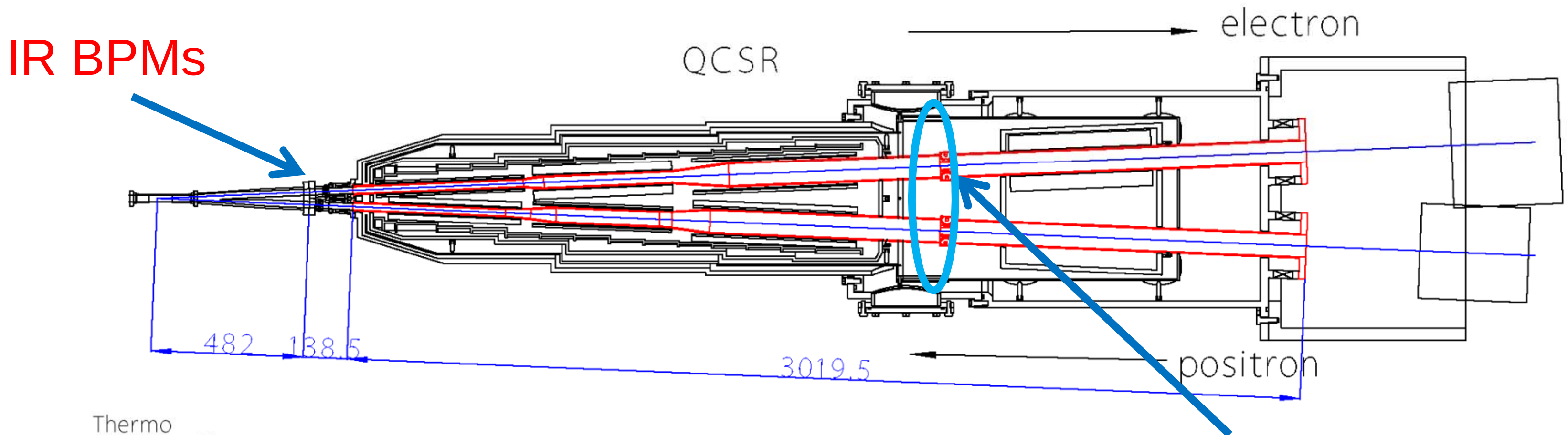


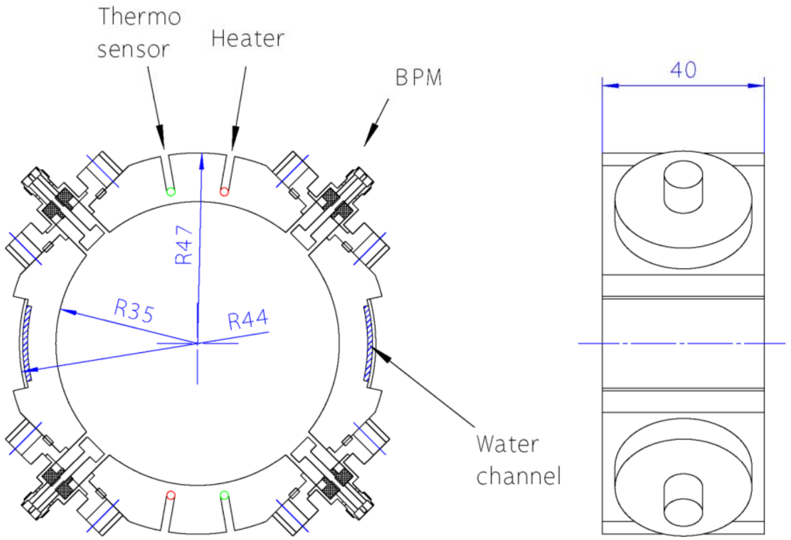
Button electrodes for near IP BPM



- **Small button (rod) size:**
  - 1.8mm diameter
  - Low loss, low εr ceramics
  - SMA-Reverse connector
- **Estimated beam power using GdfidL:**
  - Total passing power : ~11W
  - 508MHz power : ~6dBm

BPM between QC1 and QC2

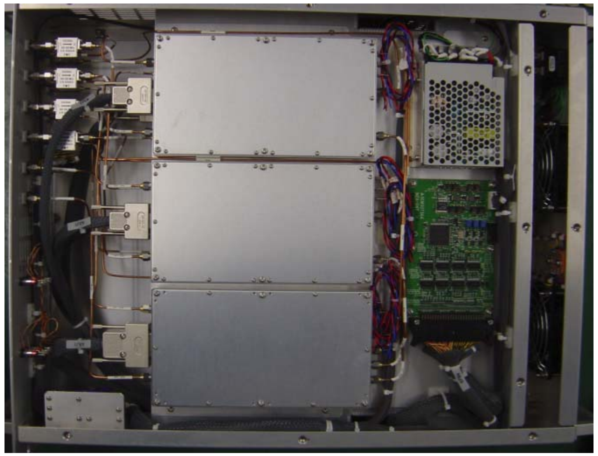


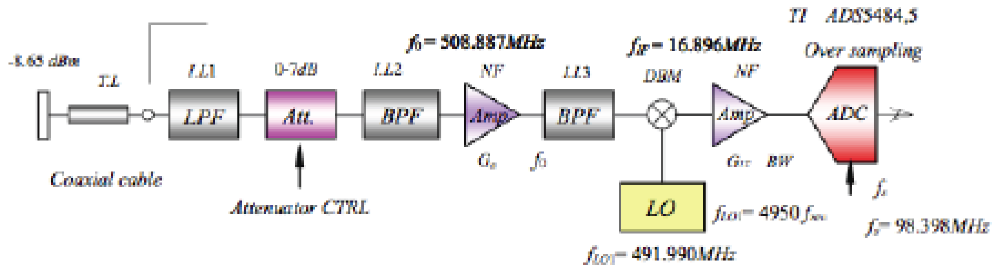


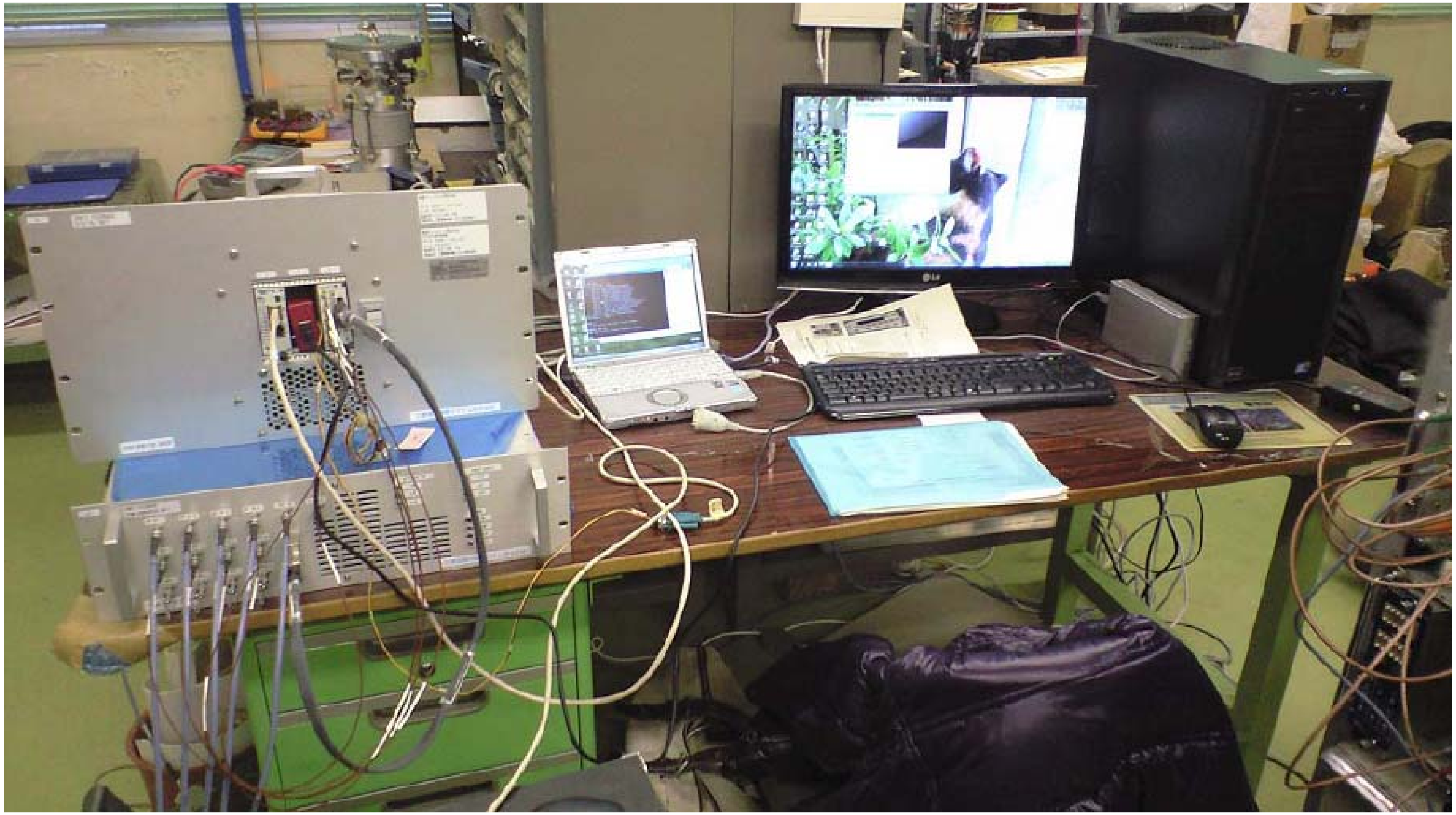
- Pick-ups for BPM are screwed after the beam pipes are inserted into the cryostat using service ports.
- Leaf support
- Rooting of signal cables

Detector

- Down convert 508.8MHz component to IF of 16.9MHz with analog mixer (with level FB).
- Convert IF signal with 16 bit ADCs (99.4MHz=4950 frev).
- Digitally down convert to DC (I & Q ch) through CIC and FIR filters.



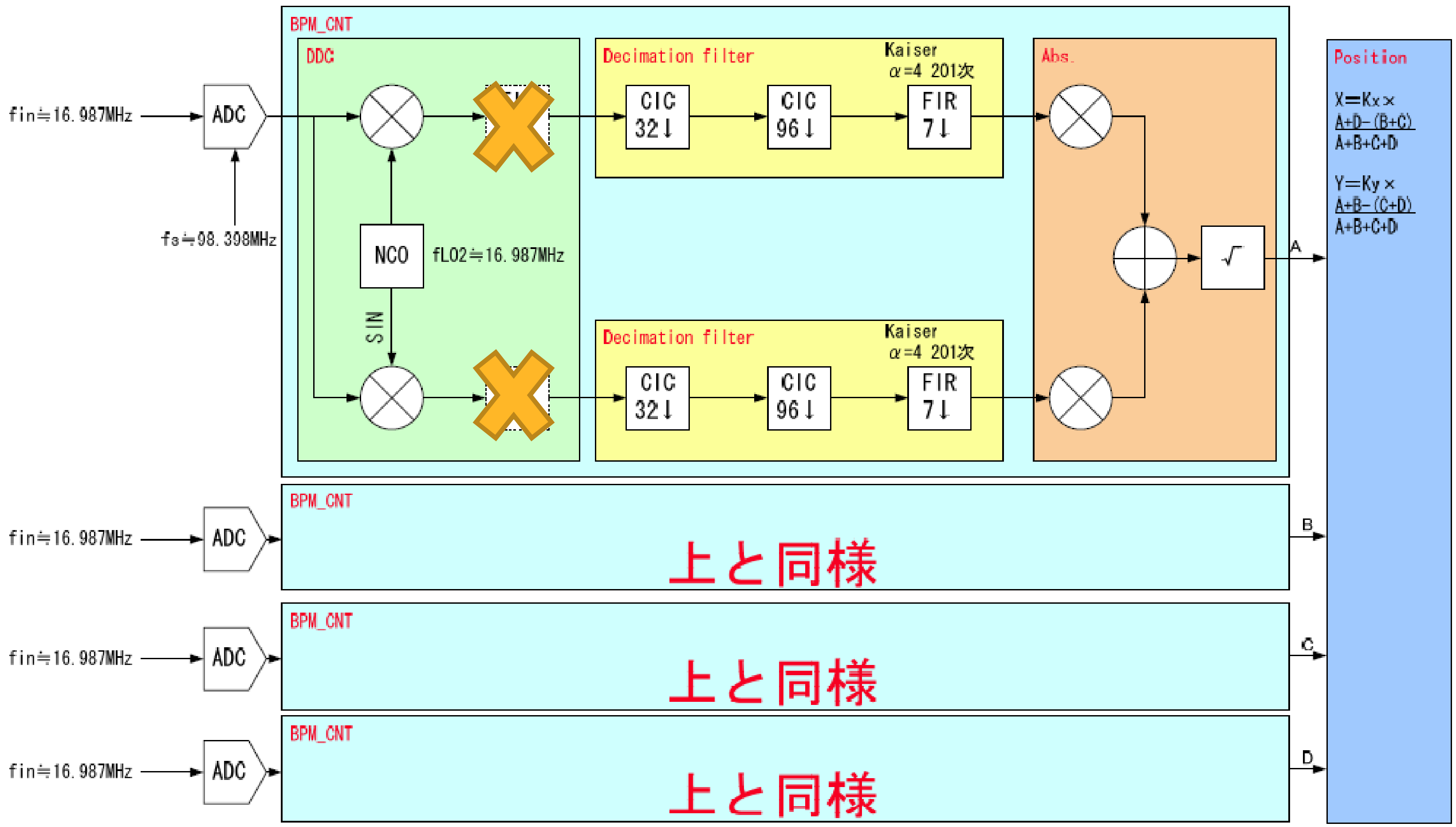




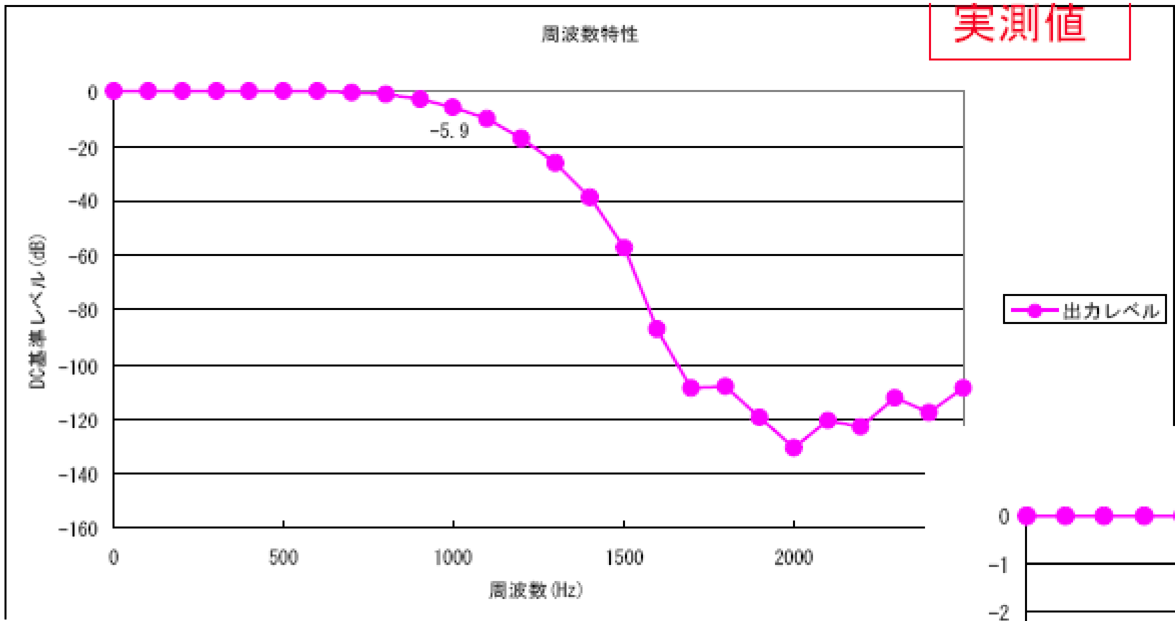
Digital signal processing

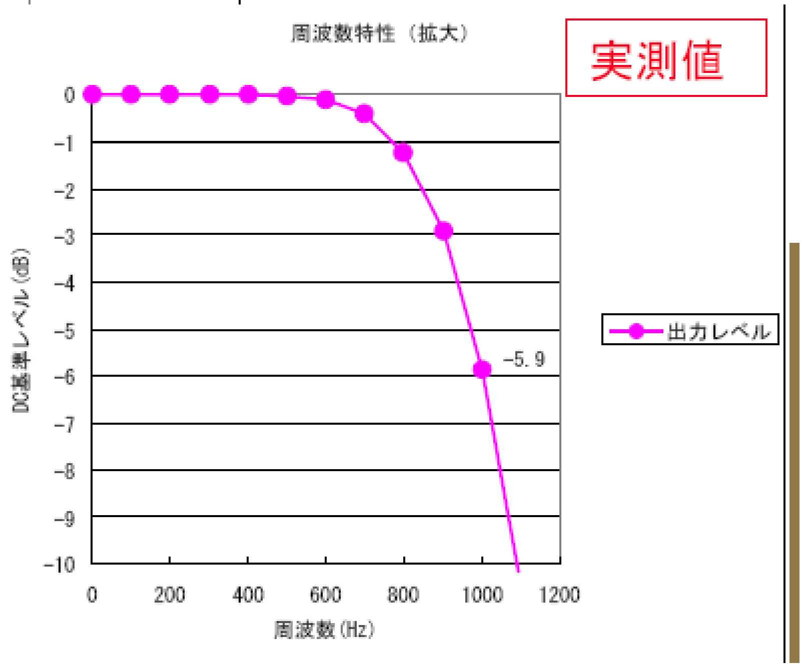
- micro-TCA form factor
- Virtex-5 FGPA with PPC is used.
- Embedded EPICS on PPC in the Virtex5 FPGA

Digital filter block



Frequency response

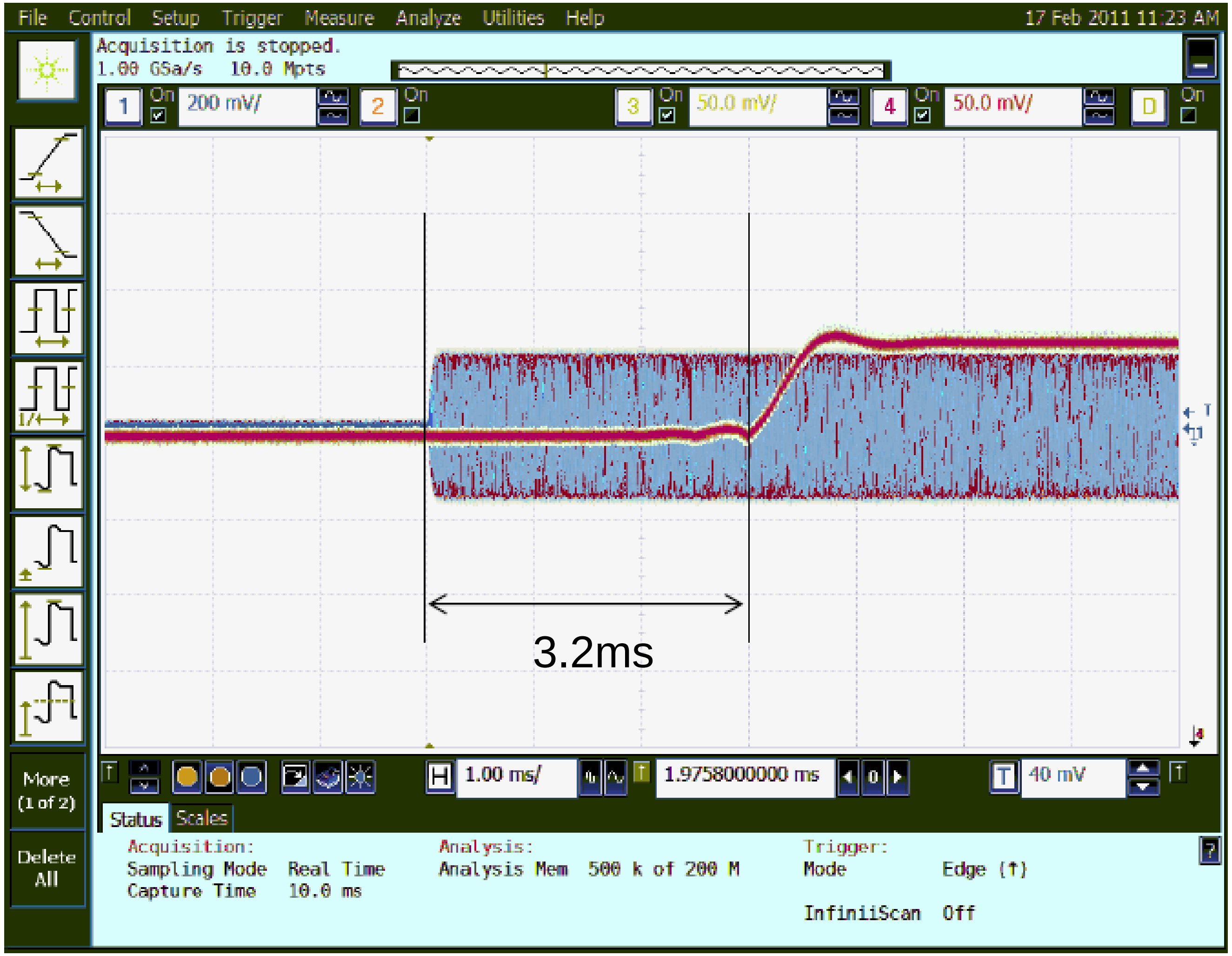




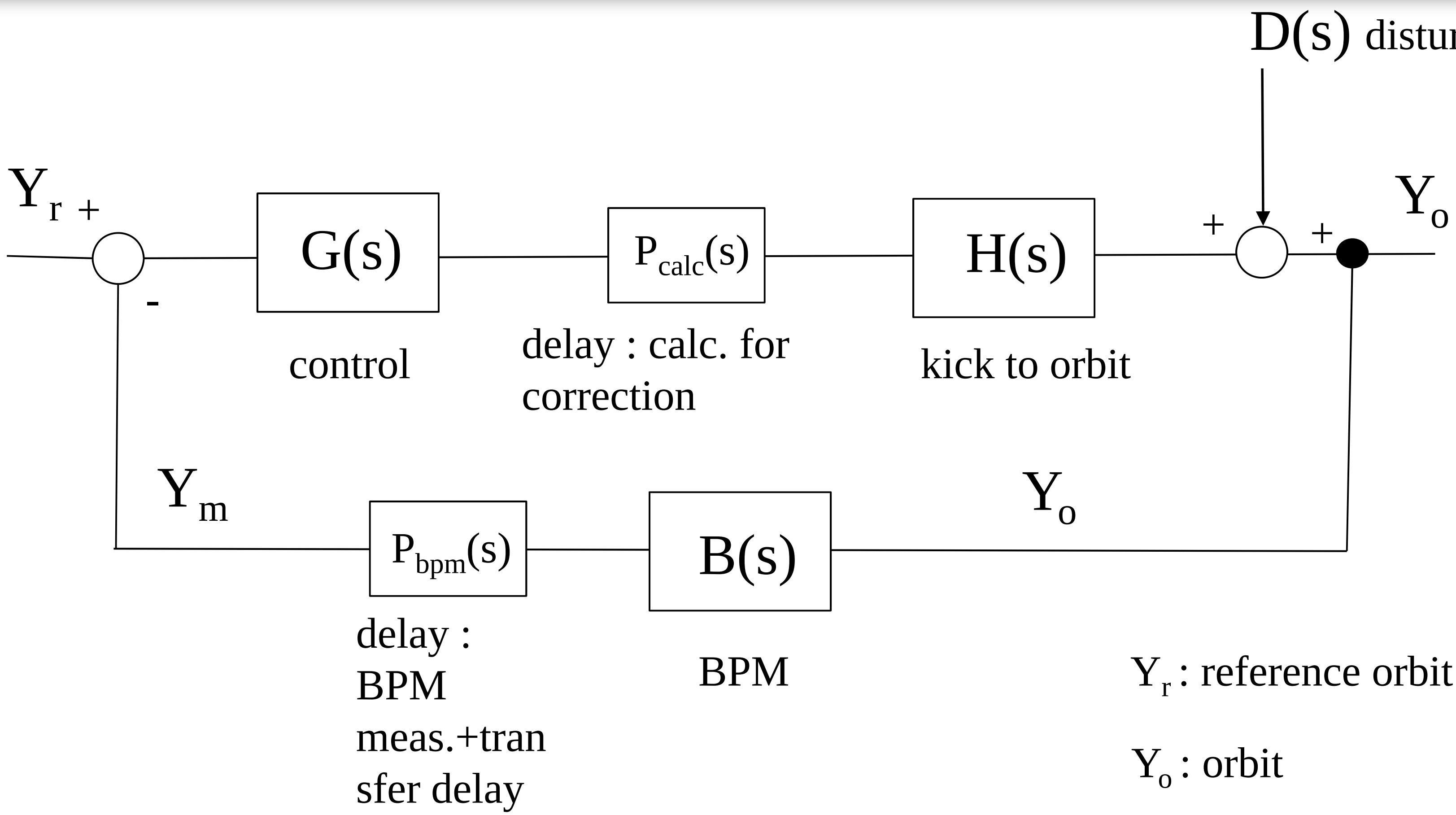
Total S/N including analog part
>90dB has been confirmed

resolution <0.11um

Latency


File Control Setup Trigger Measure Analyze Utilities Help
17 Feb 2011 11:23 AM
Acquisition is stopped.
1.00 GSa/s 10.0 Mpts
200 mV/
50.0 mV/
50.0 mV/
3.2ms
1.00 ms/
1.9758000000 ms
40 mV
More (1 of 2)
Delete All
Status Scales
Acquisition:
Sampling Mode Real Time
Capture Time 10.0 ms
Analysis:
Analysis Mem 500 k of 200 M
Trigger:
Mode Edge (↑)
InfiniiScan Off

Feedback model (analog feedback)



Y_r : reference orbit

Y_o : orbit

Y_m : measured orbit

Tracking simulation of orbit feedback system

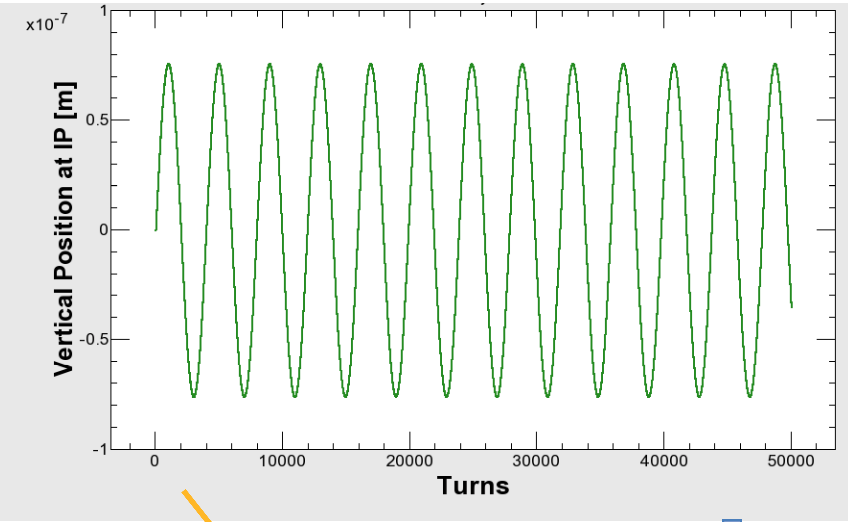
- **The transfer function which includes the PID controller has been implemented in the tracking.**
- **The effectiveness of the orbit feedback has been studied by this tracking.**
  - Two cases
    - Case 1: QC1L, QC1R, QC2L, QC2R (HER) oscillation from KEKB measurement
    - Case 2: QC1L (HER) oscillation only from recent simulation
- **The effect of BPM resolution has also been studied.**

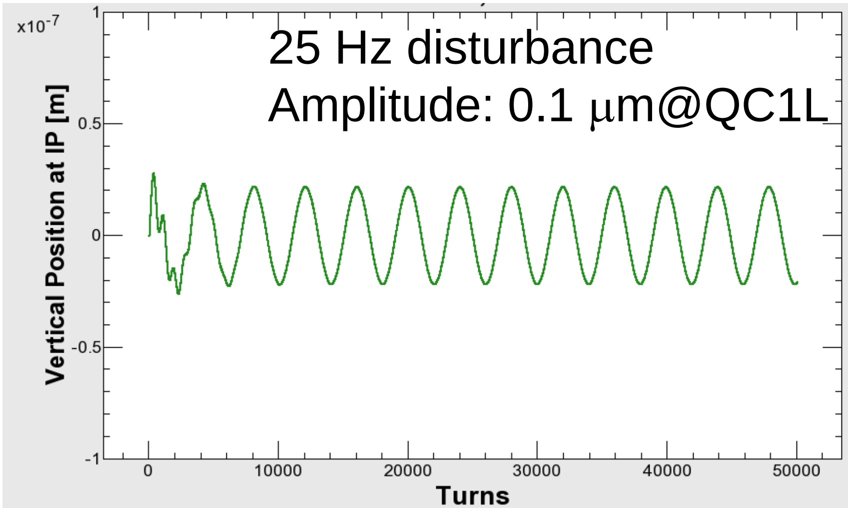
Tracking check with simple disturbance (single frequency)

Disturbance : Sin[2*Pi*25t]
w/o FB

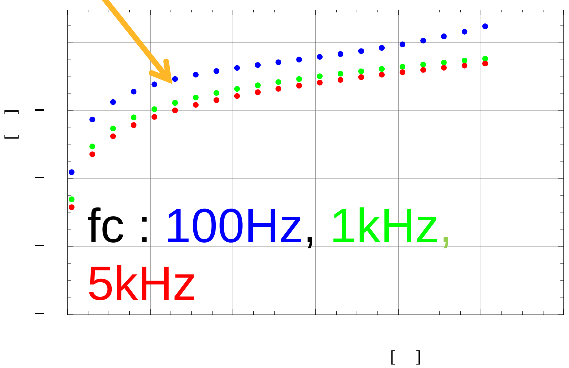
25 Hz disturbance
Amplitude: 0.1 μm@QC1L

Disturbance : Sin[2*Pi*25t]
w/ FB fc=100kHz, teddy=0.85ms



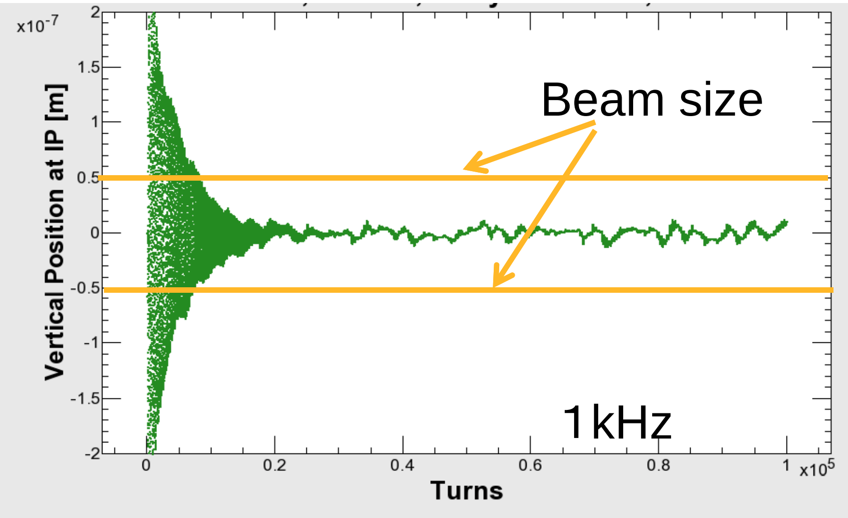


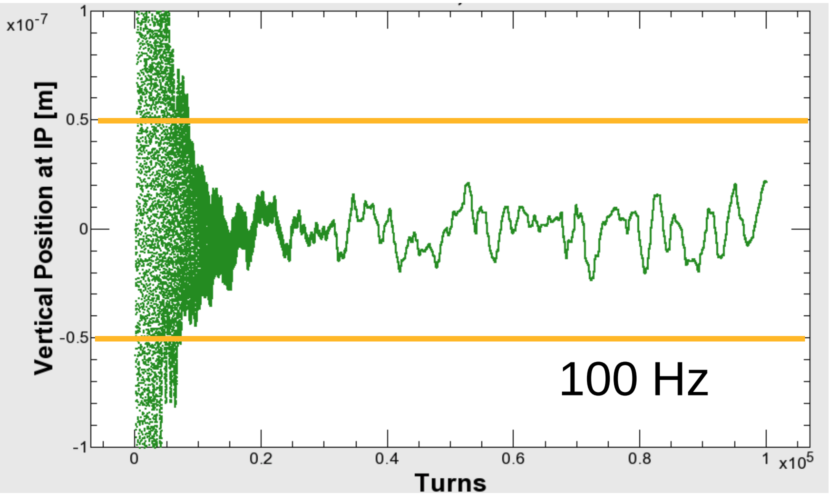
~ -11dB



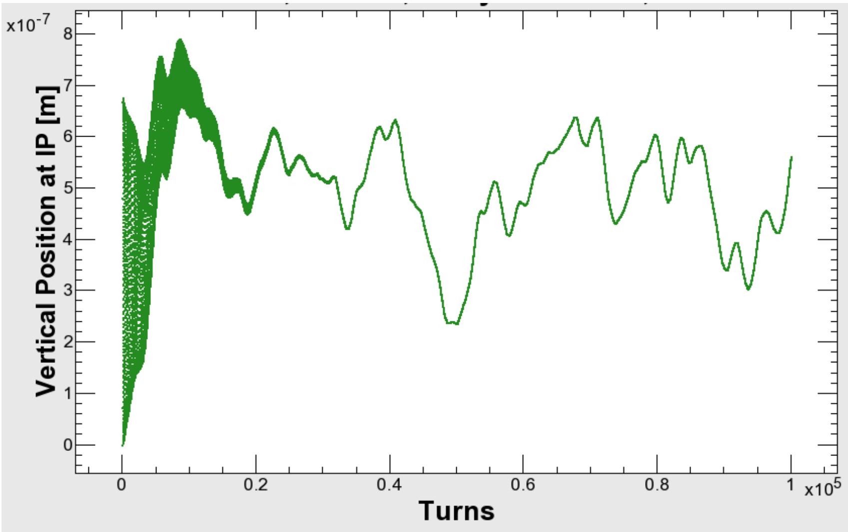
Tracking (case 1)

QC1L, QC1R, QC2L, QC2R
from KEKB measurement
w/ FB





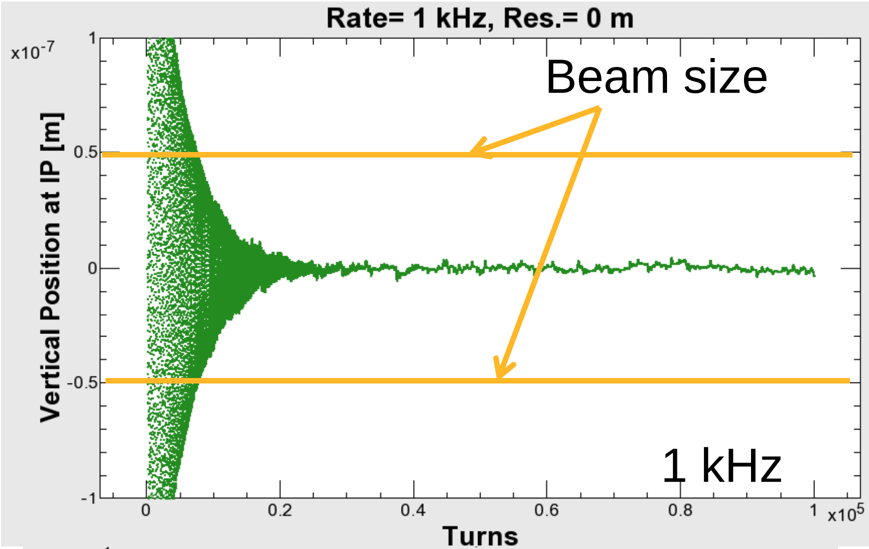
QC1L, QC1R, QC2L, QC2R
from KEKB measurement
w/o FB

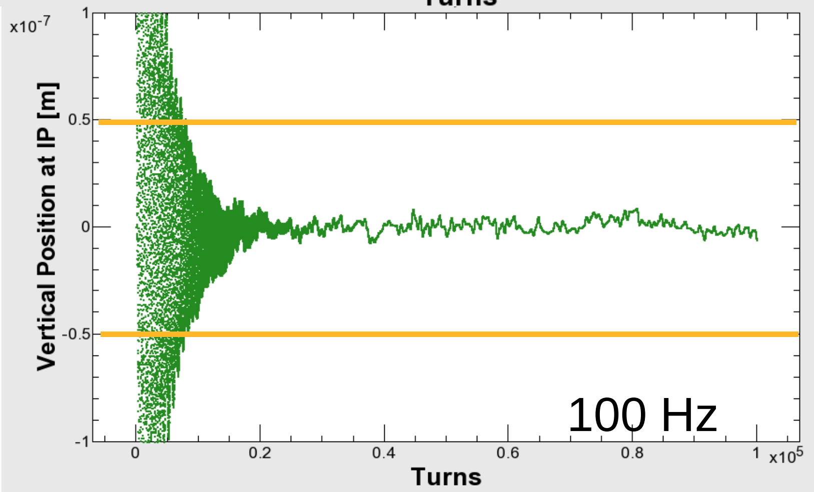


The 100 Hz fc(BPM) is not enough.

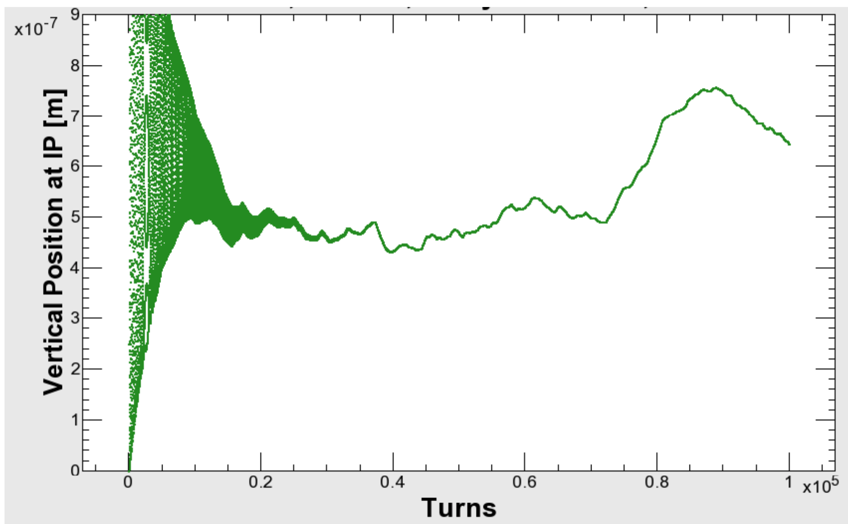
Tracking (case 2)

QC1L from simulation w/ FB



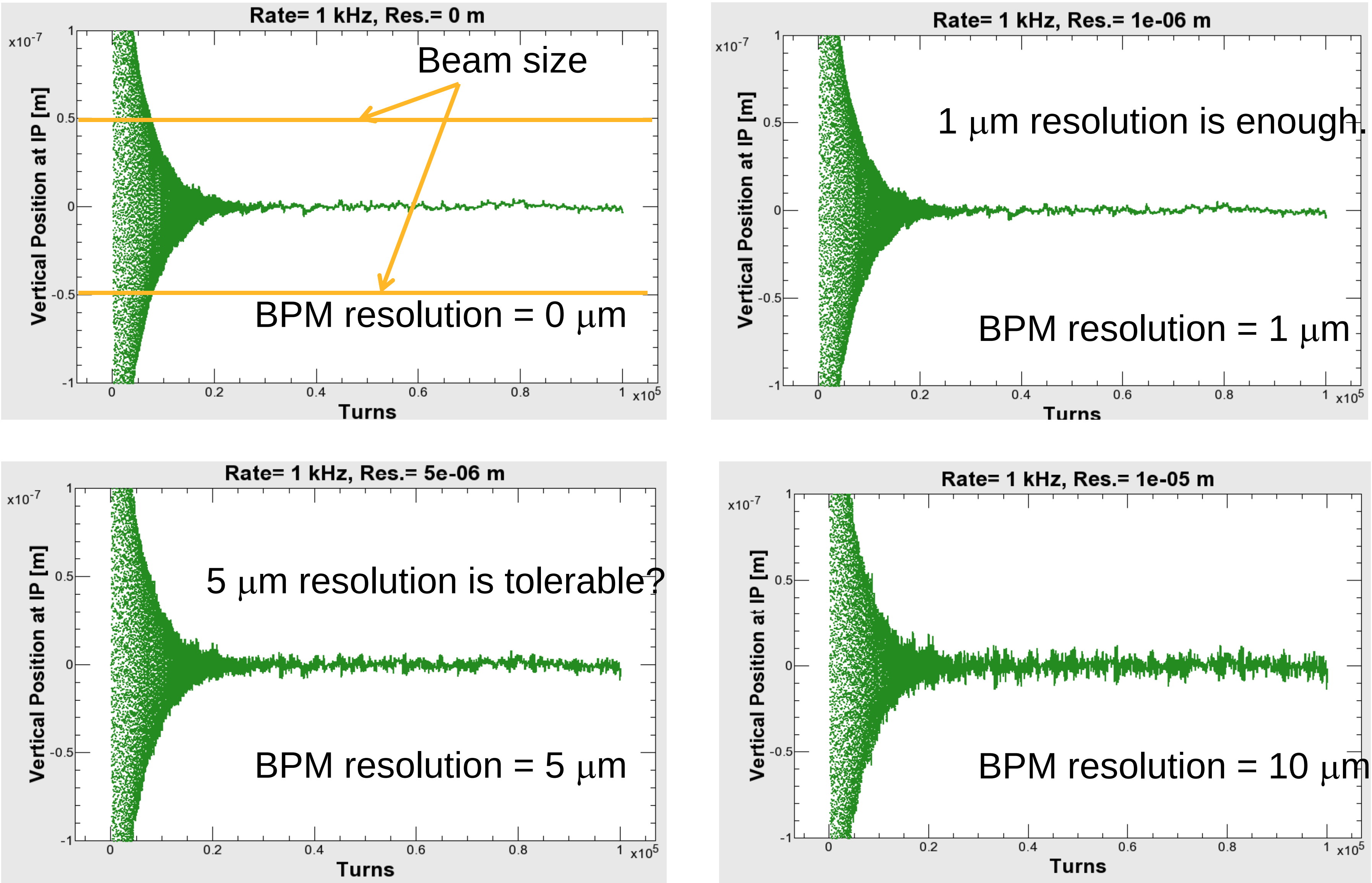


QC1L from simulation w/o FB



The orbit change can be effectively suppress
by the feedback with 100 Hz fc(BPM).

Effect of BPM resolution



Summary(1)

- Construction works from KEKB to SuperKEKB are in progress, on schedule.
- Design work, especially around IP are also in progress, going to much detailed considerations.
- Collaboration with SLAC and FNAL for the construction of SuperKEKB, especially around injector, will formally start under US-Japan collaboration on HEP.
- Funding situation:
  - Damping ring
  - Special budget for "Very Advanced Research Support Program"
  - Annual construction budget for FY2011 has been approved.

KEK Director General (Prof. A. Suzuki) said "The budget has been almost fully (>85%) funded "

Summary(2)

- The IP orbit control at SuperKEKB is much more difficult than that at KEKB.
- Major difficulty comes from the mechanical vibration of IR quadrupoles.
  - Simulation on the quads of SuperKEKB has given a better result than KEKB.
  - Further suppression of the vibration may be possible.
  - The coherence of vibration of the two rings may help.
- In parallel to the efforts to suppress the quadrupole vibration, we will develop the orbit feedback based on the beam-beam deflection.
- BPM requirement
  - Resolution: 1μm is enough. 5μm is tolerable?
  - Bandwidth: ~ 1kHz
- Horizontal orbit feedback
  - We need to develop a method other than the beam-beam deflection such as luminosity feedback or beam size feedback.

Summary(3)

- **Prototype of IR special BPM system has been constructed and under testing.**
  - Need the special fast connection form BPM detector to Bump calculator (and Magnet power supplies), such as Rapid-IO connection, will be needed.
- **This system (with much cheaper analog front-end) might be used to stabilize orbit around local chromaticity correction area (medium-band BPM circuit, like Libera).**