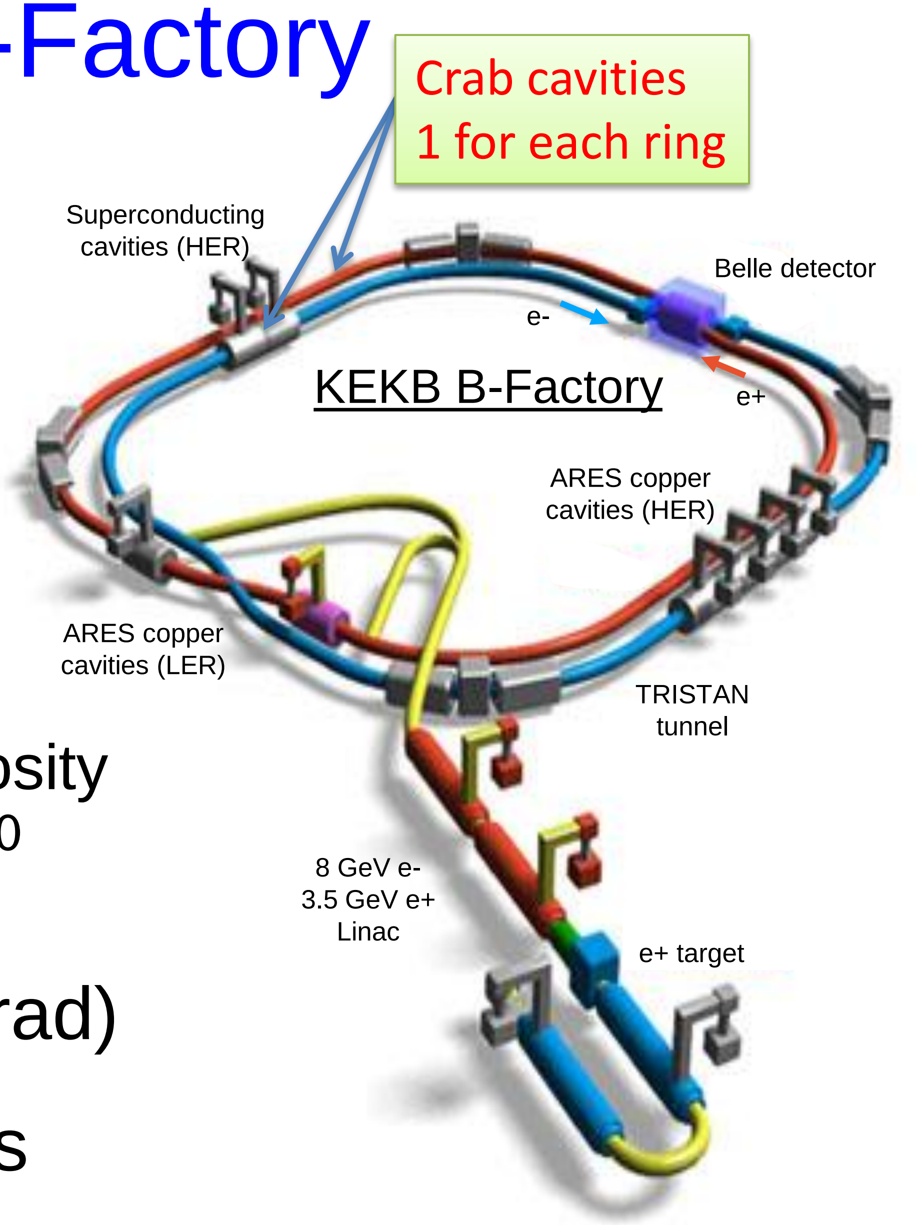
Pushing Luminosity of e+e- Colliders: the SuperKEKB project

Y. Funakoshi
KEK
Oct. 17 2013 6th TLEP workshop@CERN

CONCEPT OF SUPERKEKB

KEKB B-Factory


Crab cavities
1 for each ring

◆World-highest Peak Luminosity

- $2.11 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Twice as high as design value

◆World-highest Integrated Luminosity

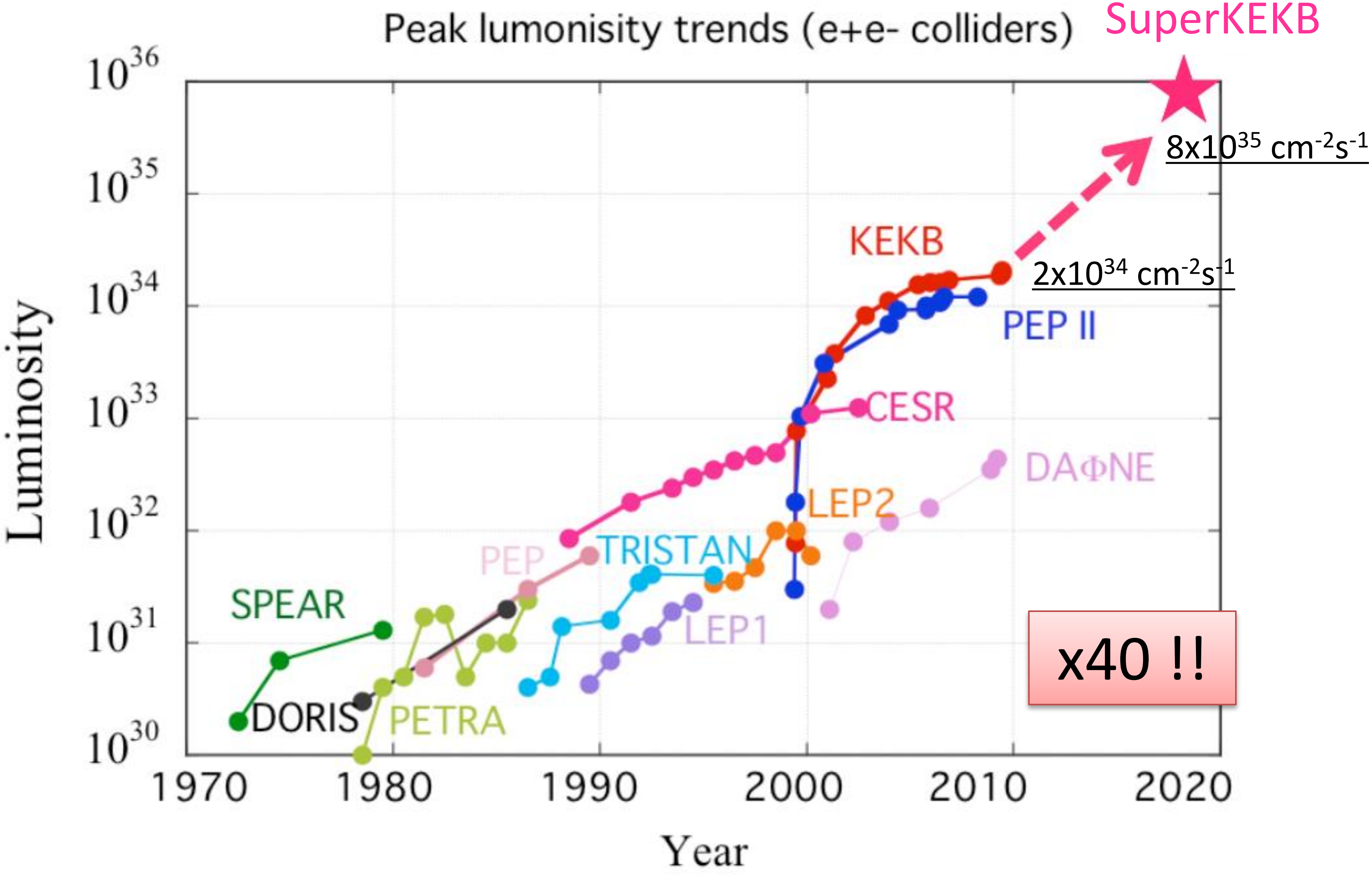
- Total: $1041 \mathrm{fb}^{-1}$ as of June 30th 2010

◆Crab crossing ($\phi = 11$ mrad)

◆Skew-sextupole magnets

The KEKB operation was terminated at the end of June 2010 for the upgrade toward SuperKEKB. Operation of SuperKEKB will start in Jan. 2015.

SuperKEKB Luminosity Target



x40 !!

Luminosity of KEKB and SuperKEKB

	KEKB Acieved		SuperKEKB Nano-Beam	
	LER	HER	LER	HER
I_{beam} [A]	1.6	1.2	3.6	2.6
β_y^* [mm]	5.9	5.9	0.27	0.30
ξ_y	0.09	0.12	0.088	0.081
Luminosity [$cm^{-2}\ s^{-1}$]	2.1×10^{34}		8.0×10^{35}	

$$L = \frac{\gamma_\pm}{2 e r_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{y\pm}}{\beta_{y\pm}^*}\frac{R_L}{R_{\xi_y}}$$

← Factor 2

← Factor 20

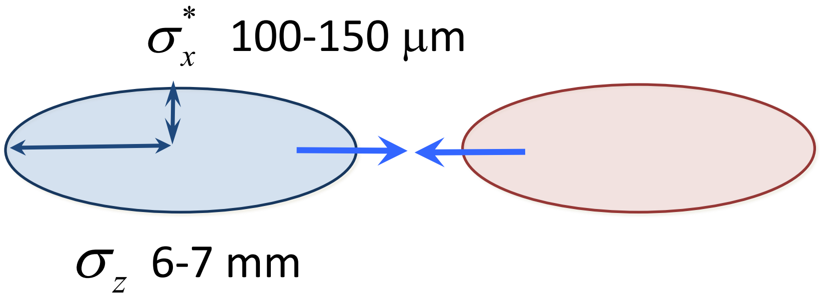
← Almost same

← 40 times higher

Collision Scheme

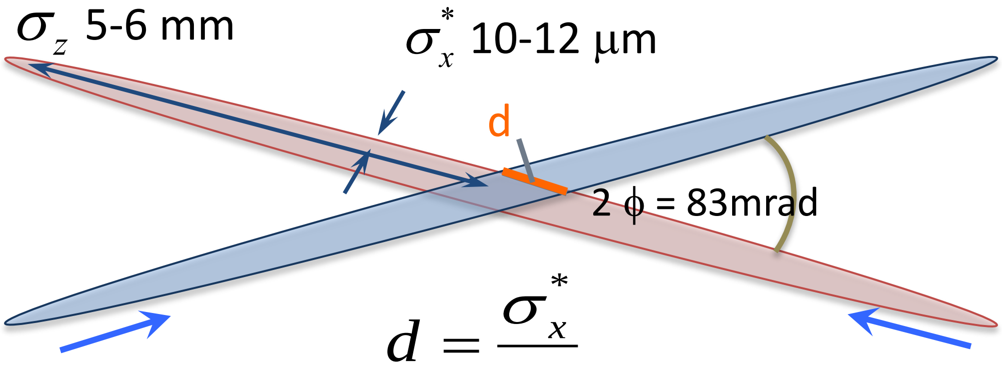
P. Raimondi

KEKB head-on (crab crossing)



overlap region = bunch length

Nano-Beam Scheme SuperKEKB



$$d = \frac{\sigma_x^*}{\phi}$$

Half crossing angle: φ

overlap region << bunch length

Hourglass requirement

$$\beta_y^* \geq \sigma_z \quad \sim 6 \text{ mm}$$

$$\beta_y^* \geq \frac{\sigma_x^*}{\phi} \quad \sim 300\ \mu\text{m}$$

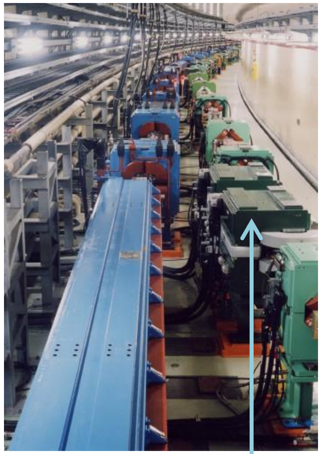
Vertical beta function at IP can be squeezed to ~300μm.
Need small horizontal beam size at IP.
→ low emittance, small horizontal beta function at IP.

No crab waist scheme has been assumed at SuperKEKB

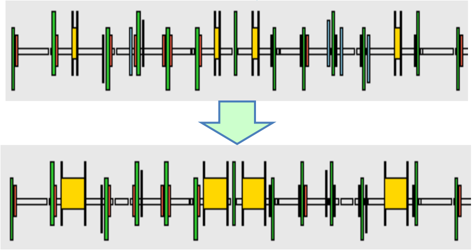
Machine Design Parameters

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	4.6	nm
Emittance ratio	κ	0.88	0.66	0.27	0.28	%
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	0.088	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}**		**$cm^{-2}s^{-1}$**

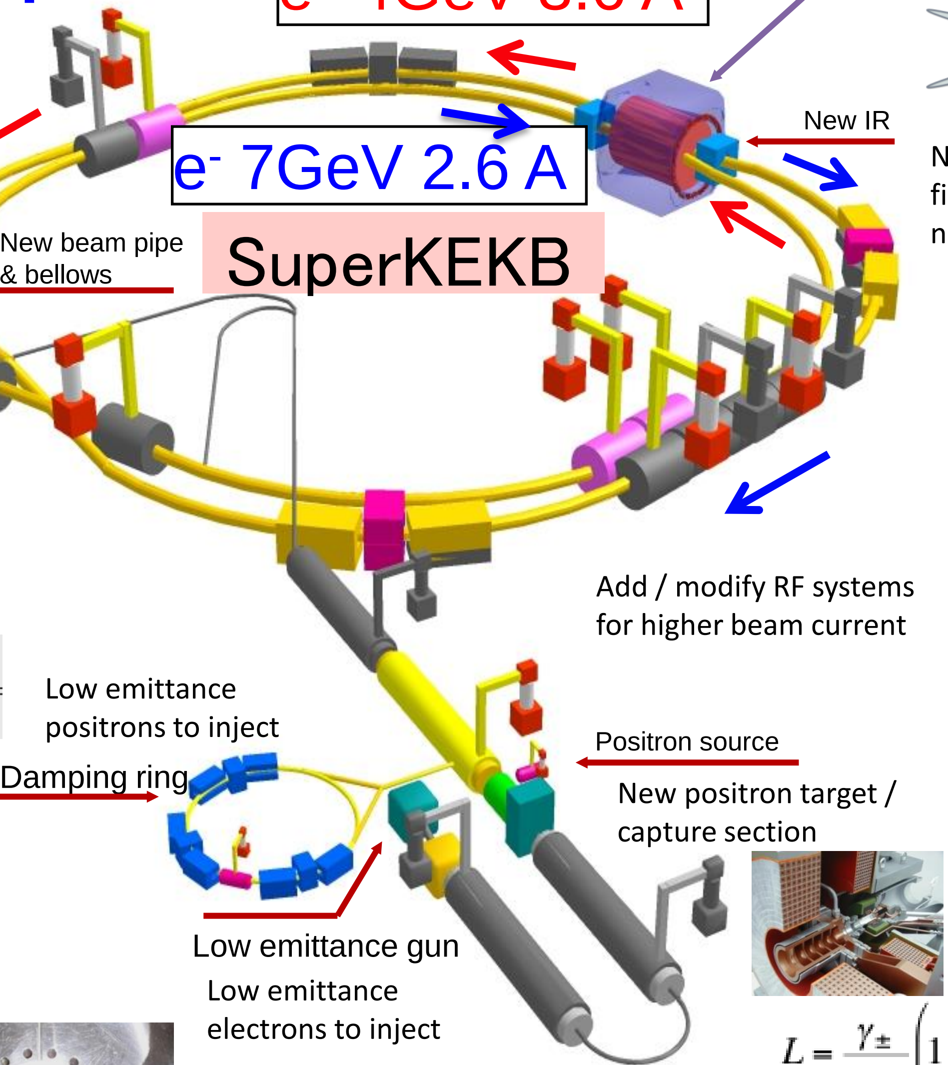
What's new at SuperKEKB



Replace short dipoles with longer ones (LER)



Redesign the lattices of LER to squeeze the emittance



Belle II

e+ 4GeV 3.6 A

e- 7GeV 2.6 A

SuperKEKB

New IR

New beam pipe & bellows

Low emittance positrons to inject

Damping ring

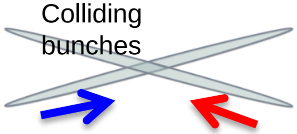
Low emittance gun

Low emittance electrons to inject

Positron source

New positron target / capture section

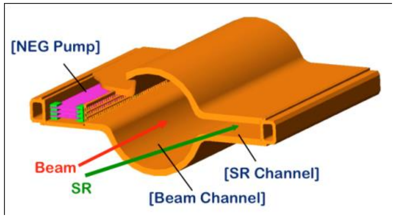
Add / modify RF systems for higher beam current

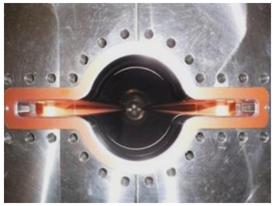


Colliding bunches

New superconducting final focusing quads near the IP

TiN-coated beam pipe with antechambers





$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm\xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

Target: $L = 8\times10^{35}/\mathrm{cm}^2/\mathrm{s}$

The construction works are in full swing at SuperKEKB.

However, in this talk, instead of describing the construction status, I will focus on issues for SuperKEKB.

Issues

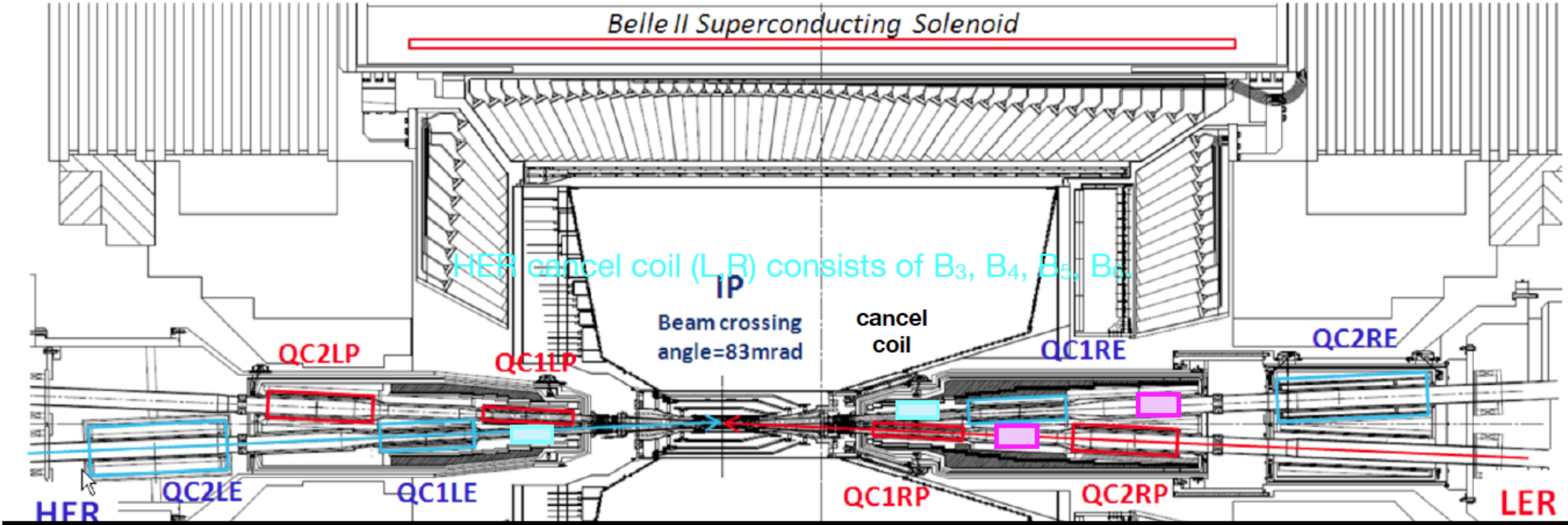
- IR design and dynamic aperture
- Low emittance tuning
- Magnet alignment strategy
- Beam-beam related issues
- IP orbit control
- Beam loss and beam injection
- Electron clouds
- Detector beam background

IR design and dynamic aperture

- This is one of the key issues at SuperKEKB
  - Success of SuperKEKB largely depends on how low values of IP beta-functions will be achieved with enough dynamic aperture.

Final Focus System: QCS

N. Ohuchi, Y. Arimoto

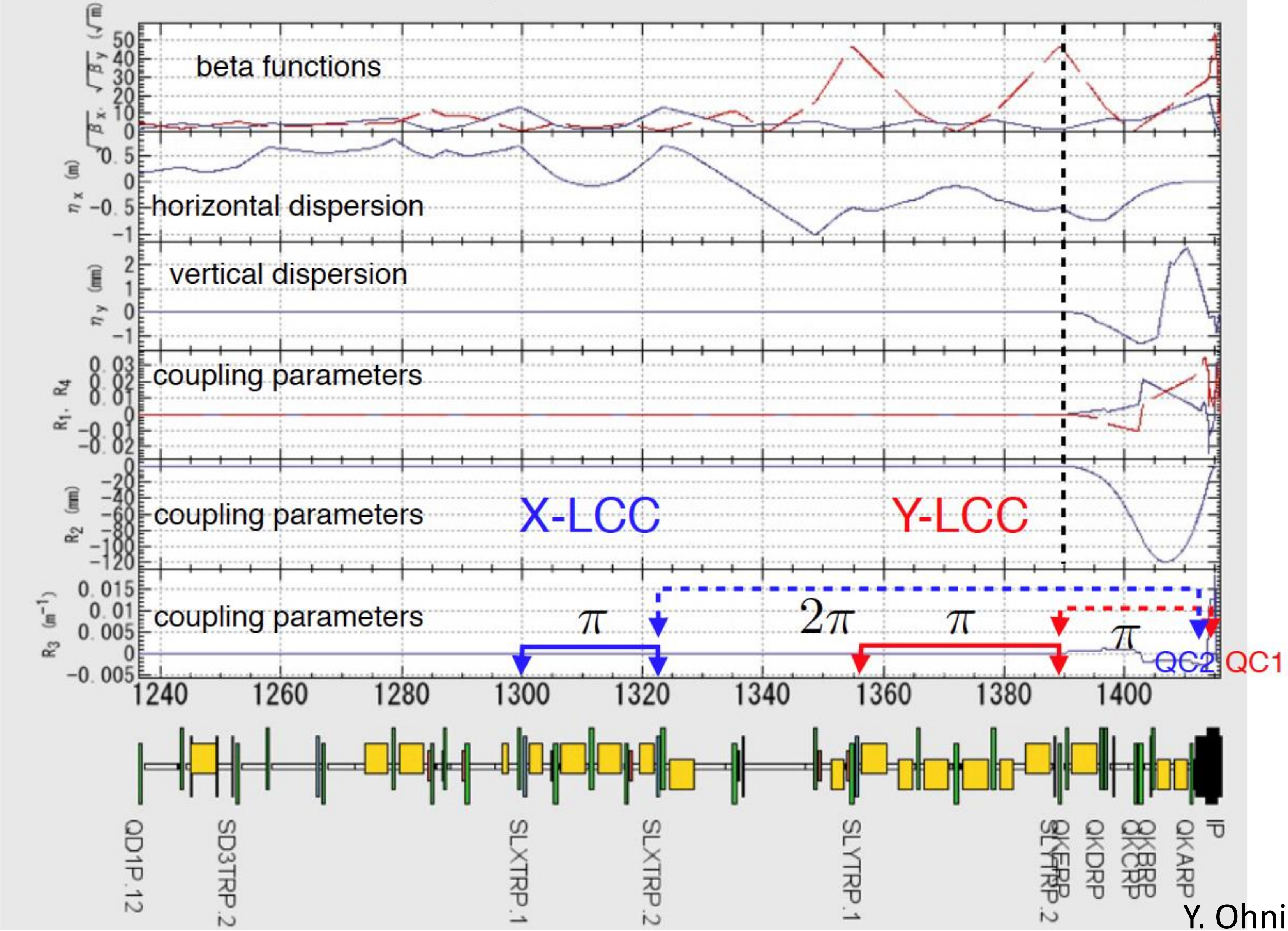


HER cancel coil (L,R) consists of B_3, B_4, B_5, B_6.

Design param.	Dipole	Skew dipole	Quad	Skew quad	Sextupole	Skew sext	Octupole
	B_1L (Tm)	A_1L (Tm)	B_2L/r_0 (T)	A_2L/r_0 (T)	B_3L/r_0^2 (T/m)	A_3L/r_0^2 (T/m)	B_4L/r_0^3 (T/m^2)
QC1LP	0.004	-0.002	-22.96	-9.50E-05			-27.0
QC2LP	-0.0217	0.022	11.48	0.0095			48.2
QC1RP	0.0050	-0.0086	-22.96	1.92E-05		0.0	-26.7
QC2RP	-0.0023	0.0214	11.54	-6.30E-06		0.0	
QC1RP-QC2RP					0.0		
QC1LE	0.030	0.0092	-26.94	-0.0729			8.9
QC2LE	0.000	-0.0016	15.27	0.0271			23.6
QC1RE	-0.0305	0.0053	-25.39	0.0653		0.0	
QC2RE	0.000	-0.0022	13.04	0.0559		0.0	
QC1RE-QC2RE					0.0		

IR Optics in LER

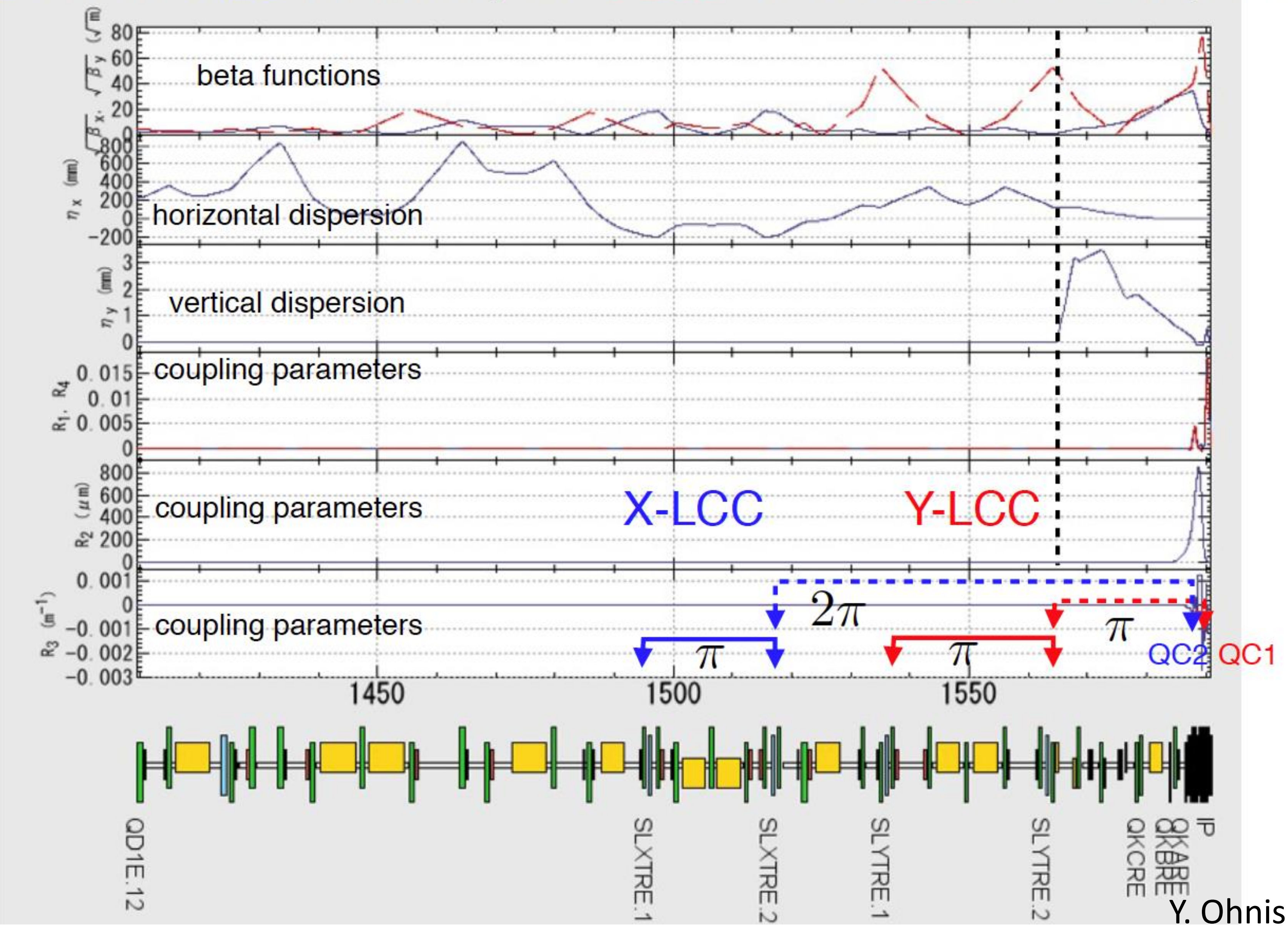
X-LCC corrects QC2 chromaticity and Y-LCC corrects QC1 chromaticity locally.



Y. Ohnishi

IR Optics in HER

X-LCC corrects QC2 chromaticity and Y-LCC corrects QC1 chromaticity locally.



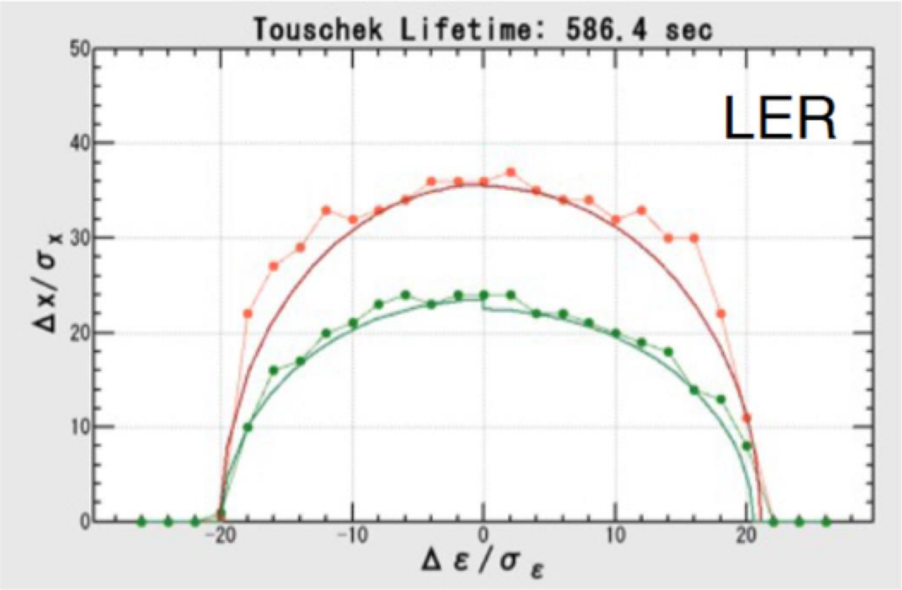
Y. Ohnishi

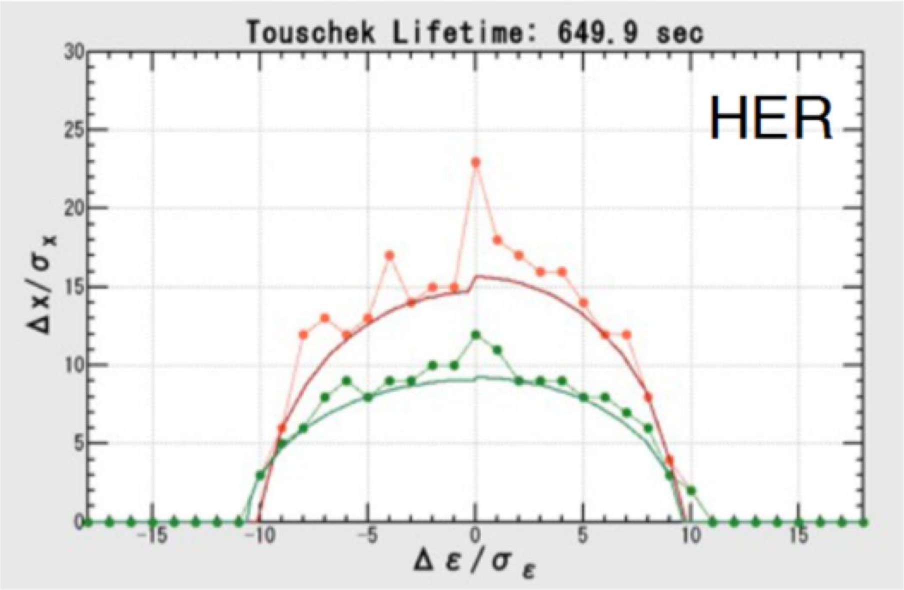
Corrector coils

- Dipole and skew dipole coils make a beam-line geometry and correct dispersions.
- Skew quadrupole coils correct x-y couplings.
- Sextupole and skew sextuple coils correct error field due to a misalignment of quadrupole coils. This error field affects the dynamic aperture significantly.
- Octupole coils at QC1 and QC2 enlarge a transverse aperture.
- HER cancel coils correct sextupole, octupole, decapole and dodecapole leakage field from QC1P in LER.

Touschek Lifetime

- Touschek lifetime depends on dynamic aperture.
- Efforts to widen dynamic aperture
  - Careful design of QCS magnets to minimize higher multipoles etc.
  - Careful IR design: LCC, x-y coupling correction etc.
  - Optimization of octupoles, ARC sextupoles, skew-sextupoles





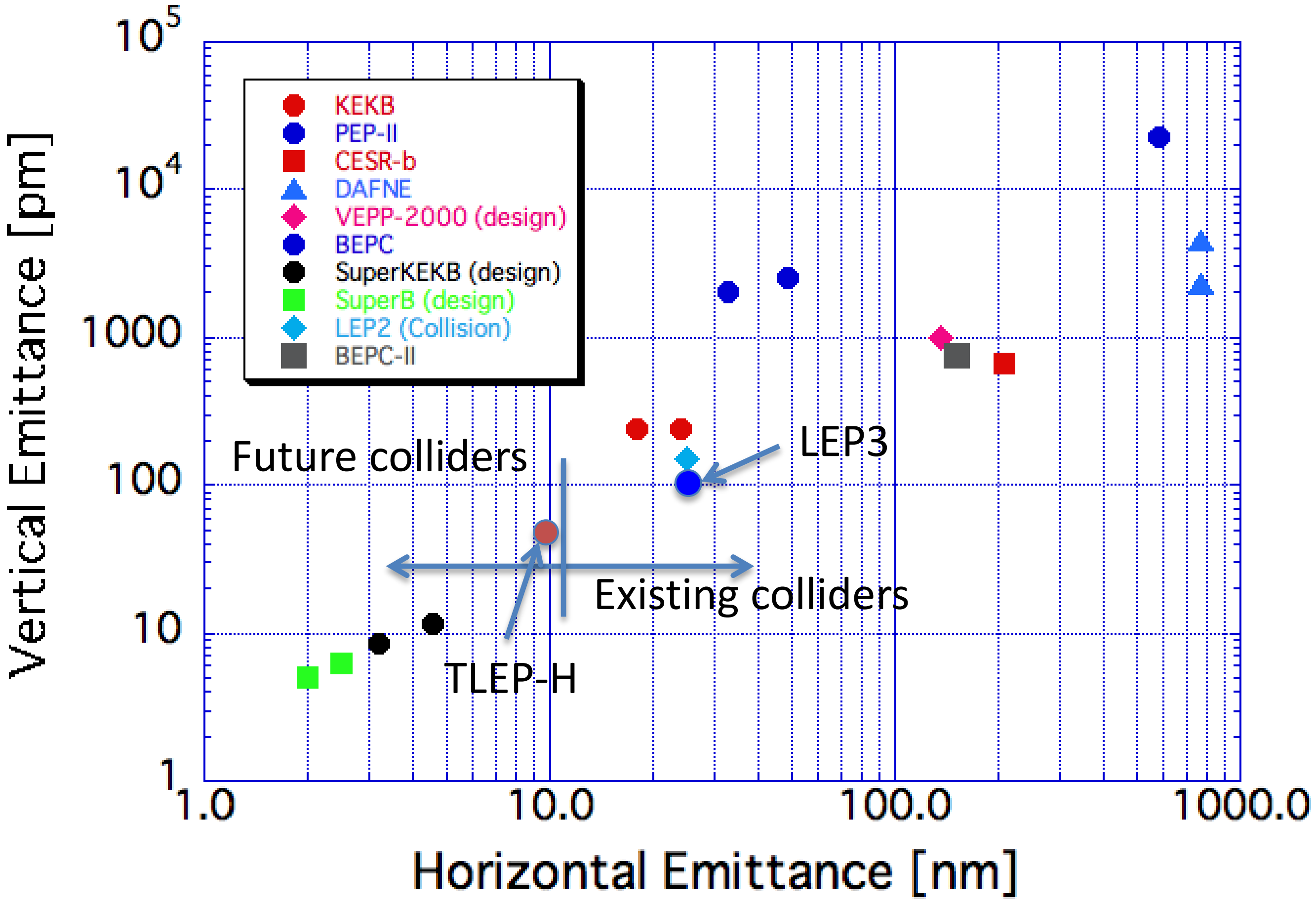
Y. Ohnishi

w/o machine errors

Low emittance tuning

- The design vertical emittance of SuperKEKB is very small compared to those of existing colliders.
- The low vertical emittances have been achieved in SR machines. However, low emittance tuning in colliders is much more difficult.
- One of the key tuning issues at SuperKEKB will be low emittance tuning.

Comparison of emittances of colliders

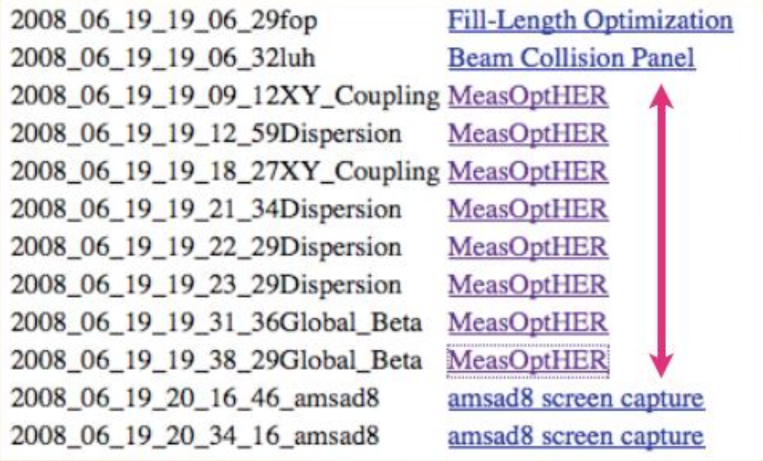


From Beam Dynamics Newsletter No. 31

Courtesy of F. Zimmermann, H. Burkhardt and Q. Qin

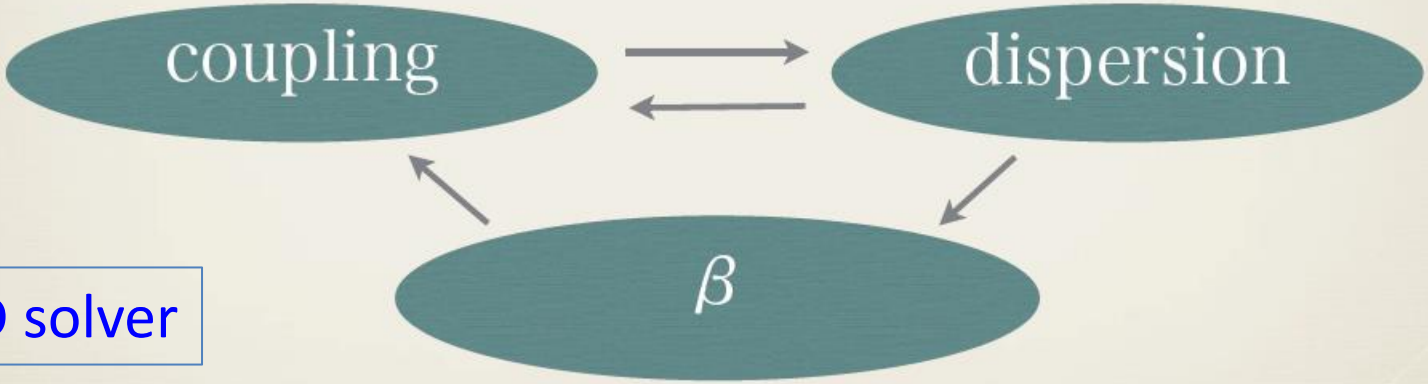
KEKB method of optics correction

Iteration



2008_06_19_19_06_29fop	Fill-Length Optimization
2008_06_19_19_06_32luh	Beam Collision Panel
2008_06_19_19_09_12XY_Coupling	MeasOptHER
2008_06_19_19_12_59Dispersion	MeasOptHER
2008_06_19_19_18_27XY_Coupling	MeasOptHER
2008_06_19_19_21_34Dispersion	MeasOptHER
2008_06_19_19_22_29Dispersion	MeasOptHER
2008_06_19_19_23_29Dispersion	MeasOptHER
2008_06_19_19_31_36Global_Beta	MeasOptHER
2008_06_19_19_38_29Global_Beta	MeasOptHER
2008_06_19_20_16_46_amsad8	amsad8 screen capture
2008_06_19_20_34_16_amsad8	amsad8 screen capture

- A loop of coupling, dispersion, β corrections takes **30-60 minutes** per ring to converge. (1 correction takes 3.5 to 7 minutes)

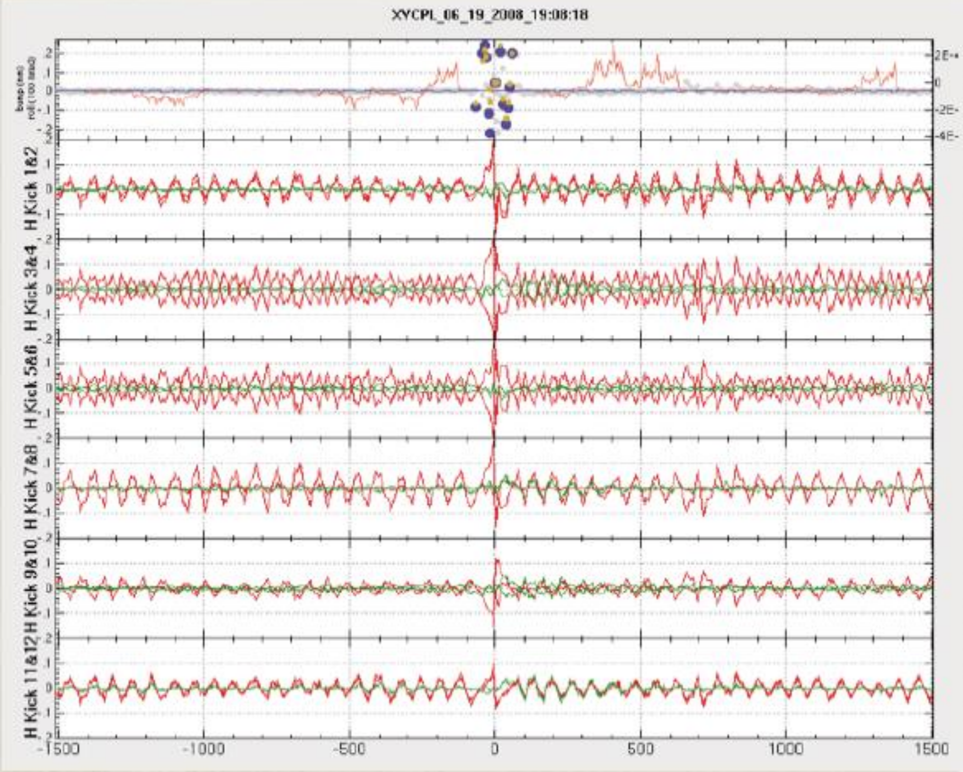


SVD solver

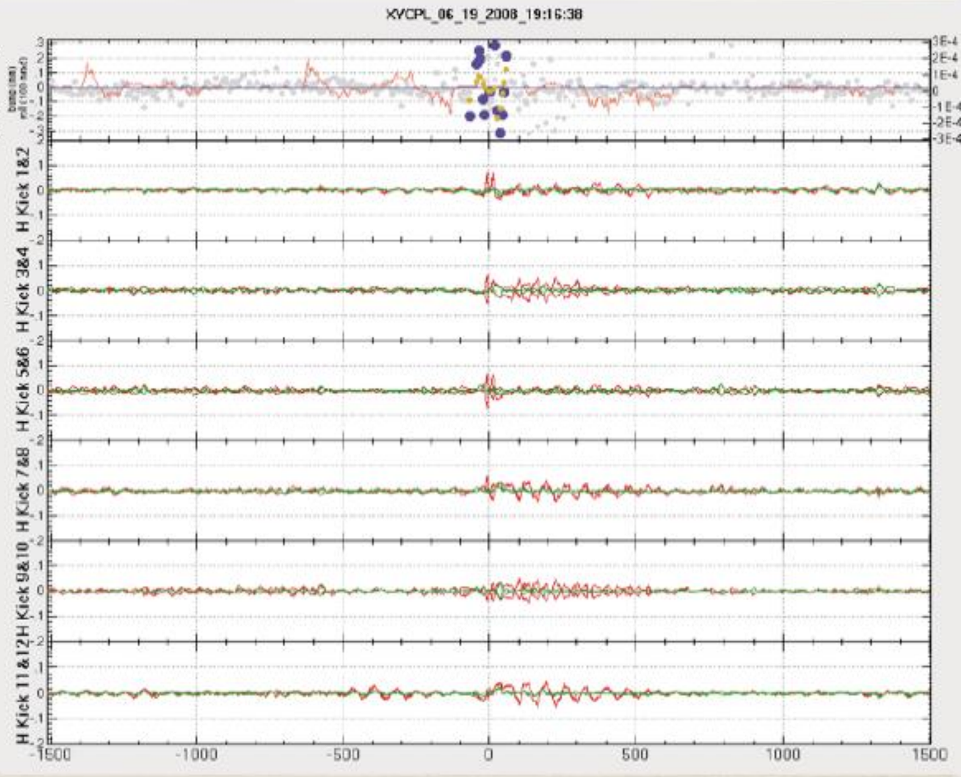
- We do not have to solve the entire problem at once by a single big matrix.
- Although these corrections are not independent, their cross-talks are smaller than the diagonal parts, so the iteration converges quickly.

X-y coupling correction

- Kick the beam by horizontal dc correctors at non-coupled, non-dispersive places.
- Measure leaked closed orbit in the vertical plane.
- Correct the leak by **vertical symmetric bumps at sextupole pairs** and skew quads around the IP. At SuperKEKB we will use skew-quad winding at sextuples instead of bumps.
- Only 12 correctors, with equally separated phases, are used.



before



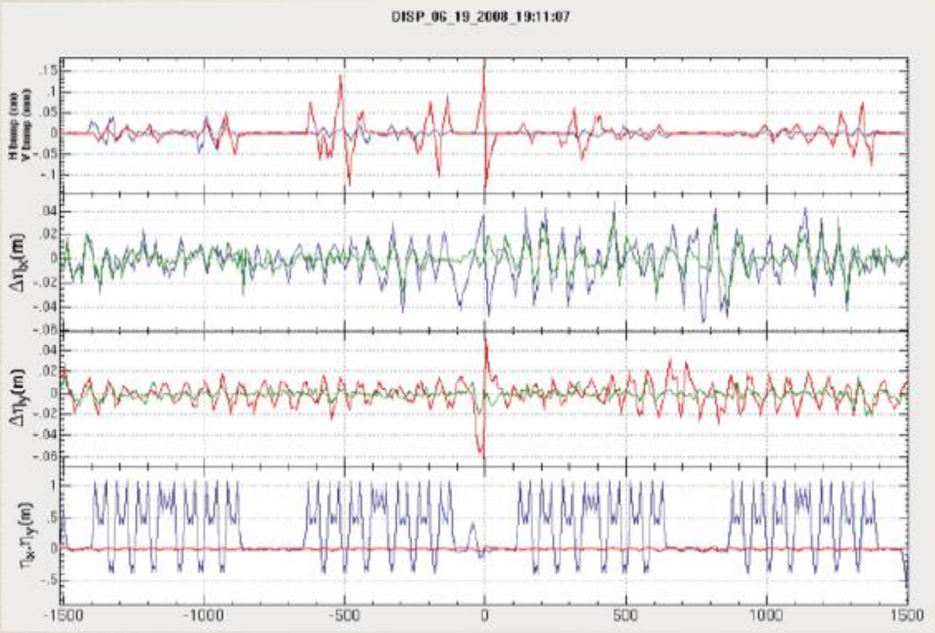
after 1 correction

Dispersion correction

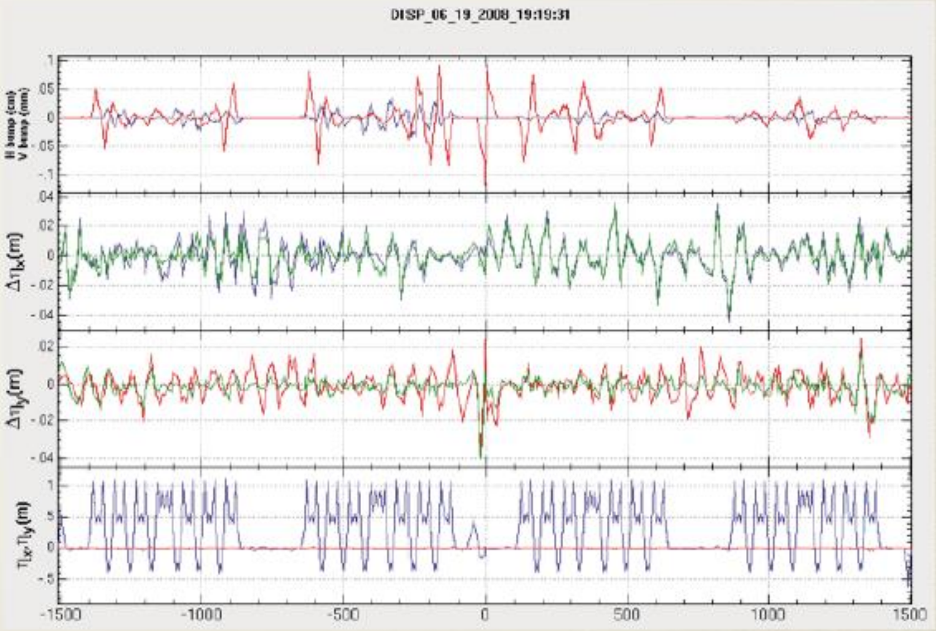
- Change rf frequency by ±100 Hz, measure the orbit change in x and y.
- Correct the difference from the model by horizontal & **vertical antisymmetric bumps at sextupole pairs.**

At SuperKEKB we will use skew-quad winding at sextuples instead of bumps.

- Residuals: $\Delta\eta_{x,\mathrm{rms.}} \approx 10\ \mathrm{mm}, \quad \Delta\eta_{y,\mathrm{rms.}} \approx 8\ \mathrm{mm}$



Before correction

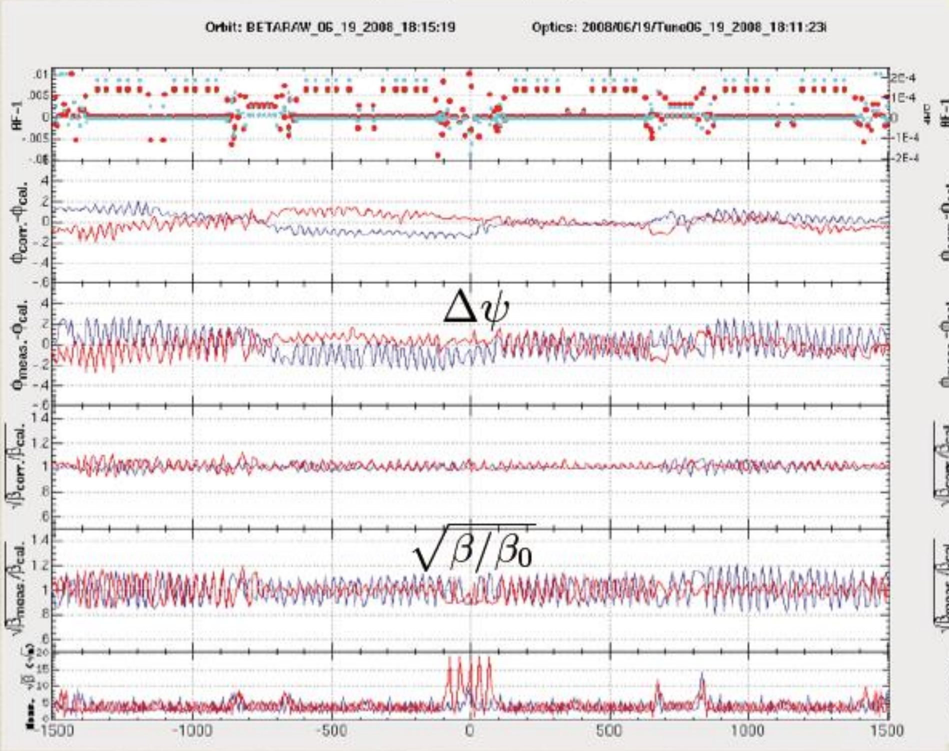


After 1 dispersion and 1 coupling correction applied alternatively.

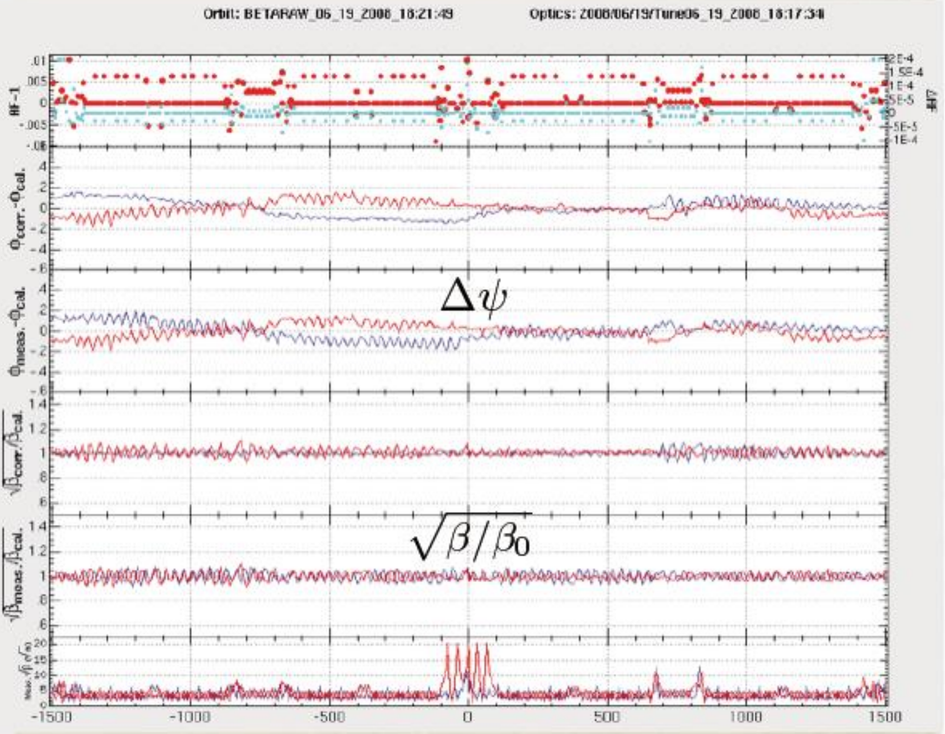
Note that the vertical scale becomes less than half.

β correction

- Kick the beam by dc correctors in x and y, measure the orbit response in each plane.
- Fit the response with βs and phases at each BPM and the kicked correctors, assuming x-y coupling to have been already corrected. 6 correctors per plane.
- Correct the difference from the model by fudge factors of quads.
- Residuals: $(\Delta\beta/\beta_0)_{x,y\ \mathrm{rms}} \approx 6\%$



Before correction



After 1 corrrection.

Simulation for SuperKEKB with machine errors

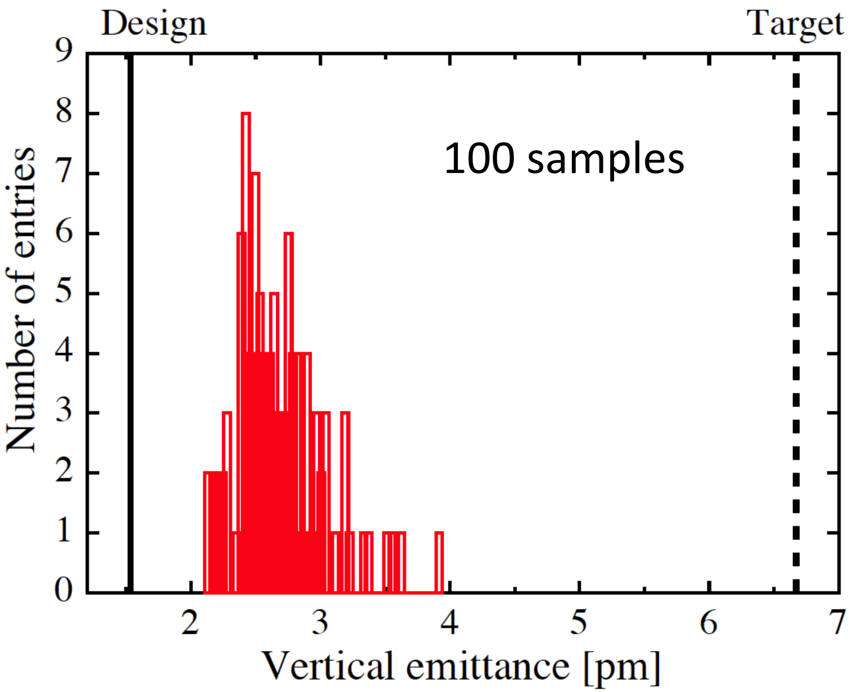
- Simulation was done by H. Sugimoto in case of HER.
- Assumed machine errors

	$\sigma_x = \sigma_y$ [μm]	σ_θ [μrad]	ΔK/K
Normal Quad	100	100	2.5×10^{-4}
Sextu.	100	100	2.5×10^{-4}
Bend.	0	100	0
QC1, QC2	100	0	0
BPM	0	10×10^{3}	2μm (resolution)

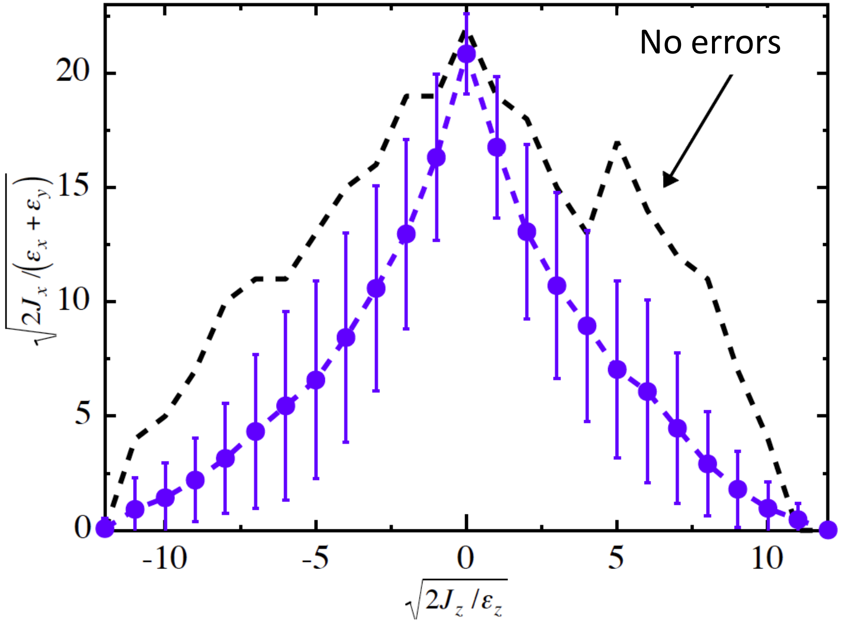
Machine errors are created randomly with gaussian distributions.

- Corrections
  - Closed orbit, x-y coupling, beta-beat, dispersions (KEKB methods)
    - SVD threshold = 10^{-2}

Results of simulation



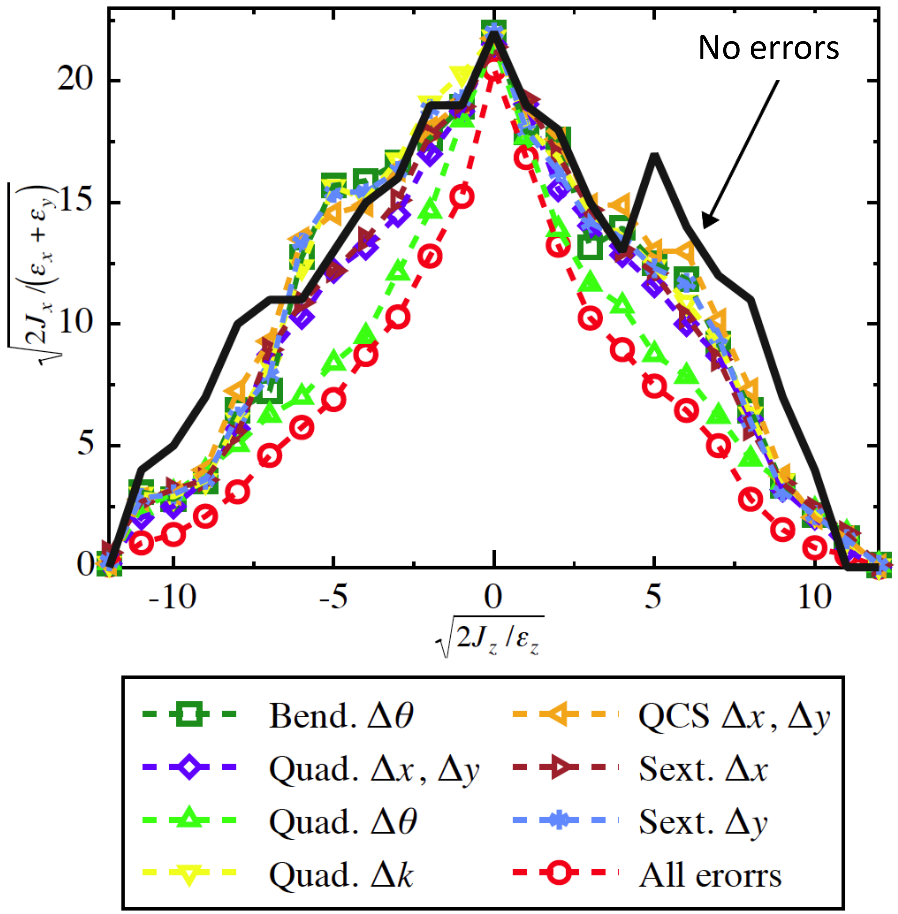
Vertical emittance distribution after LET



Dynamic aperture after LET.

H. Sugimoto

Dynamic aperture with different types of errors



Rotation errors of quadruples seems most dangerous.

Each sextuple has a skew quadrupole corrector coil.

We may have to rethink tolerance of rotation errors of normal quadrupoles.

H. Sugimoto

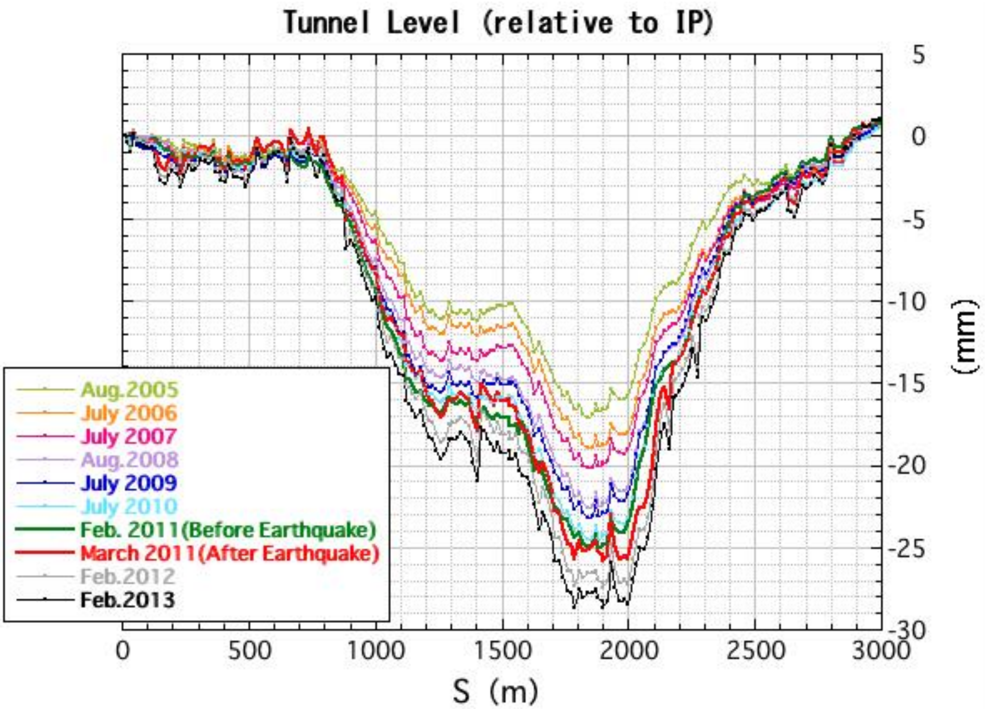
Magnet alignment strategy at SuperKEKB

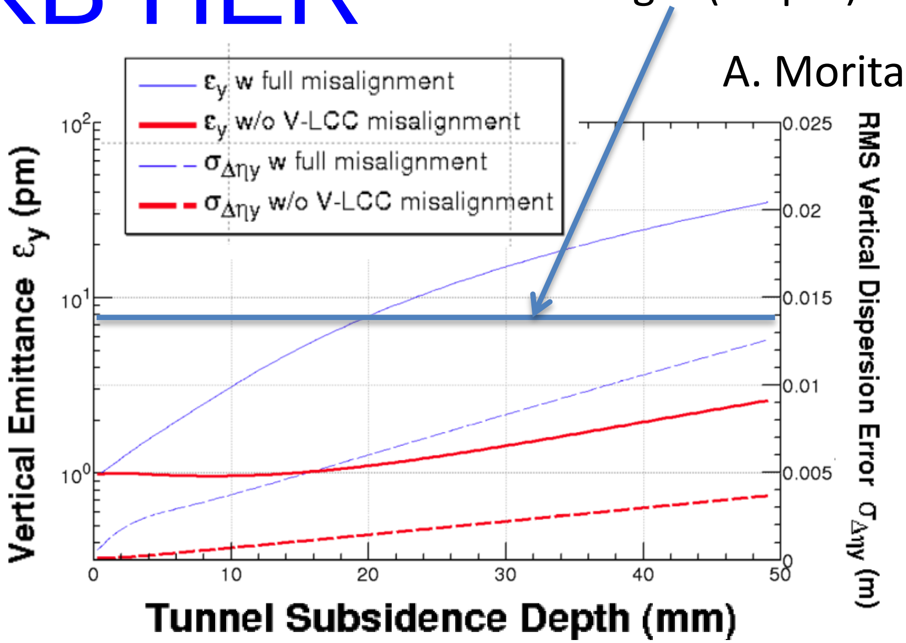
- The target positions of the initial alignment of SuperKEKB is a smoothed curve made from present (2013)magnet positions (not on a plane).
- The tolerance of magnets alignment around the target curve is the same as KEKB.
  - Position error: 100 μm (1 σ)
  - Rotational error: 100 μrad (1 σ)
    - We have to rethink about this?
- We will need special care for the alignment of the magnets around the local chromaticity correction.

Effects of Tunnel deformation at SuperKEKB HER

Target (7.8pm)

A. Morita





Tunnel deformation observed at KEKB

- A large subsidence has been observed: ~ 2mm/year and still in progress.
- In the construction period of KEKB (1998), all magnets were aligned on the same plane.

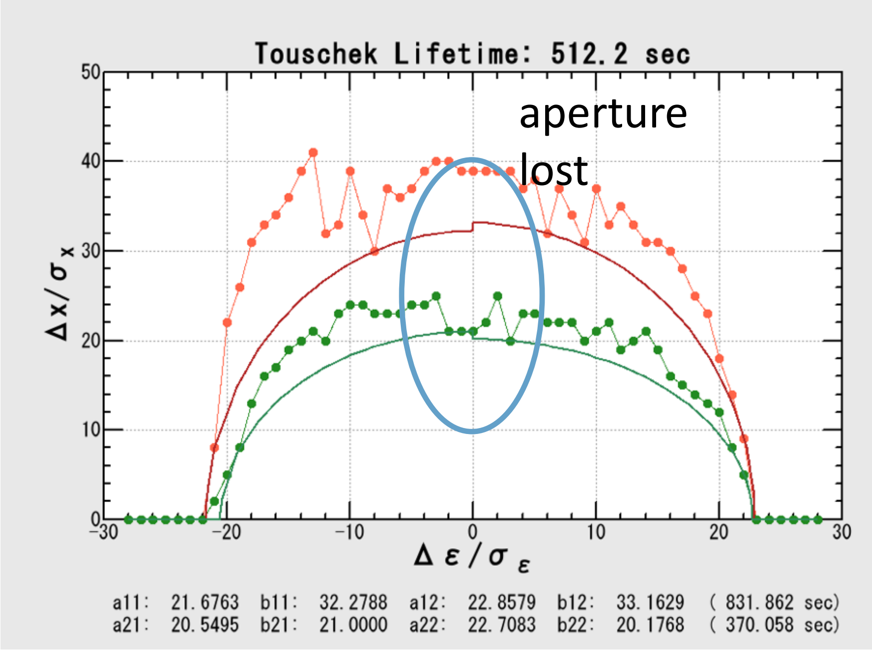
Vertical emittance

- If the alignment error around the V-LCC (vertical local chromaticity correction) area is excluded, the vertical emittance can be preserved well below the target value with optics corrections.
- As for the alignment error of V-LCC, we will need a special care. This is a remaining problem.

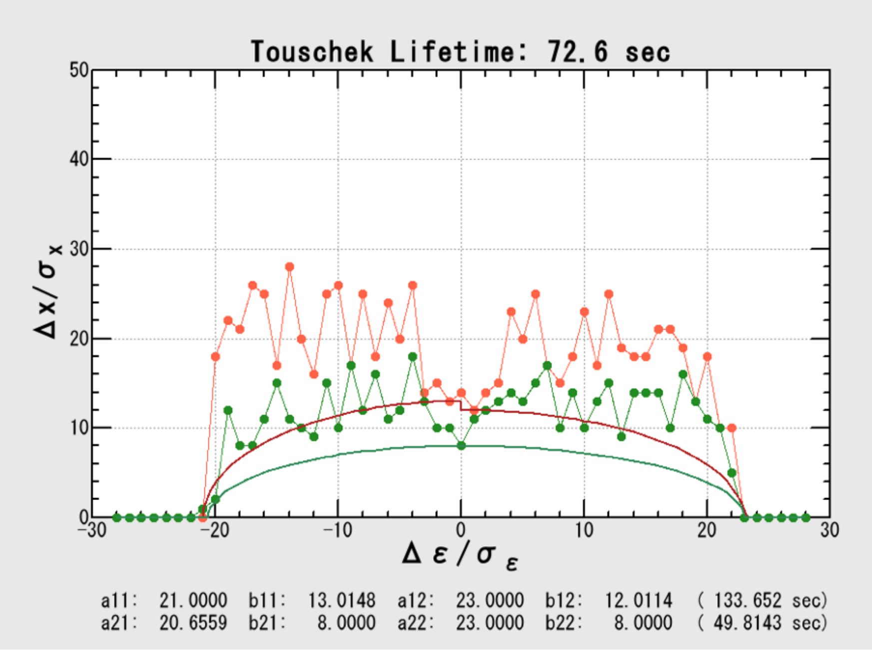
Beam-beam related issues

- Beam lifetime shortening with beam-beam
- Luminosity degradation
  - The design luminosity was determined based on the strong-strong beam-beam simulation.
  - Beam-beam + lattice nonlinearity and space charge effect

LER Dynamic Aperture

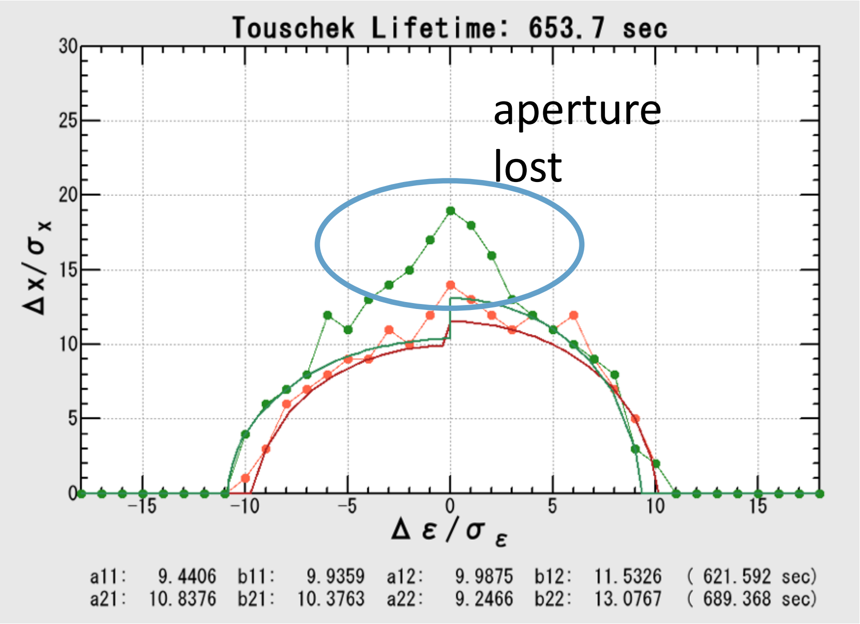

Touschek Lifetime: 512.2 sec

beam-beam


Touschek Lifetime: 72.6 sec

Y. Ohnishi

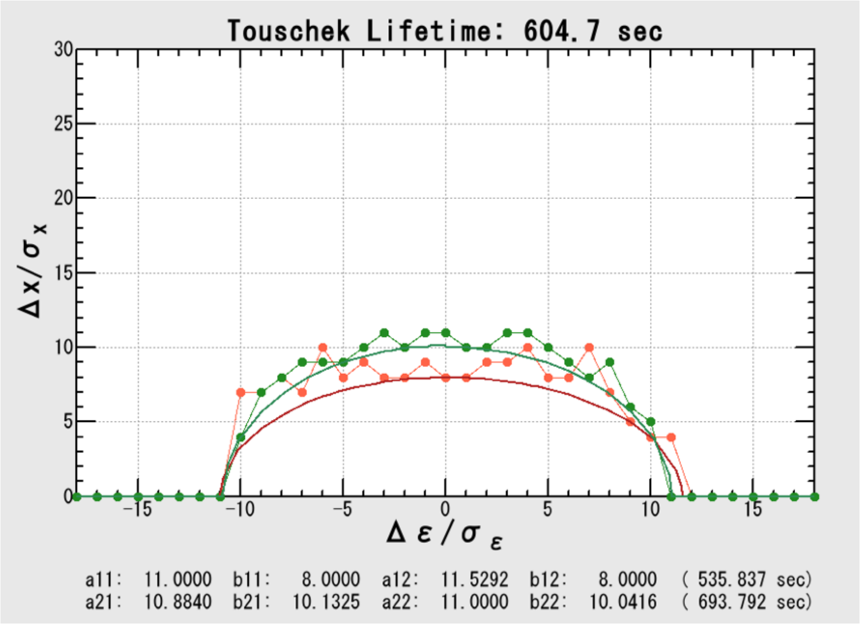
HER Dynamic Aperture



aperture lost

a11: 9.4406 b11: 9.9359 a12: 9.9875 b12: 11.5326 (621.592 sec)
a21: 10.8376 b21: 10.3763 a22: 9.2466 b22: 13.0767 (689.368 sec)

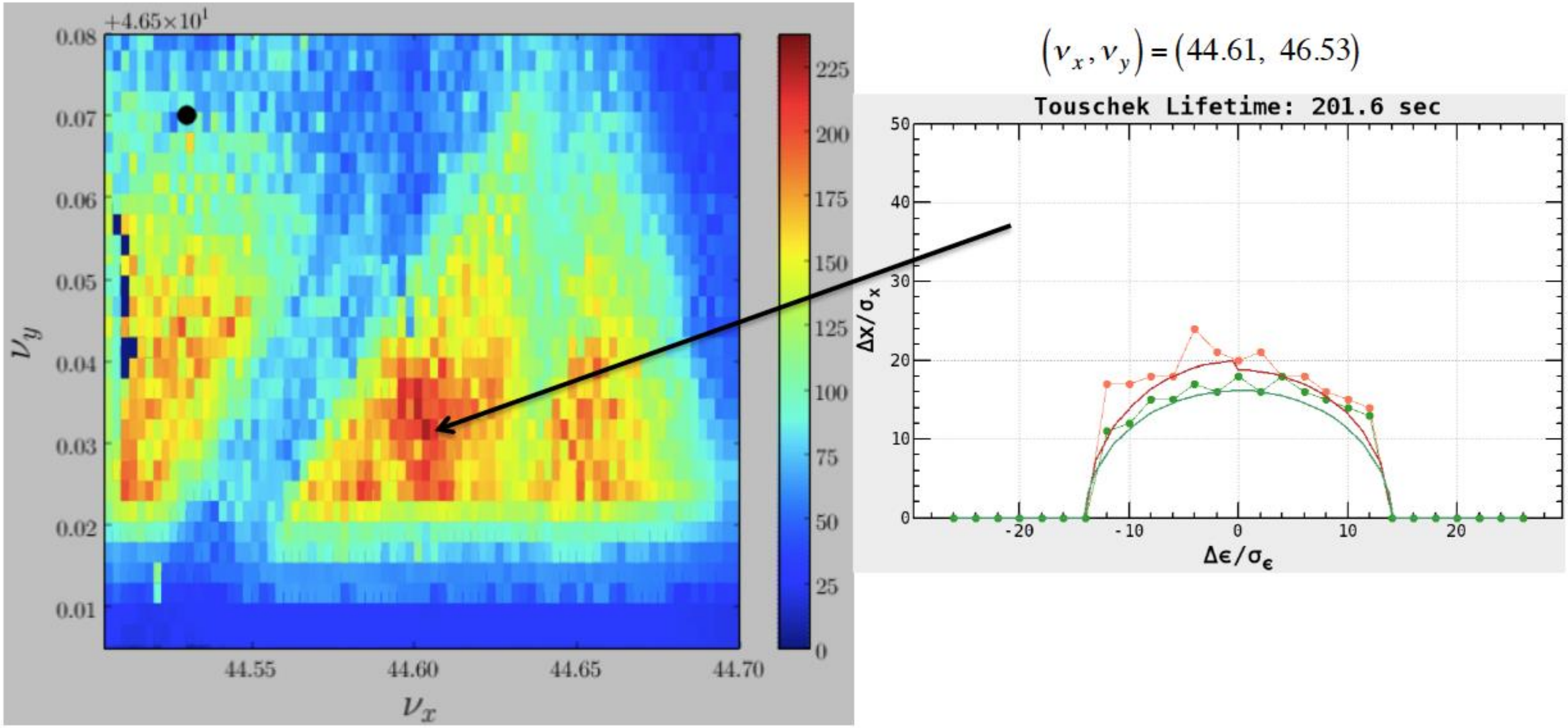
beam-beam



a11: 11.0000 b11: 8.0000 a12: 11.5292 b12: 8.0000 (535.837 sec)
a21: 10.8840 b21: 10.1325 a22: 11.0000 b22: 10.0416 (693.792 sec)

Y. Ohnishi

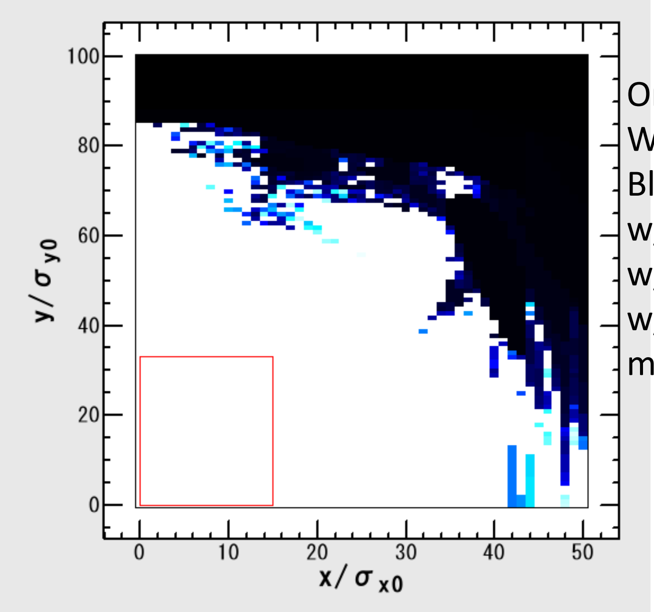
Tune survey (LER)



$(\nu_x, \nu_y) = (44.61,\ 46.53)$

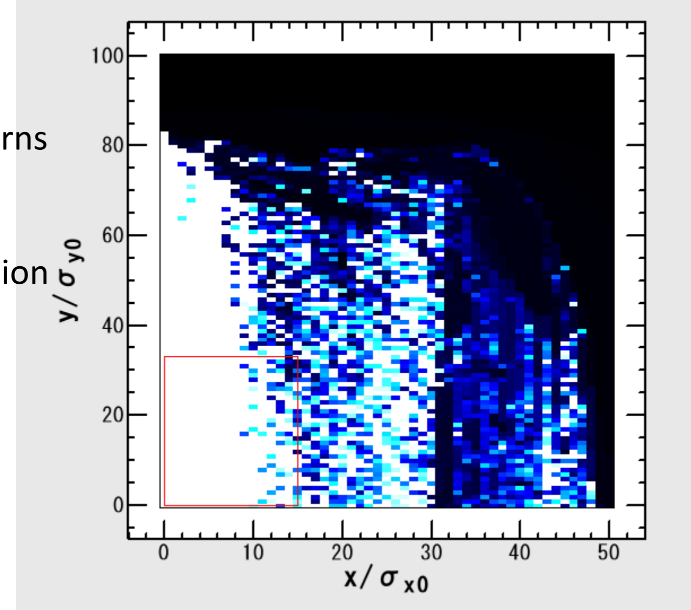
H. Sugimoto

LER Dynamic Aperture

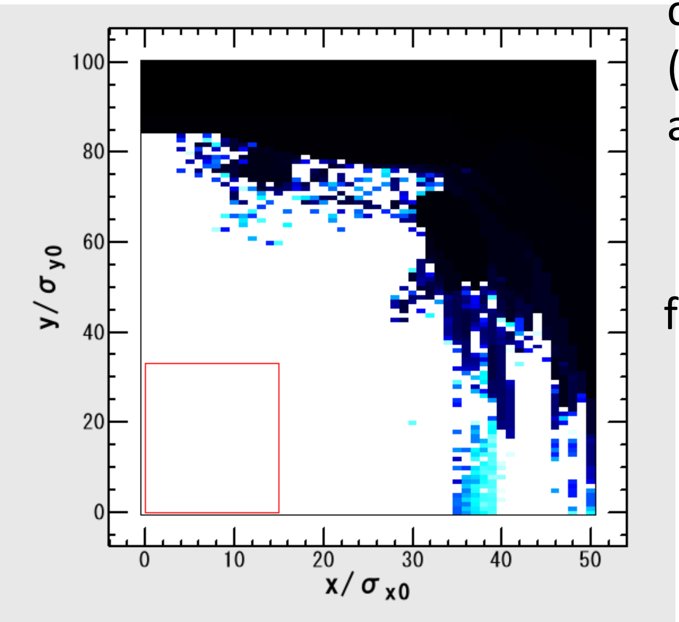


On-momentum
White > 1000turns
Black < 1 turn
w/ damping
w/o rad. Excitation
w/ synchrotron motion

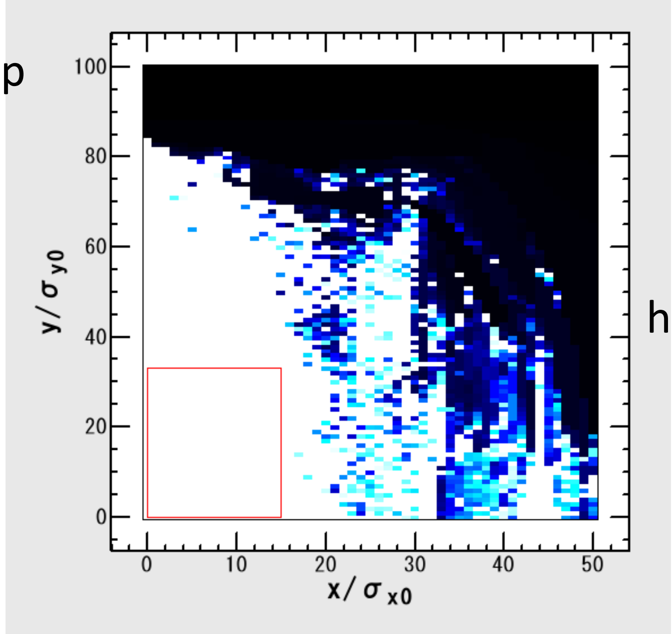
beam-beam



crab waist
(simple map at IP)



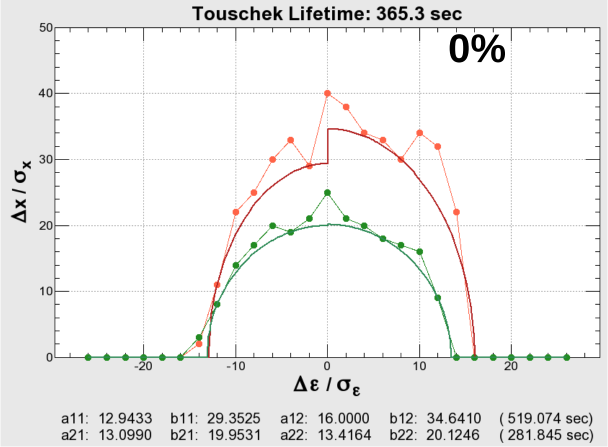
full



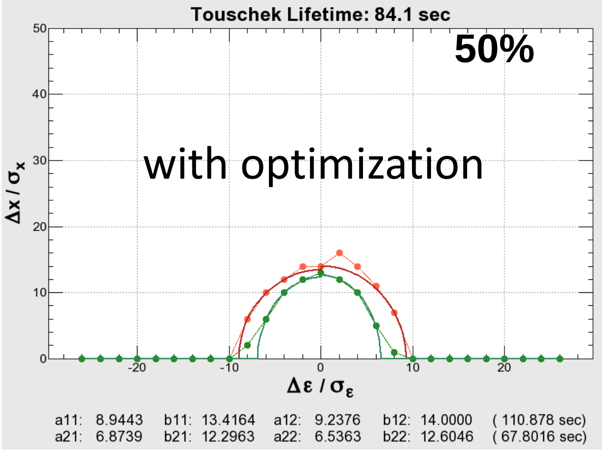
half

Y. Ohnishi

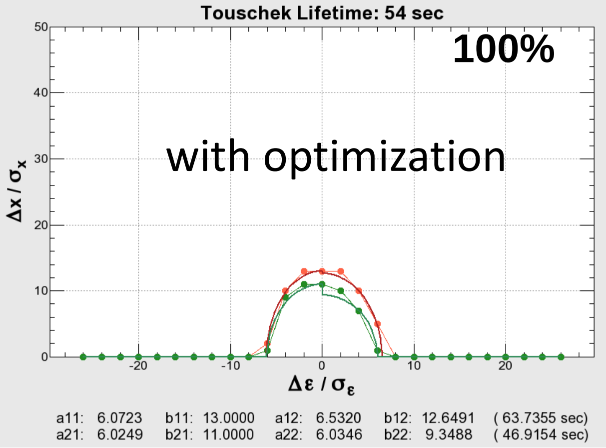
Preliminary results on dynamic aperture study with sextupoles for crab waist



a11: 12.9433 b11: 29.3525 a12: 16.0000 b12: 34.6410 (519.074 sec)
a21: 13.0990 b21: 19.9531 a22: 13.4164 b22: 20.1246 (281.845 sec)

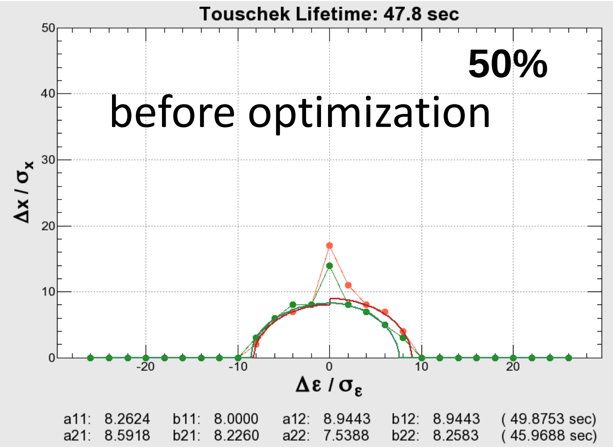


a11: 8.9443 b11: 13.4164 a12: 9.2376 b12: 14.0000 (110.878 sec)
a21: 6.8739 b21: 12.2963 a22: 6.5363 b22: 12.6046 (67.8016 sec)

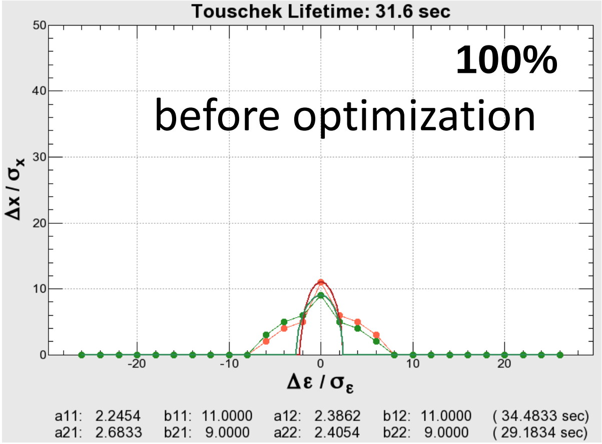


a11: 6.0723 b11: 13.0000 a12: 6.5320 b12: 12.6491 (63.7355 sec)
a21: 6.0249 b21: 11.0000 a22: 6.0346 b22: 9.3488 (46.9154 sec)

H. Koiso



a11: 8.2624 b11: 8.0000 a12: 8.9443 b12: 8.9443 (49.8753 sec)
a21: 8.5918 b21: 8.2260 a22: 7.5388 b22: 8.2583 (45.9688 sec)

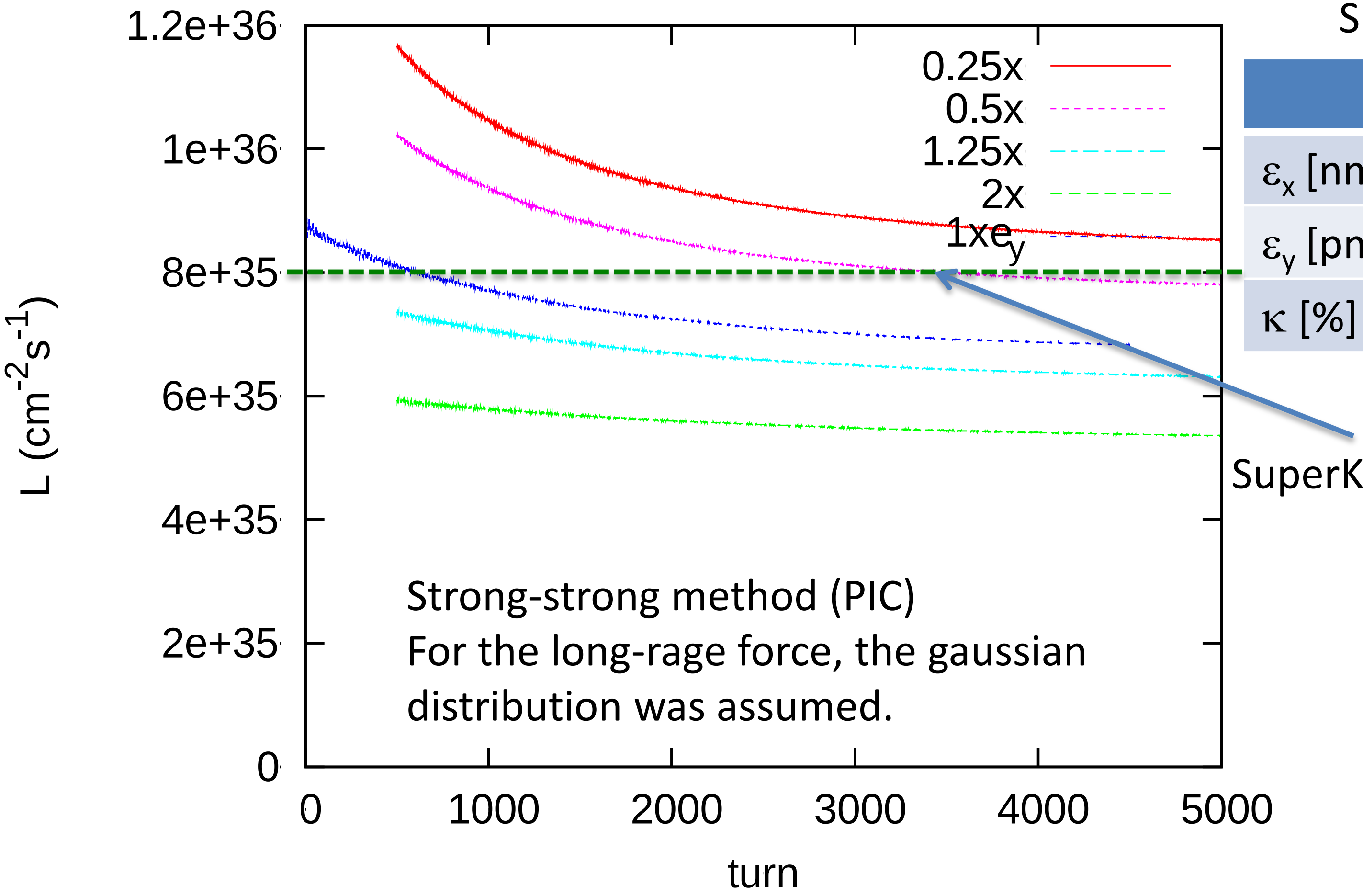


a11: 2.2454 b11: 11.0000 a12: 2.3862 b12: 11.0000 (34.4833 sec)
a21: 2.6833 b21: 9.0000 a22: 2.4054 b22: 9.0000 (29.1834 sec)

We have considered that the crab waist scheme can not be used at SuperKEKB due to the degradation of dynamic aperture. Now, we have started to study this scheme more seriously.

We are collaborating with people in BINP.

SuperKEKB beam-beam simulation



Strong-strong method (PIC)
For the long-rage force, the gaussian distribution was assumed.

SuperKEKB design luminosity

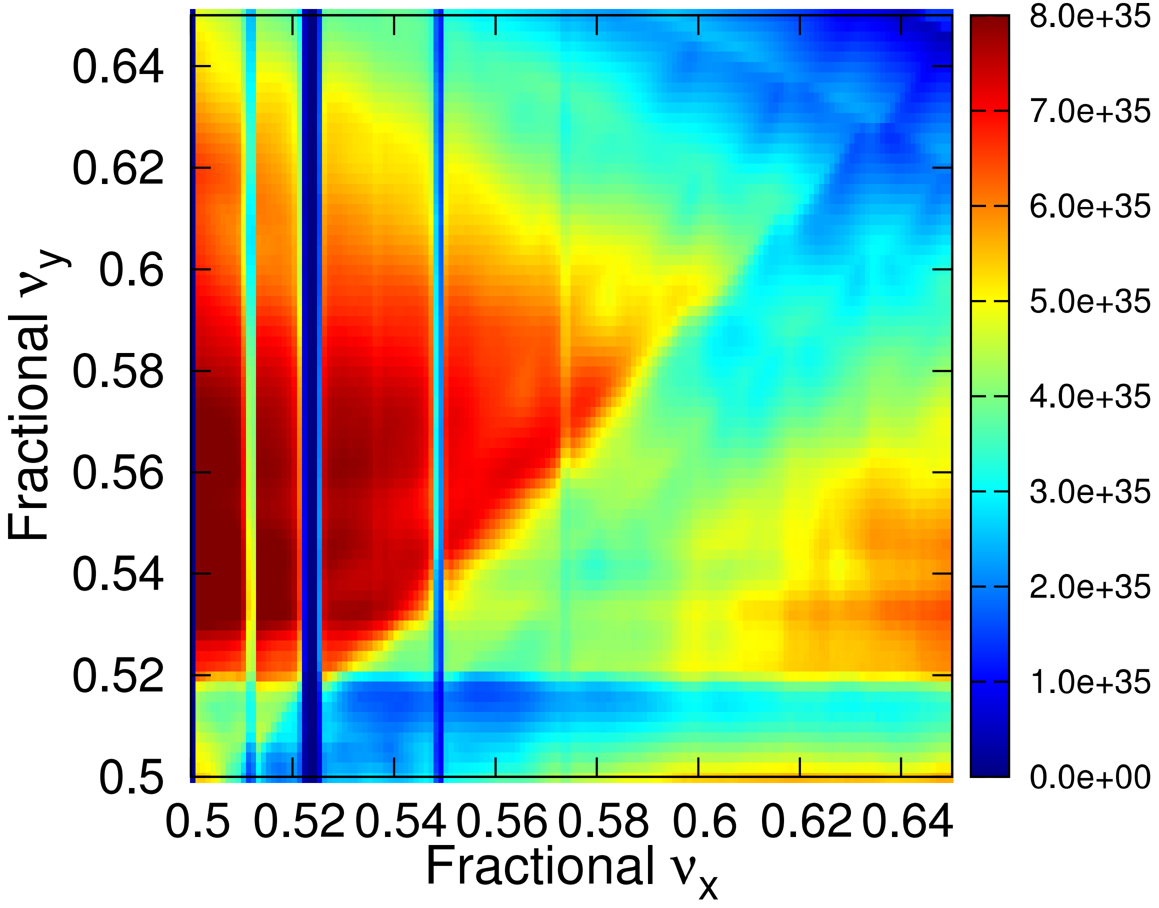
SuperKEKB design

	LER	HER
ε_x [nm]	3.2	4.6
ε_y [pm]	8.64	11.5
κ [%]	0.27	0.25

Smaller (single beam) vertical emittance gives higher luminosity.
Much lower vertical emittance than the design (about half) will be needed to achieve the design luminosity.

K. Ohmi

Strong-weak simulation (tune survey)

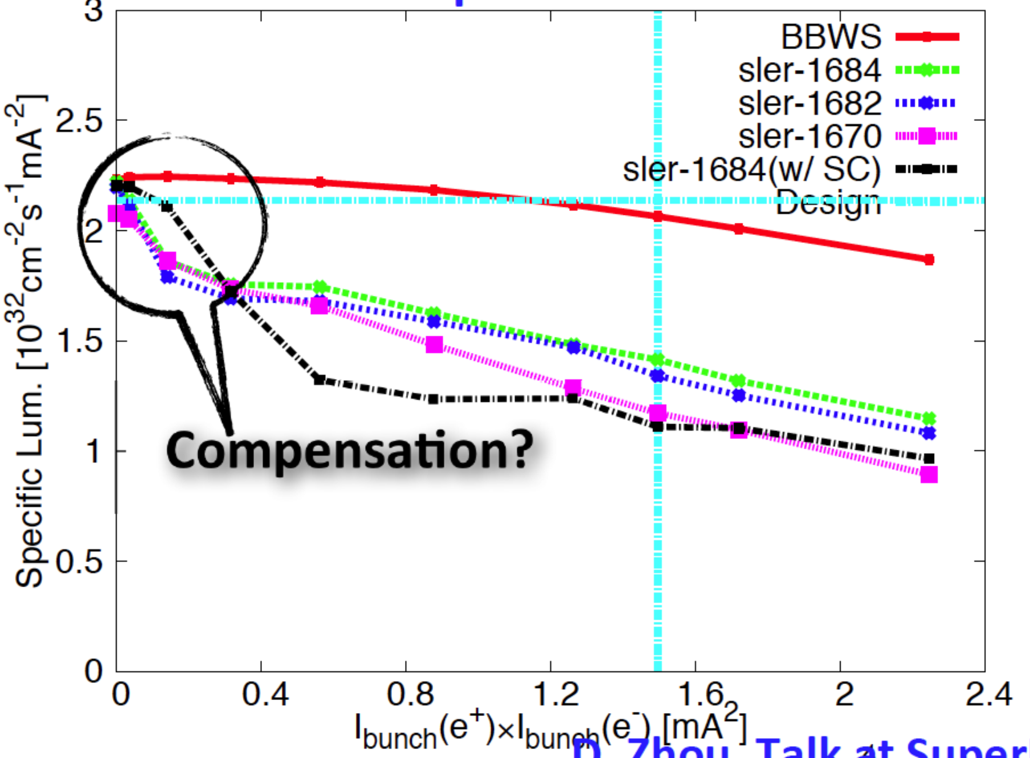


D. Zhou

1. Lum.: LER: BB + LN + SC

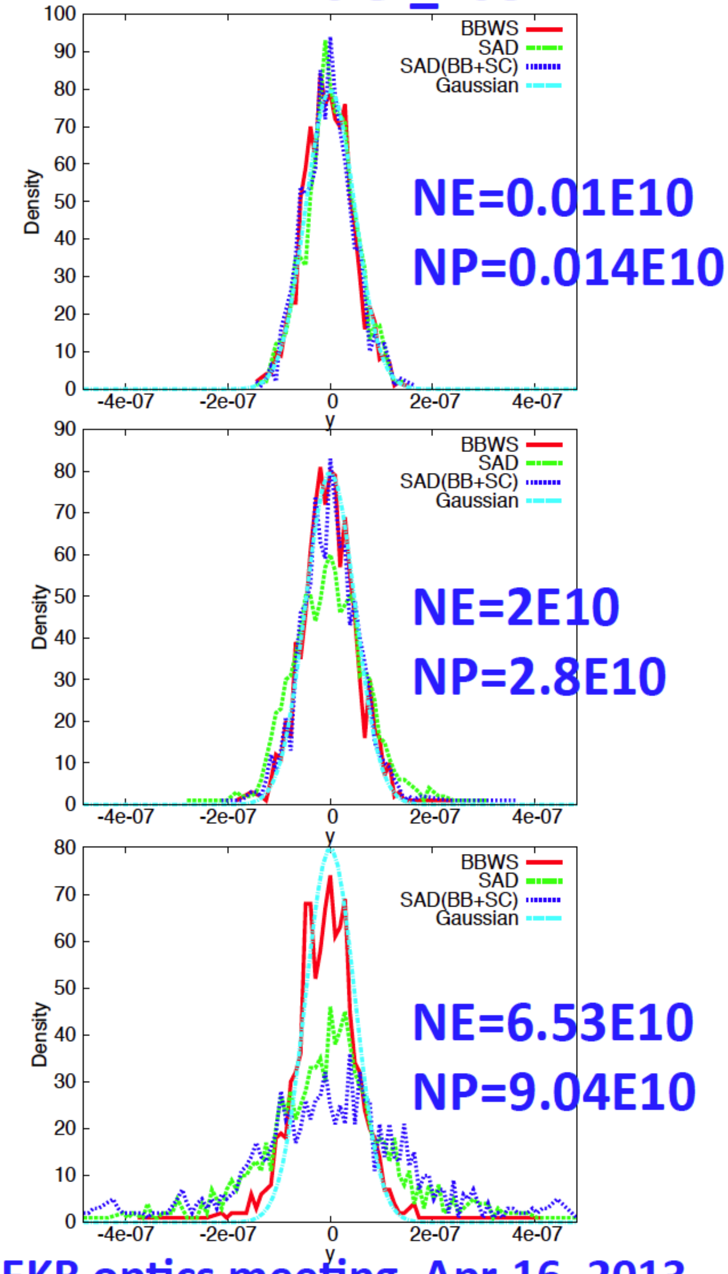
- ➤ SC causes lum. degradation
- ➤ BB + SC: compensate at low current?

LER: specific lum.



Compensation?

sler_1684



NE=0.01E10
NP=0.014E10

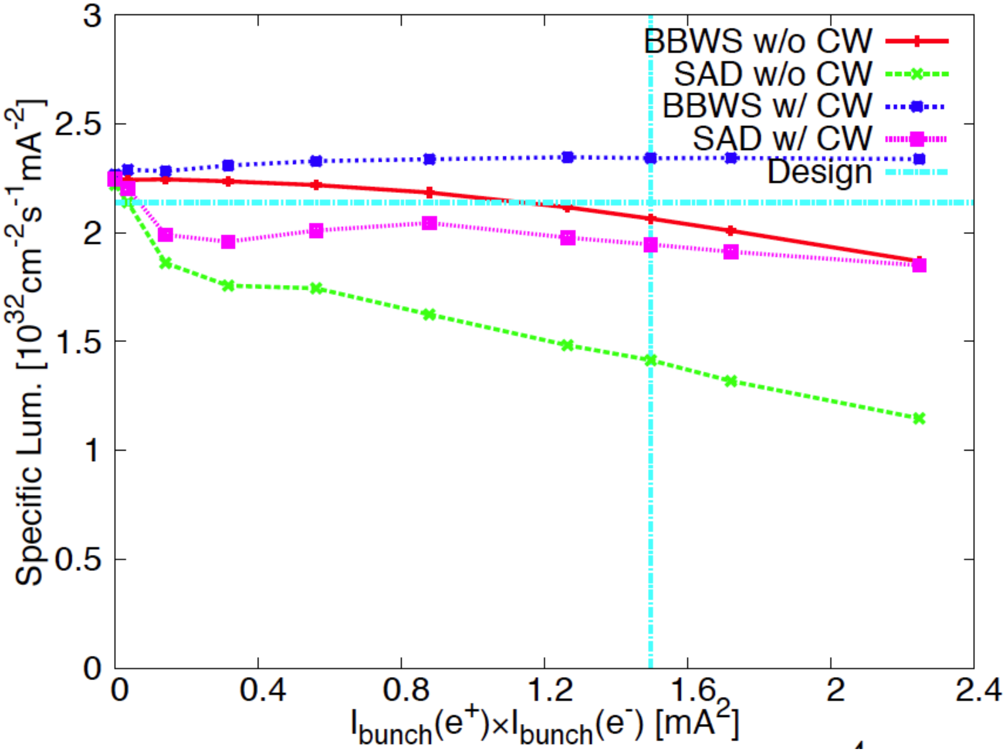
NE=2E10
NP=2.8E10

NE=6.53E10
NP=9.04E10

D. Zhou, Talk at SuperKEKB optics meeting, Apr.16, 2013 sler_1684

1. Lum.: LER: BB + Crab waist

➤ Crab waist: simple map at IP



Crab waist seems to be effective to recover also the luminosity.

D. Zhou

IP orbit control

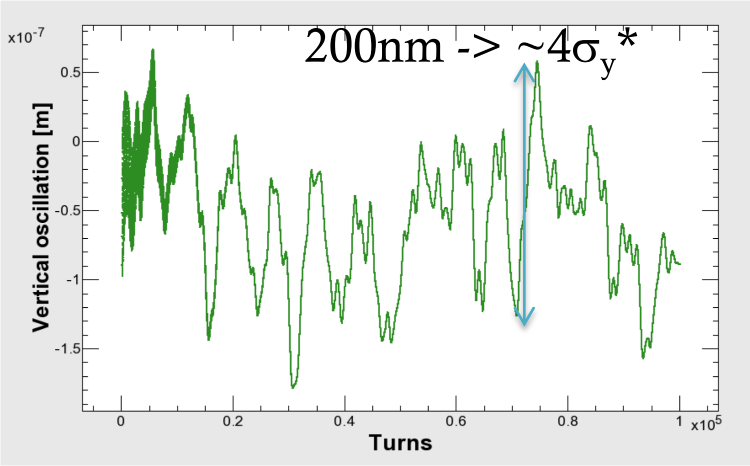
- The IP orbit control to maintain an optimum beam collision is more difficult than the KEKB case.

	KEKB	SuperKEKB
ε_y	150pm	~8.6pm (LER)
β_y^*	5.9mm	0.27mm(LER)
σ_y^*	940nm	45nm

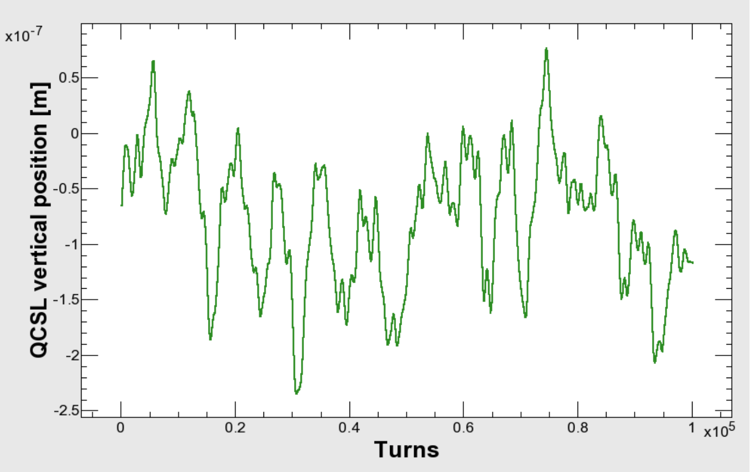
- IP orbit is very sensitive to the vibration of QCS (QC1, QC2) magnets.

QCSL vertical position oscillation (measurement) and orbit change (tracking) : SuperKEKB HER

Vertical orbit at IP (simulation)



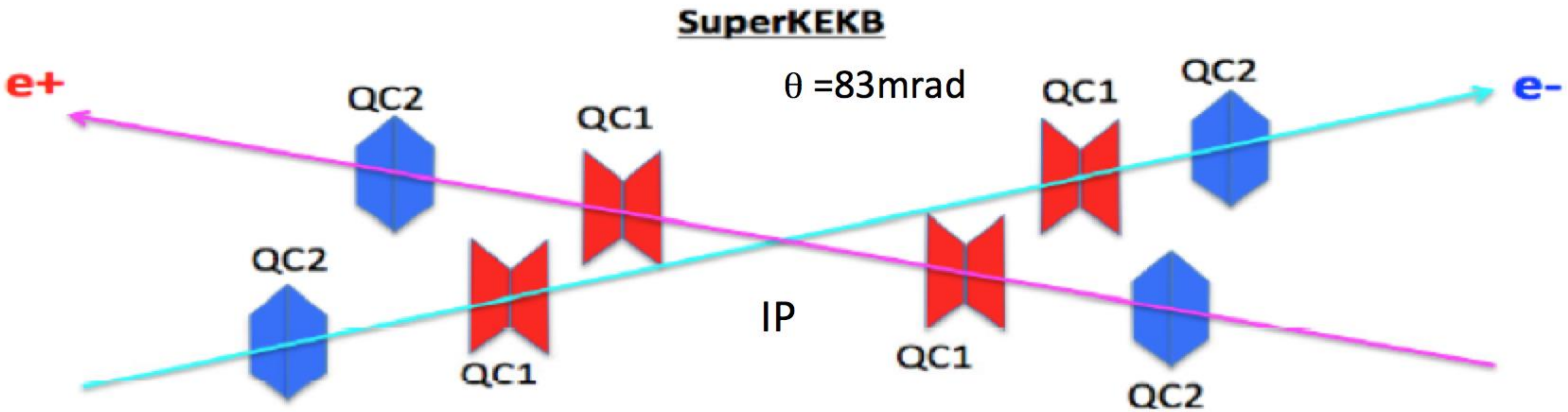
**QCSL vertical position (measurement)
-> QC1L (HER)**



If the QC1L magnets of SuperKEKB vibrates with the same amplitude of the QCSL of the KEKB, the orbit change at IP amounts to 4σ_y*.

Countermeasures

- Reinforcement of supports for QCS magnets
- Rely on the coherency of the oscillation of QC1P and QC1E (QC2P and QC1E).
- Fast orbit feedback



Orbit change at IP with 1μm offset of QCS magnets

Old optics

		K1 (/m)	Distance from IP [m]	β_Q [m]	β_{IP}[mm]	$\Delta\psi_y/2\pi$	COD@IPfor 1μm Q-offset [μm] (New optics)	
QC1L	LER	-1.717	0.912	2504.3	0.27	0.24995	-0.706 (-0.7339)	>
	HER	-1.142	1.390	5462.4	0.3	0.24997	-0.731 (-0.7684)	
QC1R	LER	-1.712	0.912	2567.7	0.27	0.24996	-0.713 (-0.7362)	>
	HER	-1.070	1.430	5592.6	0.3	0.24997	-0.693 (-0.7299)	
QC2L	LER	0.84161	1.9099	962.2	0.27	0.25004	0.2145	>
	HER	0.65023	2.6799	1923.3	0.3	0.25030	0.2470	
QC2R	LER	0.83924	1.9760	924.6	0.27	0.25005	0.2097	>
	HER	0.55577	2.9449	1806.9	0.3	0.25004	0.2046	

COD $$\Delta y = \frac{1}{2\sin\pi\nu}\sqrt{\beta_Q\beta_{IP}}\cos\left(\pi\nu - \left|\Delta\psi\right|\right)\vartheta$$

If QCS magnets for both rings move coherently, orbit difference of the two beam becomes much smaller (1/10 ~ 1/20) than non-coherent case.

Luminosity degradation due to QC1 vibration (simulation)

Y. Funakoshi

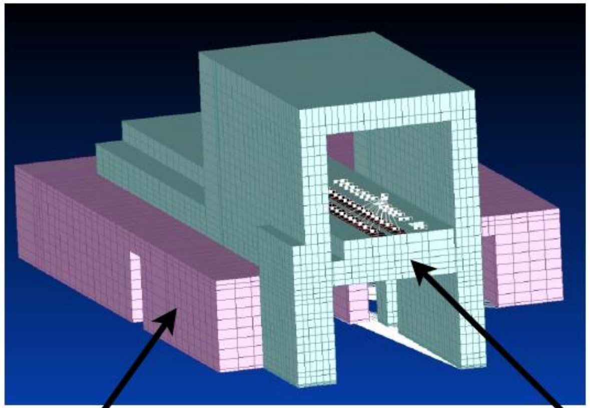
Model		QC1 R-side			
Model-A	f (Hz)	24.85	38.93	69.34	99.60
	Δy_{IP}* (nm)	18.63	1.72	8.29	3.14
	L/L_0 (%)	**95.4**	**99.8**	**99.7**	**99.7**
Model-F	f (Hz)	24.75	38.94	69.24	99.59
	Δy_{IP}* (nm)	16.7	0.97	1.08	1.57
	L/L_0 (%)	**96.1**	**99.8**	**99.8**	**99.8**

*RMS

IP feedback can resume luminosity up to 10 - 70 Hz.

Reinforcement of Bridge Structure

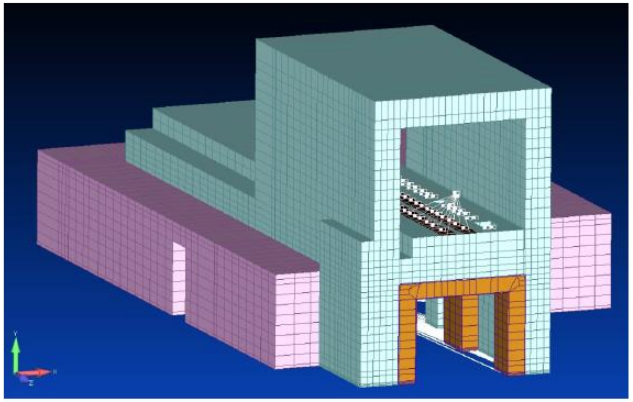
Model-A (baseline)



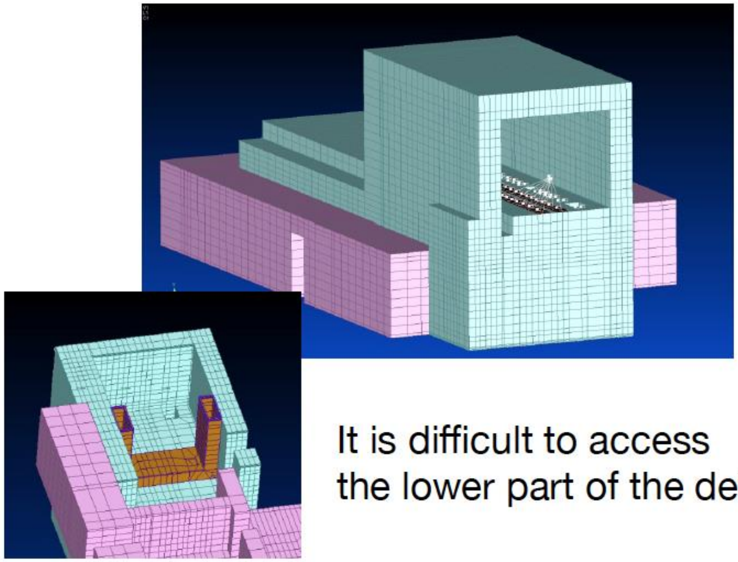
Entranceway is closed.

filling ditch

Model-B

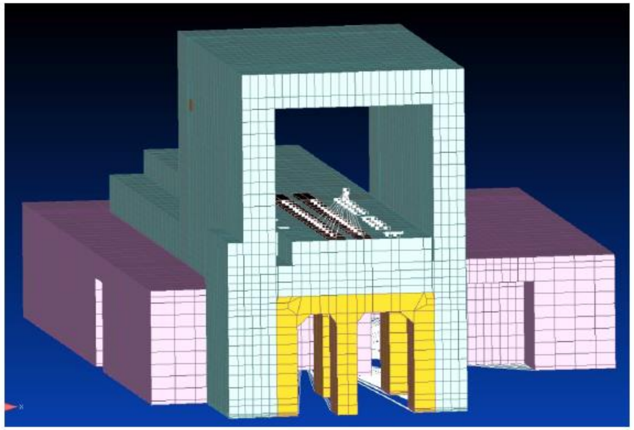


Model-C



It is difficult to access
the lower part of the detector.

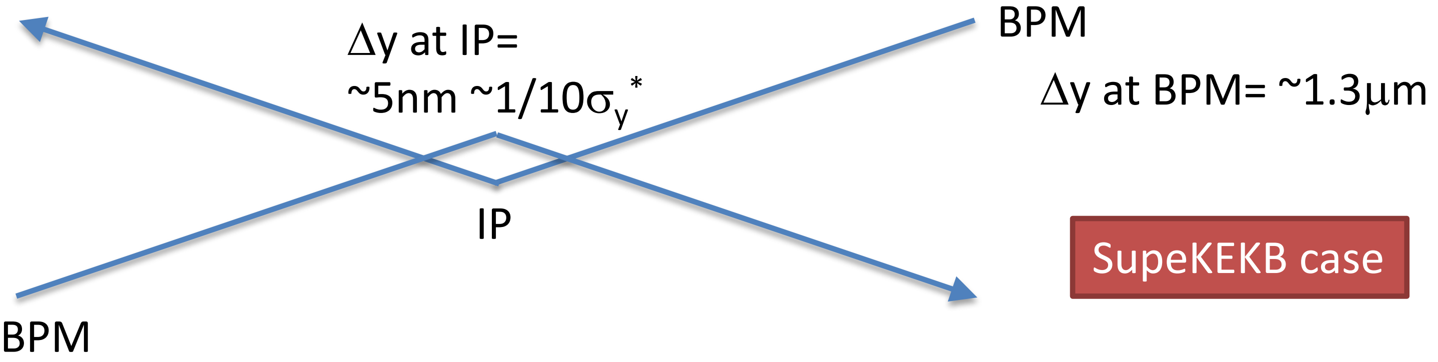
Model-F



Additional supports

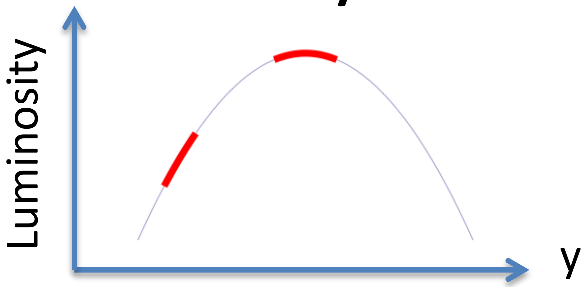
Orbit feedback at IP :Algorism

- Beam-beam deflection (SLC, KEKB vertical)



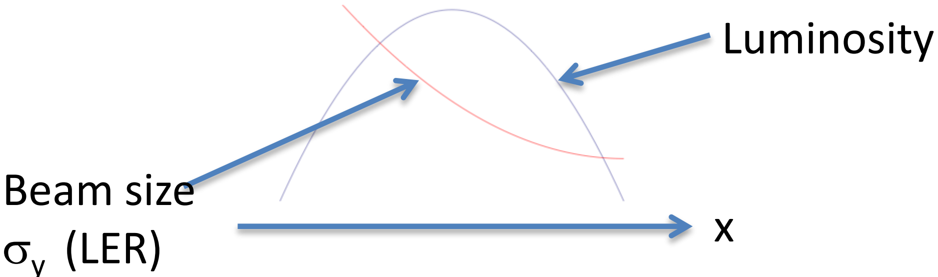
SupeKEKB case

- Luminosity feedback (dithering)(PEP-II)



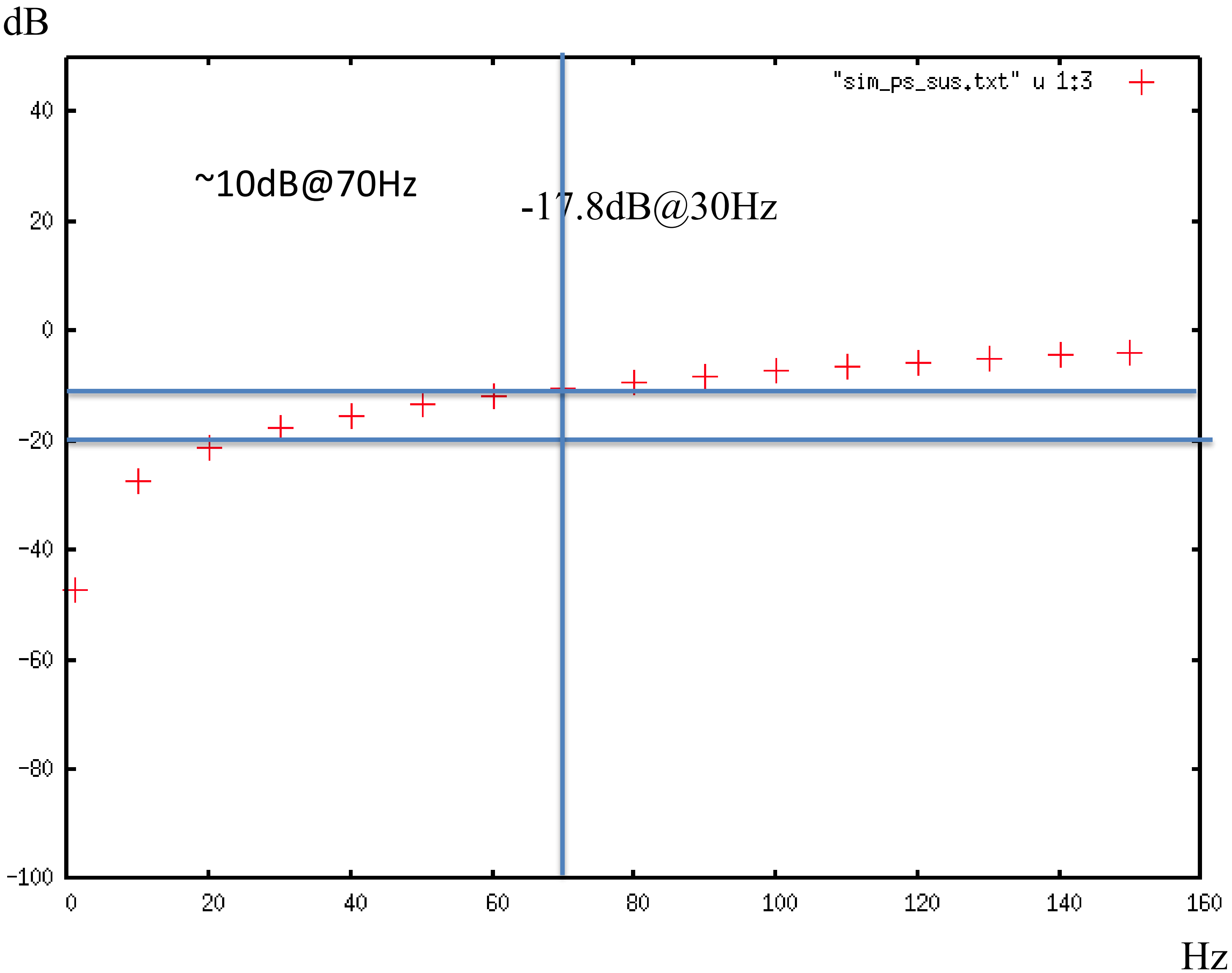
When we shake the beam at around the peak of the luminosity, there appears twice of the frequency of the dithering frequency.

- Beam size feedback (KEKB horizontal)



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

Rejection gain by fast orbit feedback



~10dB@70Hz

-17.8dB@30Hz

H. Fukuma

Electron cloud issues

Y. Suetsugu

- The single bunch instability is main concern.
  - Leads to increase in emittance
  - Coupled bunch instabilities will be cured by feedback system.
- Simulation and calculation by Ohmi, et al.

K. Ohmi , KEK Preprint 2005-100 (2006)

Threshold of density

$$\rho_{e,th} = \frac{2\gamma\nu_s\omega_{e,y}\sigma_z/c}{\sqrt{3}KQr_e\beta L}.$$

Here,

$$\omega_{e,y} = \sqrt{\frac{\lambda_+ r_e c^2}{\sigma_y(\sigma_x+\sigma_y)}}$$

E [GeV]	= 4.0			
γ	= 7828	N_b	= 6.25E+10	
ν_s	= 0.026	Q_b[C]	= 1.4E-08	(1.4 mA/bunch)
		S_b [m]	= 1.2	(4ns)
σ_z [m]	= 6.E-03	λ [C/m]	= 5.2E+12	($Q_b/2/\sigma_z$)
c [m/s]	= 3.E+08	σ_y [m]	= 2.E-05	
K	= 11	σ_x [m]	= 2.E-04	
Q	= 7			
r_e [m]	= 2.80E-15	ω_e	= 5.46E+11	$K = \omega_e\ \sigma_z/c$
β_y [m]	= 25	$\omega_e\ \sigma_z/c$	= 10.9	$Q = \mathrm{Min}(Q_{nl},\ \omega_e\ \sigma_z/c)$
L [m]	= 3016			Q_{nl} ~7

ρ_{th} [e^-/m^3] =1.59E11 → **Target: 1E11**

Latest simulation result on the threshold value of instability

- Simulation with PEHTS2 by D. Zhou and K. Ohmi
  - With uniform beta functions and uniform electron cloud density along the ring, the threshold for electron cloud density is about 5.E11 m^{-3}.
  - With realistic beta functions and uniform electron cloud density along the ring, the threshold reduces to about 1.6E11 m^{-3}.
  - With realistic beta functions and estimated s-dependent electron cloud density along the ring, the threshold is about 5.E11 m^{-3}.

Countermeasures

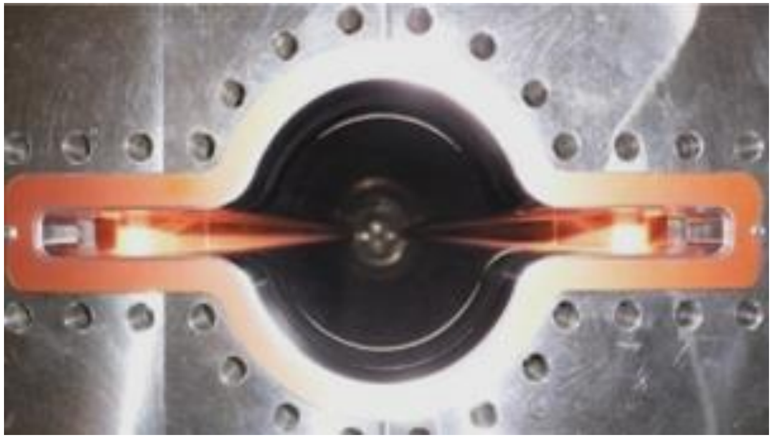
Y. Suetsugu

- For the upgrade of the vacuum system for SuperKEKB, the electron cloud is a key issue.

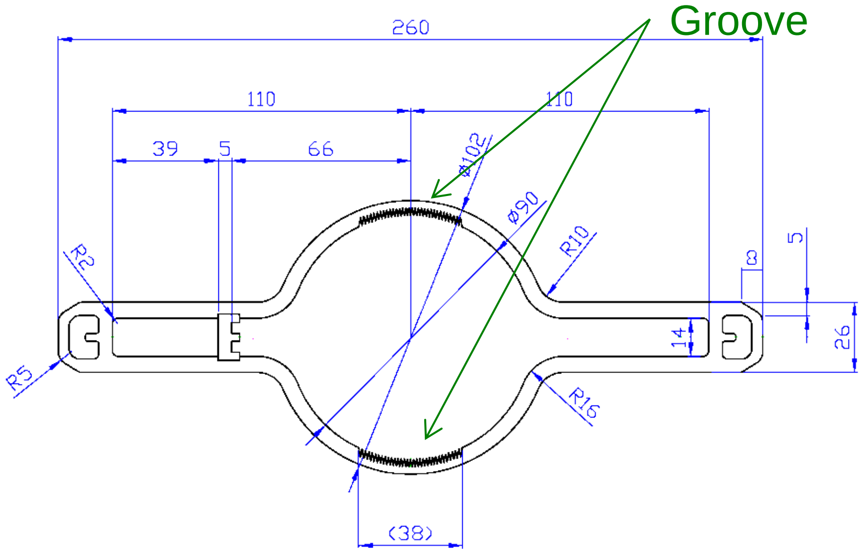
- Countermeasures are carefully chosen based on the various studies.

Drift section	Antechamber +Solenoid +TiN Coating
Q and Sx mag.	Antechamber +Solenoid +TiN Coating
Bend section	Antechamber +Groove+ TiN Coating
Wiggler section	Antechamber +Electrode (Cu)

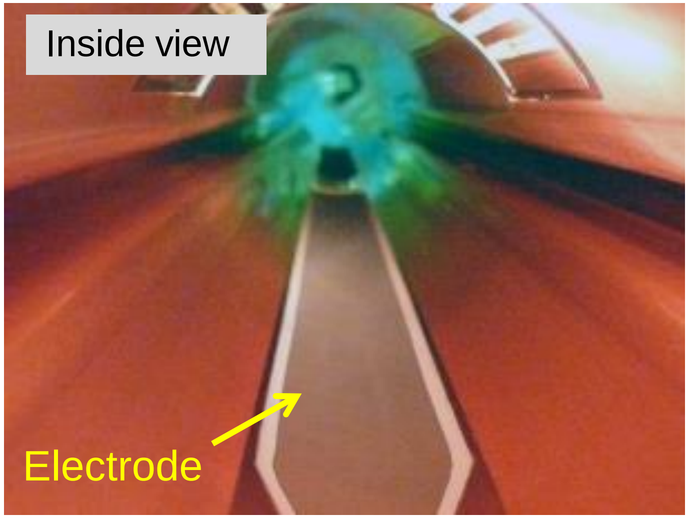
Countermeasures for electron clouds



Drift section: Antechamber + TiN coating



Arc Bend Cross Section



Wiggler section:
Antechamber + Clearing electrode

Y. Suetsugu

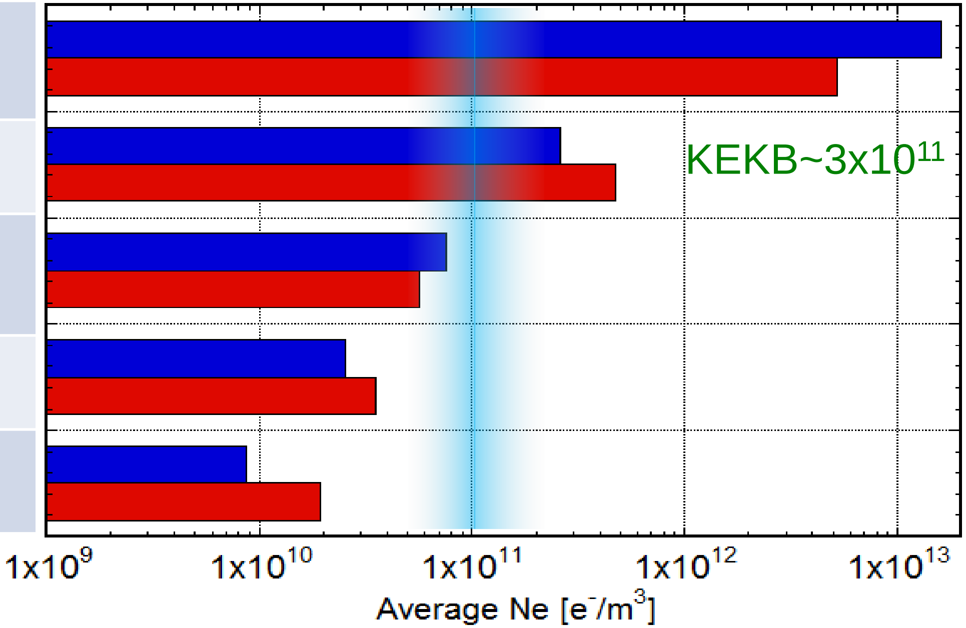
Expected electron density

Y. Suetsugu

- n_e after applying countermeasures: estimated from experiments (Red)
- Compared with results of CLOUDLAND (Blue)
  - δ_{max}=1.2, Solenoid field=50G (→n_e=0), Antechamber; photoelectron yield =0.01 (1/10)
- n_e of approx. 1/5 of the target value is expected.

Condition	ne [m^{-3}]
Circular Cu chamber [KEKB beam pipe]	5.2E12
+Solenoid at Drift (1/50)	4.7E11
+Antechamber (1/5)+TiN (3/5)	5.7e10
+Electrode in Wiggler (1/100)	3.5e10
+Groove in Bend (1/4)	2.0E10

Target value for ne: ~$1x10^{11}$



If the latest simulation result on the threshold is true, there is a margin of a factor 25!

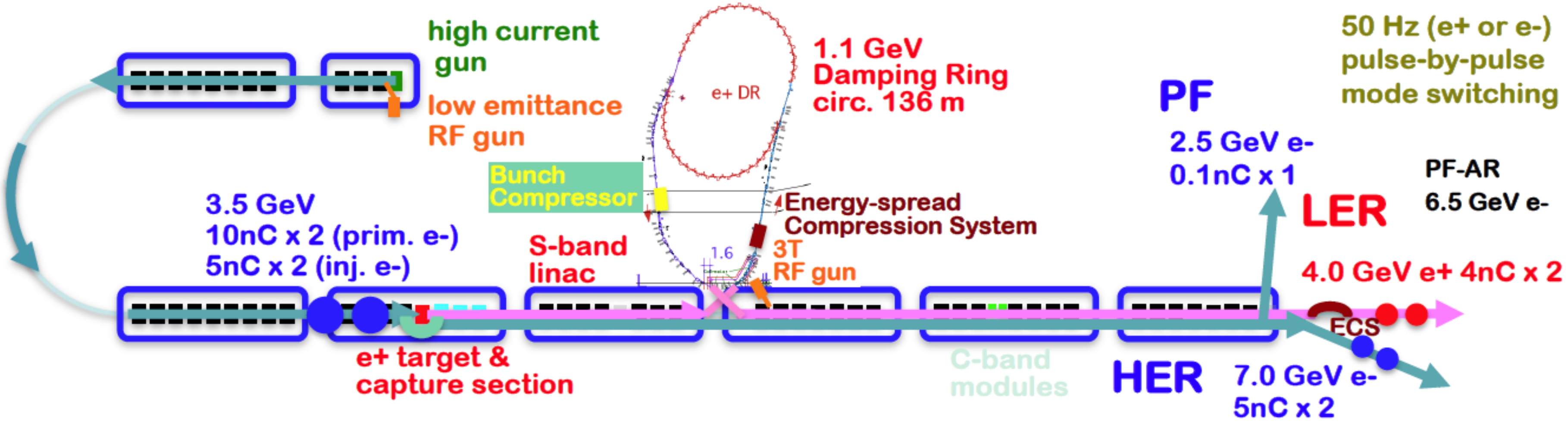
Beam lifetime

	KEKB (design)		KEKB (operation)		SuperKEKB	
	LER	HER	LER	HER	LER	HER
Radiative Bhabha	21.3h	9.0h	6.6h	4.5h	28min.	20min.
Beam-gas	45h[a)]	45h[a)]			24.5min.[b)]	46min. [b)]
Touschek	10h	-			10min.	10min.
Total	5.9h	7.4h	~133min.	~200min.	6min.	6min.
Beam current	2.6A	1.1A	1.6A	1.1A	3.6A	2.6A
Loss Rate	0.12mA/s	0.04mA/s	0.23mA/s	0.11mA/s	10mA/s	7.2mA/s

a) Bremsstrahlung
b) Coulomb scattering, sensitive to collimator setting

As for loss rate, beam loss accompanied with the beam injection should be added.

Linac



Positron capture section
920 kVA, 900 lit/min

Damping ring BT (LTR, RTL)
310 kVA

Switch yard (3SY)
300 kVA, 460 lit/min

- RF low-emittance gun for 5 nC
- Improve positron source for 4 nC
- Low-emittance transport
  - alignment error tolerance is 0.1 mm locally (0.3 mm global).
- Simultaneous and top-up injection (accompany PF and PF-AR)

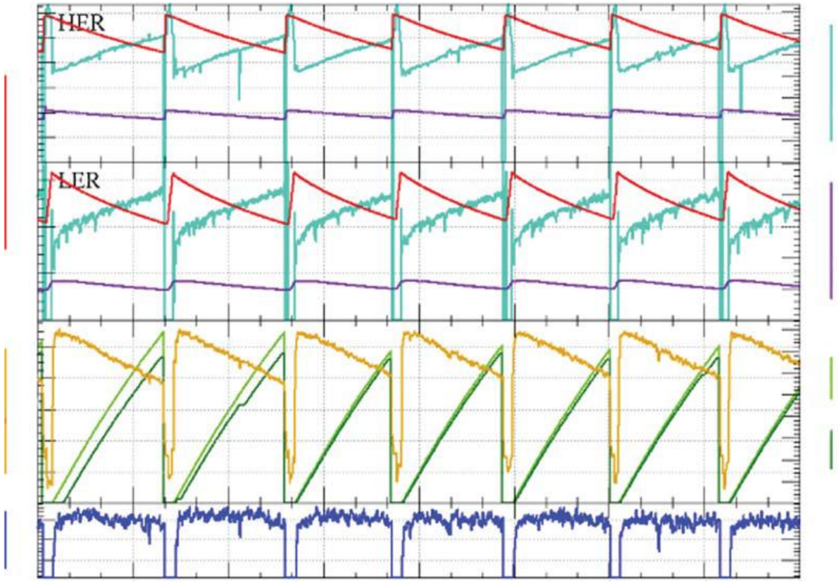
Table 1: The required injection beam parameters

	KEKB (e+/e-)	SuperKEKB (e+/e-)
Charge [nC]	1 / 1	4 / 5
Emittance [mm-mrad]	2100 / 300	10 / 20

K. Furukawa, M. Satoh, M. Yoshida, T. Kamitani

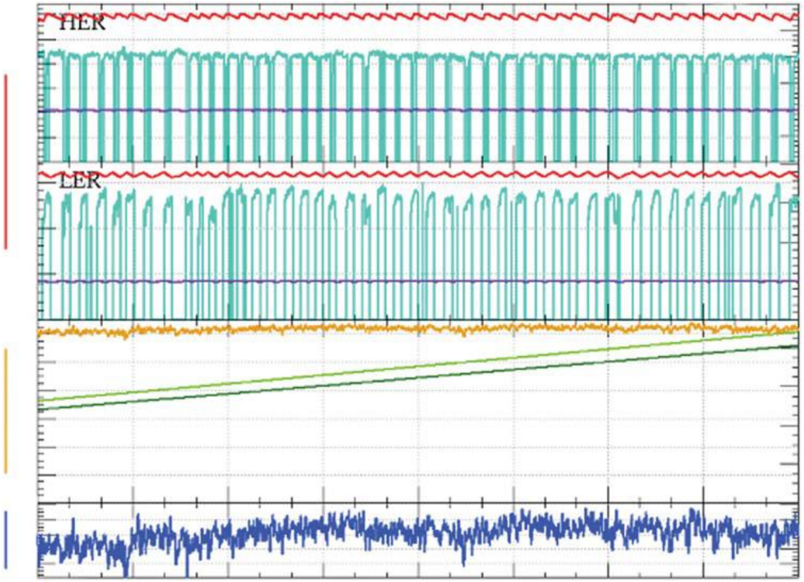
Continuous injection

- At SuperKEKB, the continuous injection (top-up injection) is indispensable, since the beam lifetime is very short.
  - Max. 50 Hz (e- + e+)
  - Azimuthal VETO (at KEKB not azimuthal 3.5msec after injection)



8 hours

Before continuous injection



8 hours

After continuous injection

Gain in integrated luminosity at KEKB: ~30%

Beam background

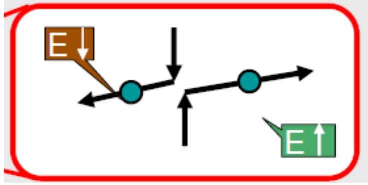
- At SuperKEKB with x40 larger Luminosity, beam backgrou o increase drastically.

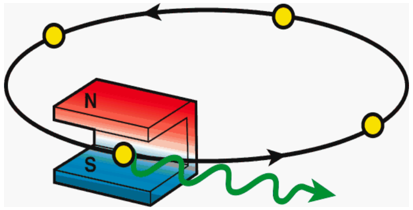
Beam-origin

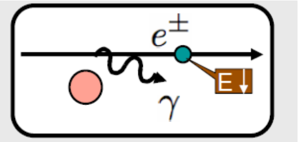
  - Touschek scattering
  - Beam-gas scattering
  - Synchrotron radiation

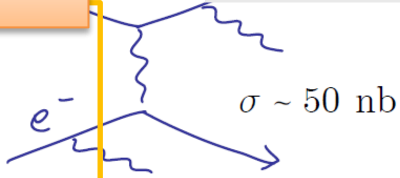
Luminosity dependent

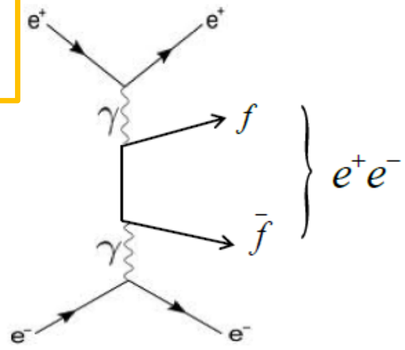
  - Radiative Bhabha event: emitted γ
  - Radiative Bhabha event: spent e+/e-
  - 2-photon process event: e+e-→e+e-e+e-
  - etc…

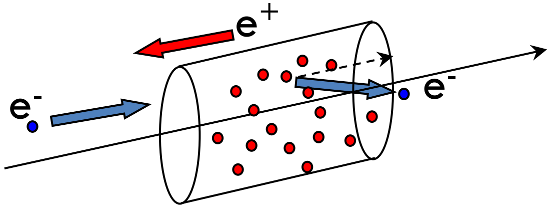






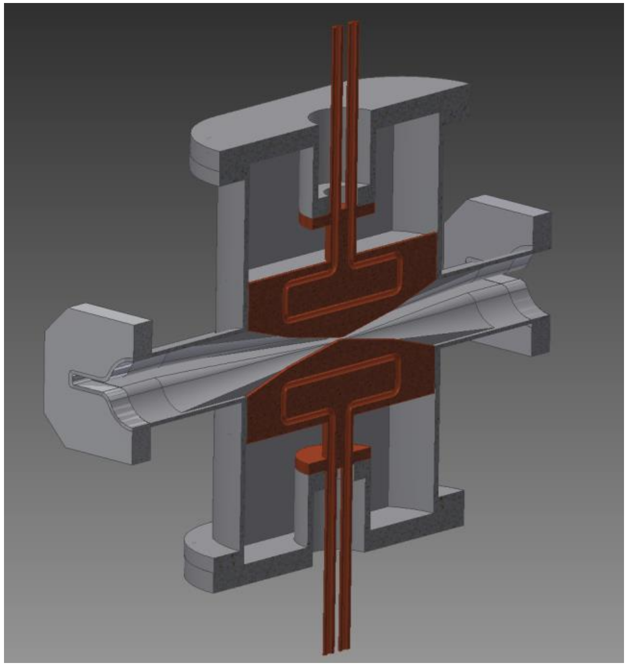






Collimators

Vertical collimator



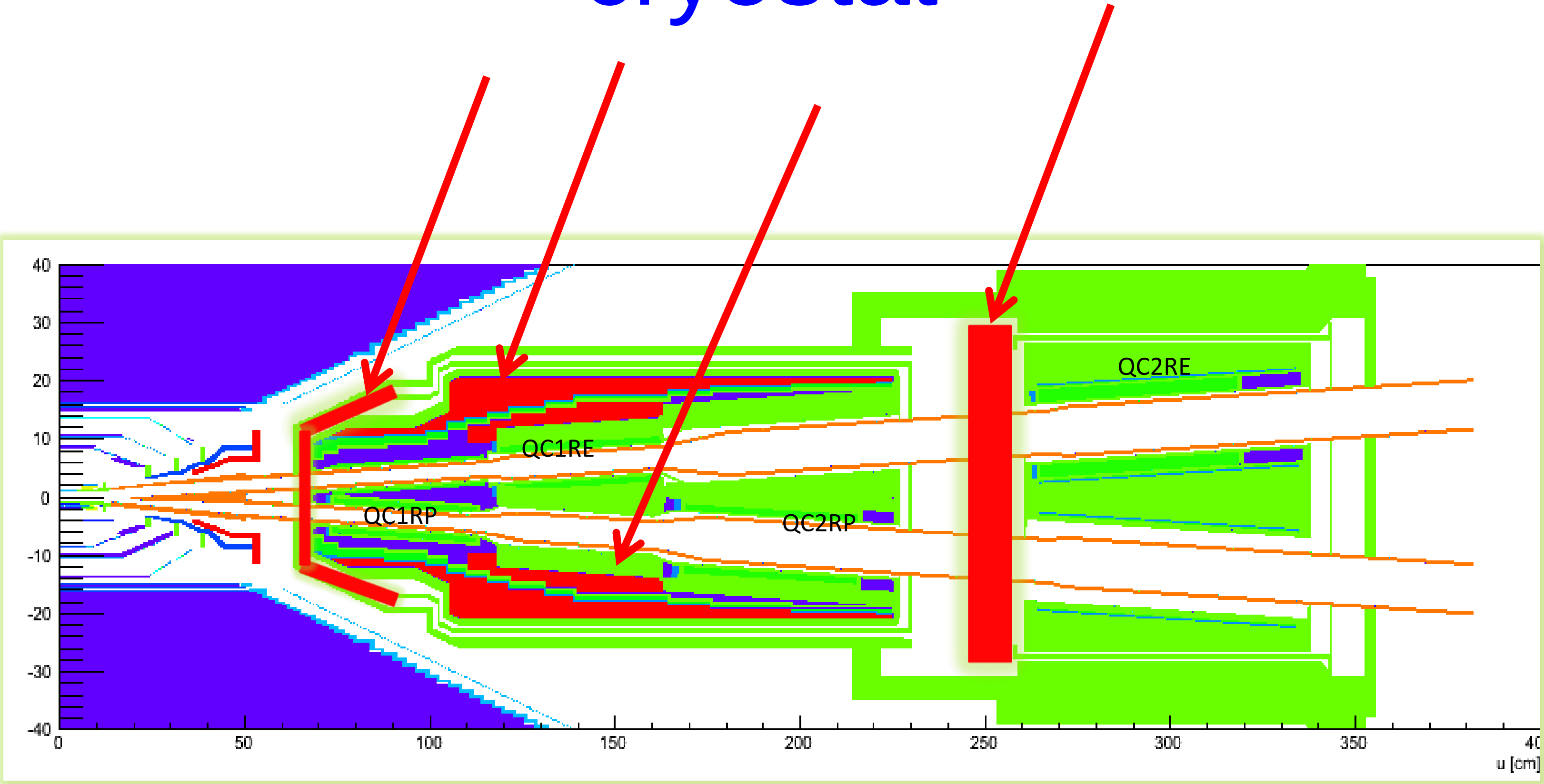
- Horizontal collimators are effective to reduce Touschek BG in IR area
- To reduce IR loss of beam-gas Coulomb BG, very narrow (~2mm half width) vertical collimator is required
- TMC instability is an issue, low-impedance design of collimator head is important
- Should withstand ~100GHz loss (tungsten)
- Precise control of collimator width is important (otherwise IR loss rapidly increase)

Life time	Touschek	Beam-gas Coulomb	Rad. Bhabha
LER	10 min.	25 min	28 min.
HER	10 min.	46 min.	20 min.

IR loss |s|<4m	Touschek	Beam-gas Coulomb	Rad. Bhabha
LER	250 MHz	90 MHz	0.6GHz*
HER	30 MHz	<10 MHz	0.5GHz*

*Effective rate

Tungsten shield inside QCS cryostat



Put as much tungsten as possible around the beam pipe to stop showers generated by beam loss

Impact on detector

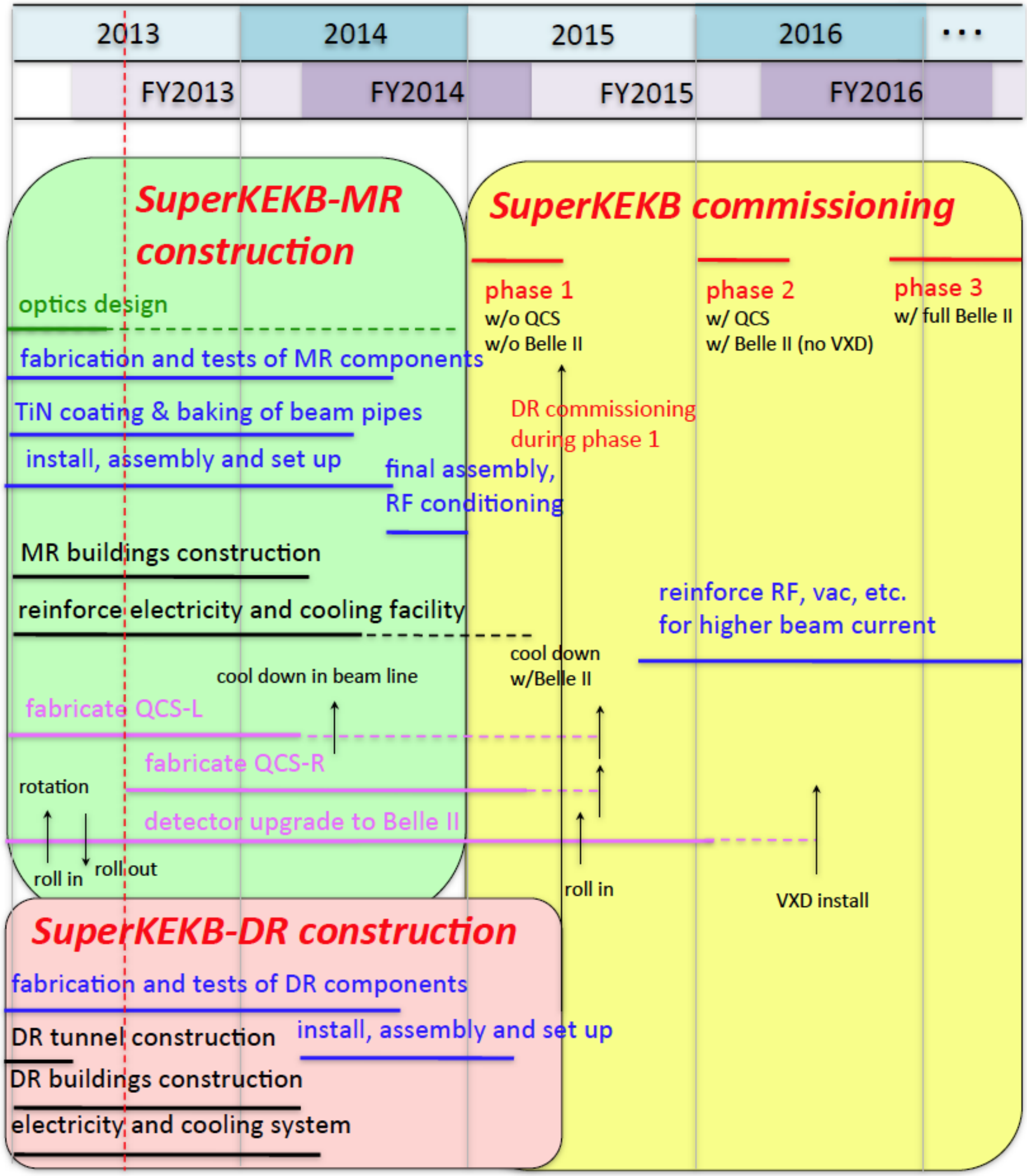
- Assuming design luminosity, BG impact on detector performance(occupancy, tracking/PID performance etc..) is tolerable.
- Assuming 10 years operation at design luminosity, most of our detector components are safe for radiation damage/neutron flux.
  - except for TOP PMT photocathode lifetime, which needs further x2 reduction.

Gammas in BGshower reach TOP quartz bar and generate electrons by Compton scattering and etc.. Those electrons emit Cerenkov photons and those photons reach PMT photocathode.

TOP: Time-of-Propagation counter, detect ring image Cerenkov radiation for particle ID

SCHEDULE

We are here.



2013 | 2014 | 2015 | 2016 | …

FY2013 | FY2014 | FY2015 | FY2016

SuperKEKB-MR construction

optics design

fabrication and tests of MR components

TiN coating & baking of beam pipes

install, assembly and set up

final assembly, RF conditioning

MR buildings construction

reinforce electricity and cooling facility

cool down in beam line

fabricate QCS-L

fabricate QCS-R

rotation

detector upgrade to Belle II

roll in

roll out

SuperKEKB commissioning

phase 1
w/o QCS
w/o Belle II

phase 2
w/ QCS
w/ Belle II (no VXD)

phase 3
w/ full Belle II

DR commissioning during phase 1

reinforce RF, vac, etc. for higher beam current

cool down w/Belle II

roll in

VXD install

SuperKEKB-DR construction

fabrication and tests of DR components

DR tunnel construction

install, assembly and set up

DR buildings construction

electricity and cooling system

K. Akai

Master Schedule

Phase-1
w/o QCS and Belle II

2015 Jan.–June

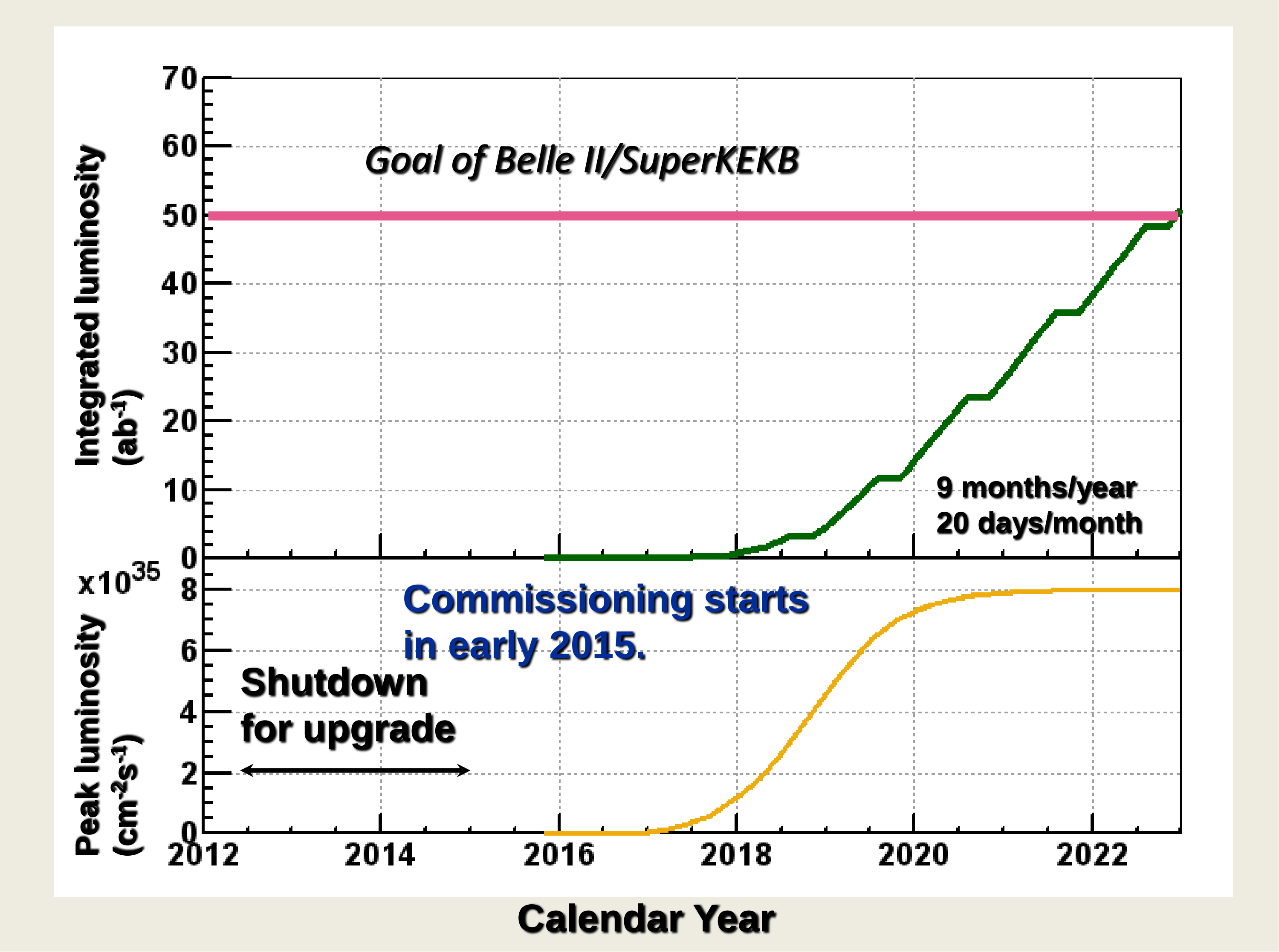
Phase-2
with QCS and Belle II

2016 Jan.–May

Phase-3
Physics Run

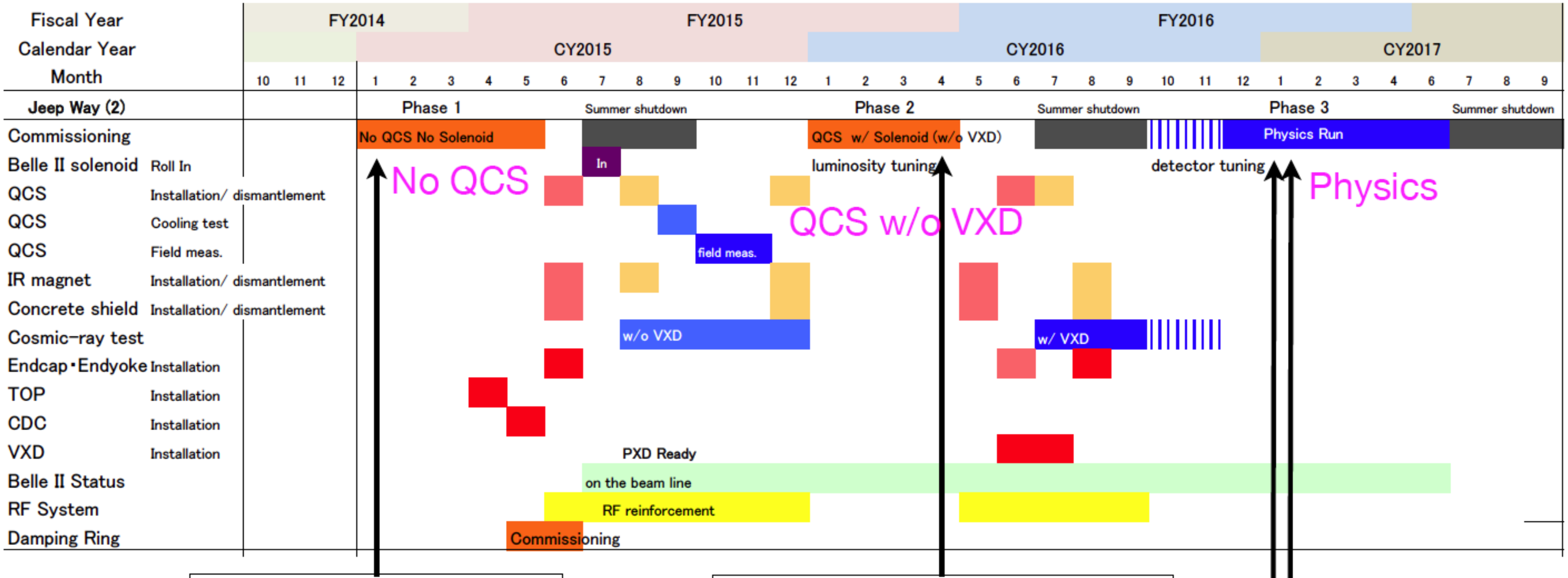
2016 Oct.–

SuperKEKB luminosity projection



Backup slides

Commissioning Schedule: Baseline



Phase-1

Target: > 500 mA

Positron injection w/o Damping Ring.

Vacuum scrubbing
Optics tuning
Detector background

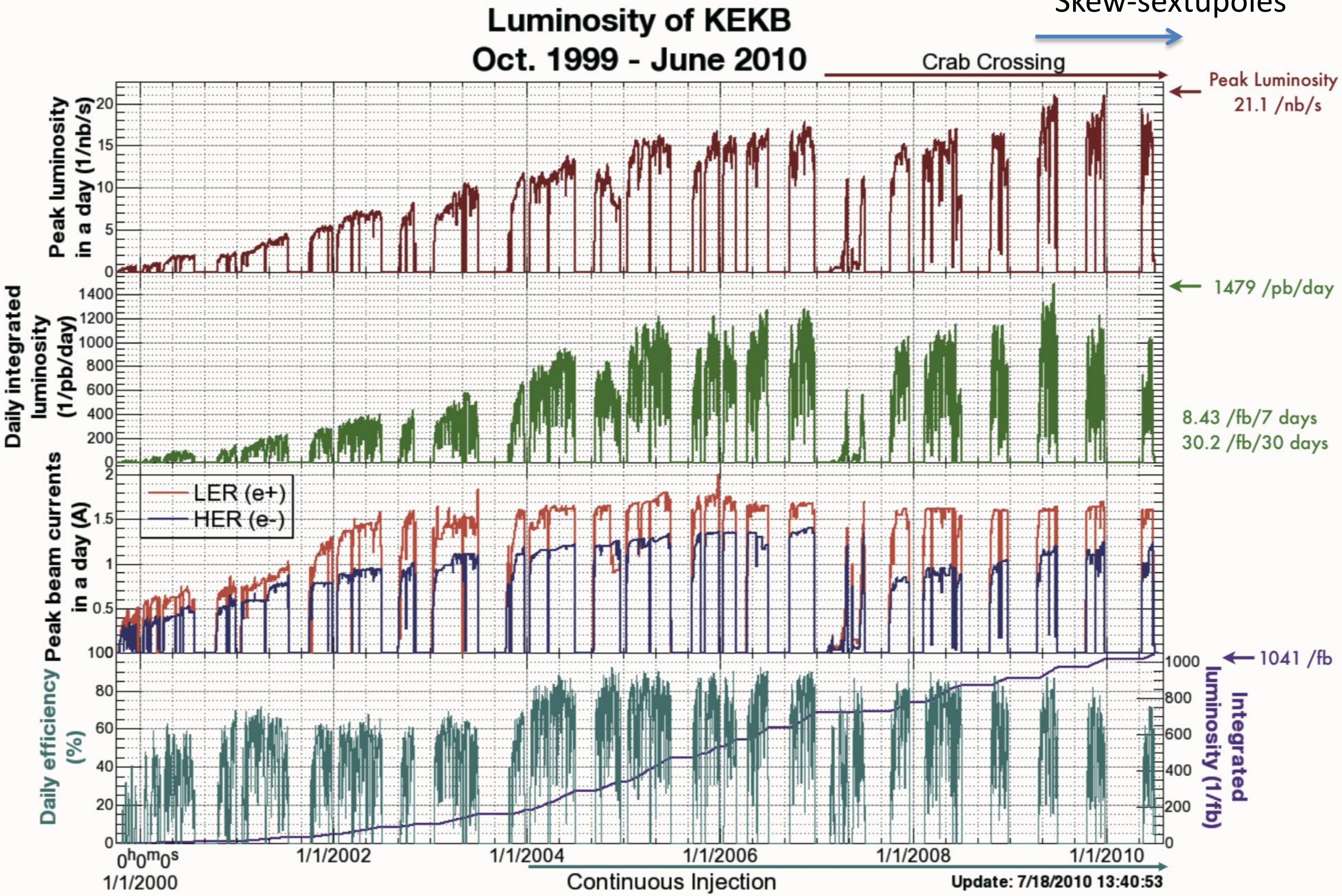
Phase-2

Target: 10^{34} cm^{-2}s^{-1}

Detuned: 10 x nominal β*
Squeezing β* gradually

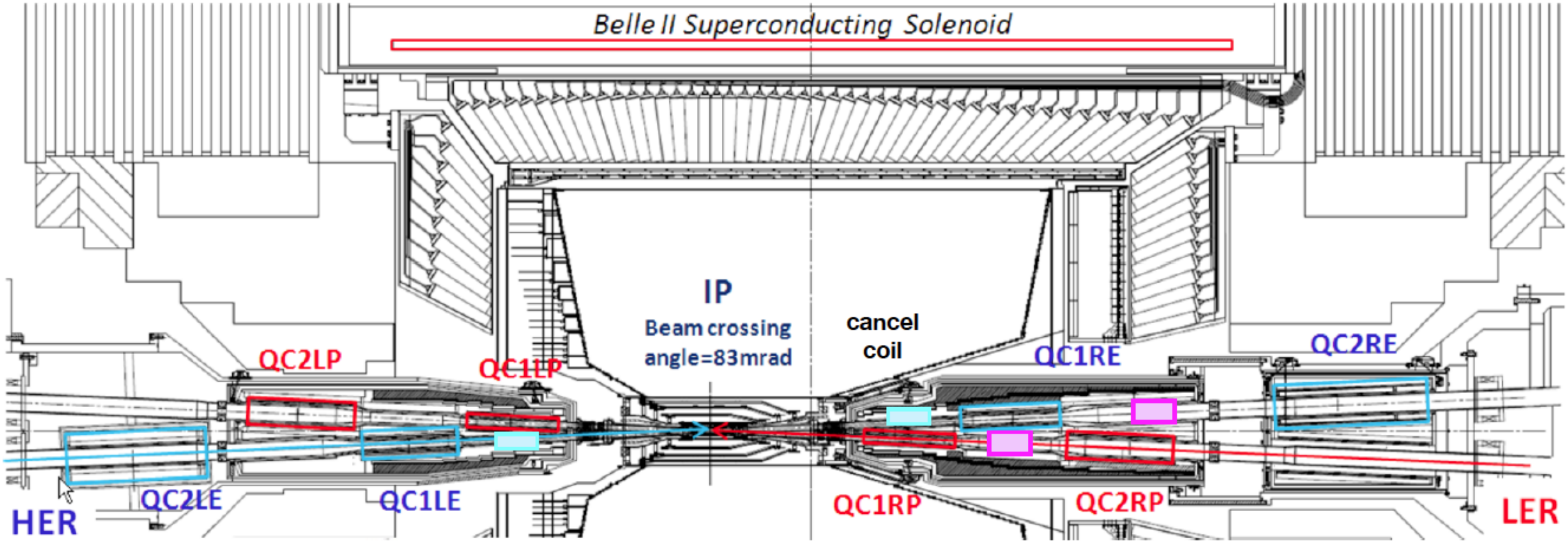
Optics tuning
Detector background
Increase currents

Skew-sextupoles



Final Focus System: QCS

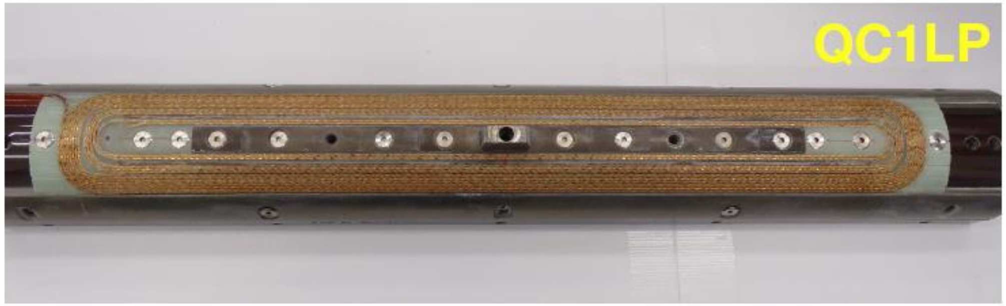
N. Ohuchi, Y. Arimoto



	Dipole	Skew dipole	Quad	Skew quad	Sextupole	Skew sext	Octupole
QC1LP	✓	✓	2013 Aug. 23	✓			✓
QC2LP	2013 Sep. 3	✓	▨	2013 Sep. 3			2013 Sep. 3
QC1RP	▨	▨	▨	▨		▨	▨
QC2RP	▨	▨	▨	▨		▨	
QC1RP-QC2RP					▨		
QC1LE	✓	✓	▨	✓			✓
QC2LE	2013 Dec. 18	2013 Dec. 18	▨	2013 Dec. 18			2013 Dec. 18
QC1RE	▨	▨	▨	▨		▨	
QC2RE	▨	▨	▨	▨		▨	
QC1RE-QC2RE					▨		

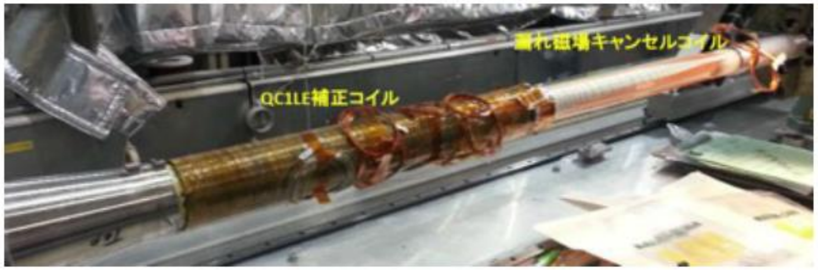
Final Focus System: QCS (cont'd)

8 main coils and 35 corrector coils, 8 cancel coils (HER)



Main coils are made by KEK.
Corrector and cancel coils are made by BLN.

fabrication of coils	schedule (2013)	
QC1LP	done	
QC1LE	June 24	July 5
QC2LE	July 10	July 19
QC2LP	July 22	August 9

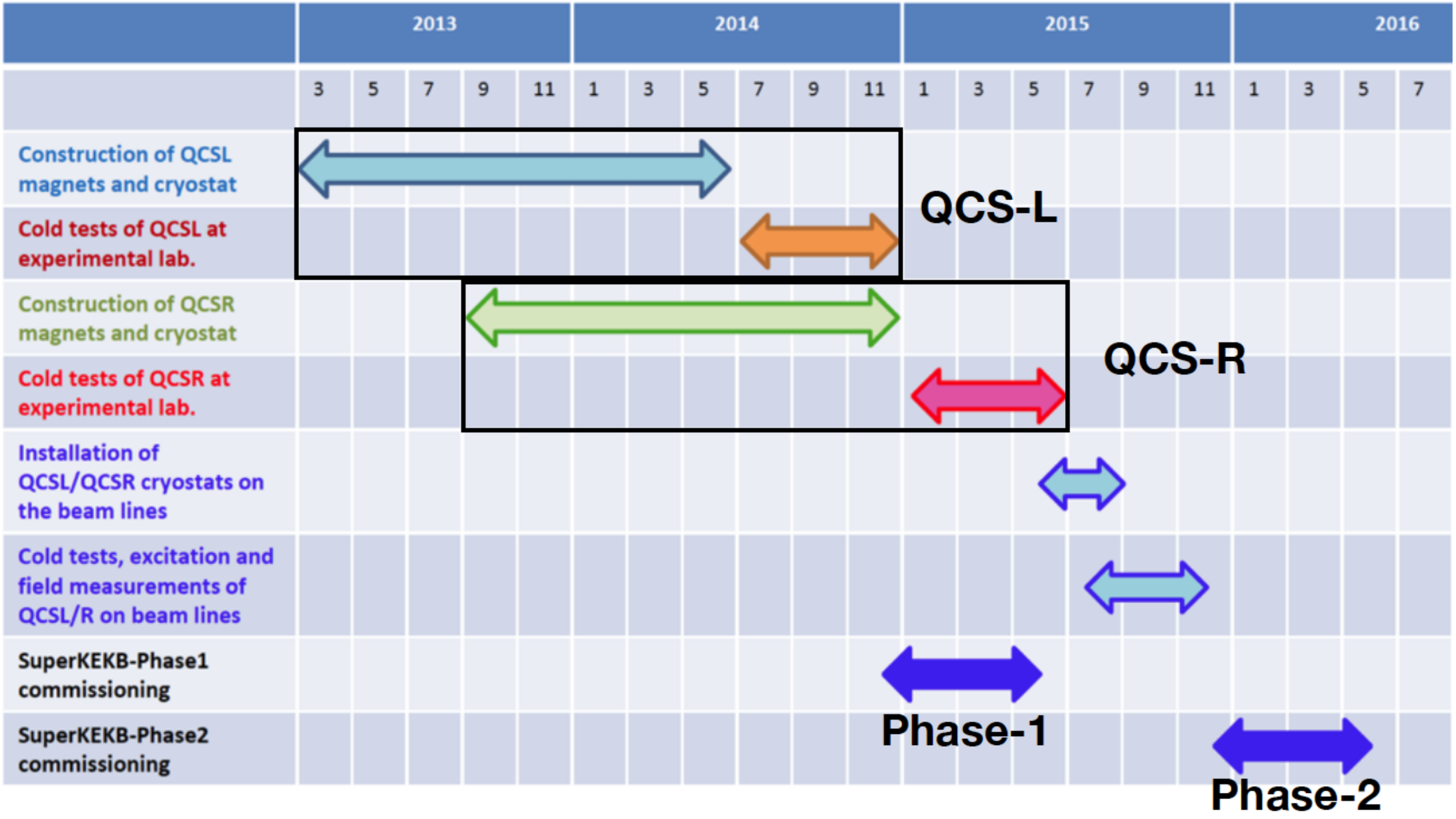


cancel coil in HER

sextupole
octupole
decapole
dodecapole

L-side will be done until September 11.

Final Focus System: QCS (cont'd)



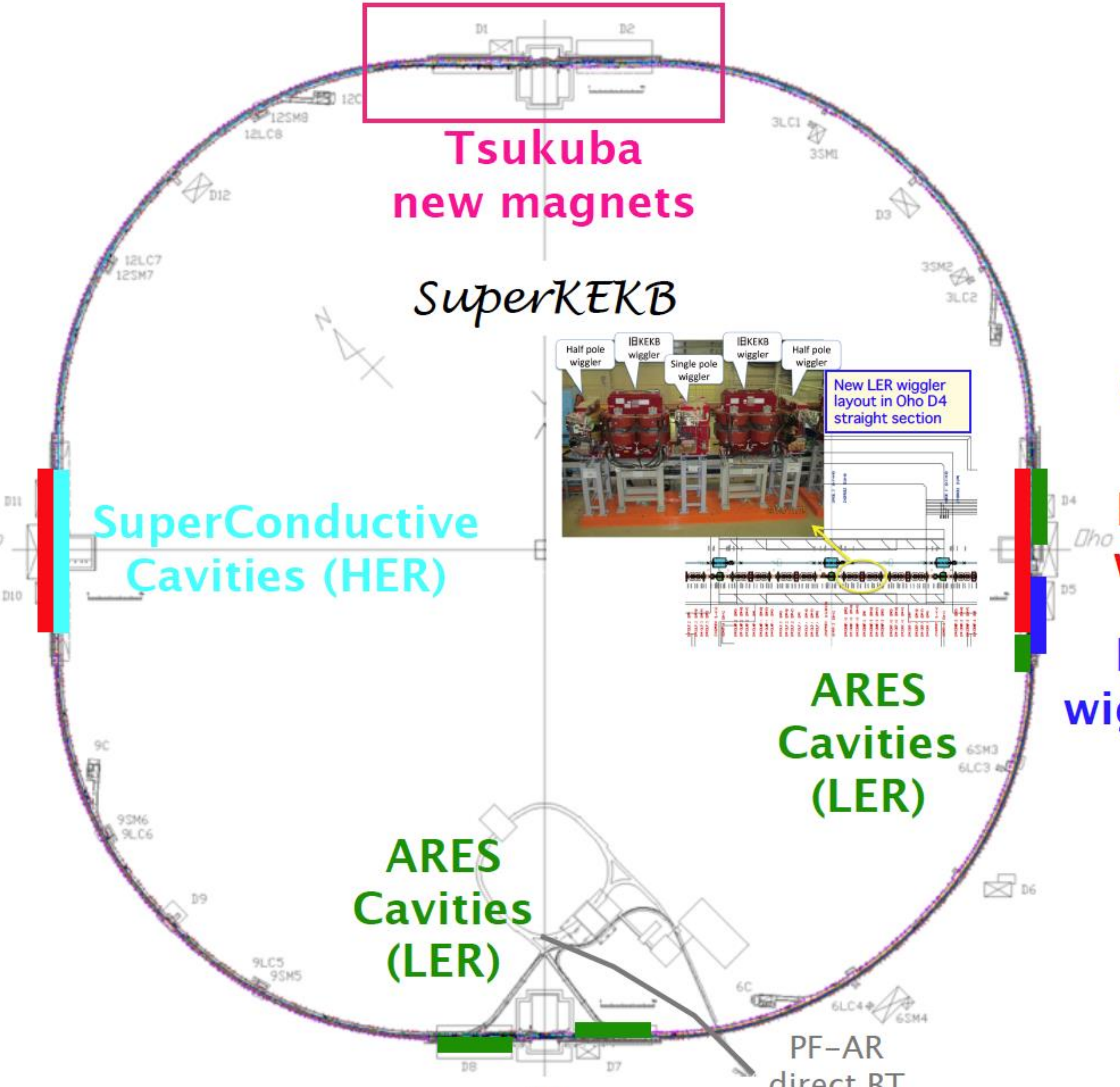
	2013					2014						2015						2016			
	3	5	7	9	11	1	3	5	7	9	11	1	3	5	7	9	11	1	3	5	7
Construction of QCSL magnets and cryostat	↔	↔	↔	↔	↔	↔	↔	↔													
Cold tests of QCSL at experimental lab.									↔	↔	↔										
Construction of QCSR magnets and cryostat				↔	↔	↔	↔	↔	↔	↔	↔										
Cold tests of QCSR at experimental lab.												↔	↔	↔							
Installation of QCSL/QCSR cryostats on the beam lines														↔	↔						
Cold tests, excitation and field measurements of QCSL/R on beam lines															↔	↔	↔				
SuperKEKB-Phase1 commissioning											↔	↔	↔	↔							
SuperKEKB-Phase2 commissioning																	↔	↔	↔	↔	

Magnet System

- Installation of LER new dipoles(100) has been finished. Preliminary alignment done.
- LER new wigglers(280) at OHO and NIKKO have been installed. Preliminary alignment done.
- HER wigglers(36) at OHO (reused those from KEKB-LER) have been installed. Preliminary alignment done.
- New IR magnets at Tsukuba straight section: Surveyed and marked on the floor. The magnets have been installed about 40 %.

M. Masuzawa

Belle II



Tsukuba
new magnets

SuperKEKB

New LER wiggler layout in Oho D4 straight section

ARES
Cavities
(HER)

LER new
wigglers

SuperConductive
Cavities (HER)

LER new
wigglers

HER
wigglers

ARES
Cavities
(LER)

ARES
Cavities
(LER)

PF-AR
direct BT

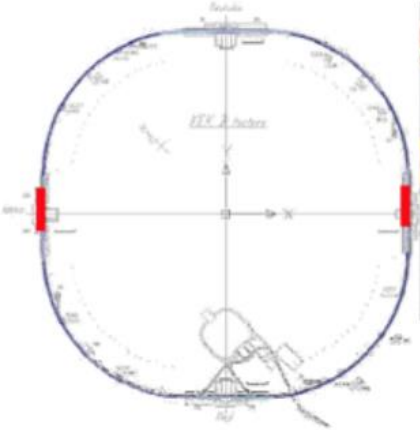
Vacuum System

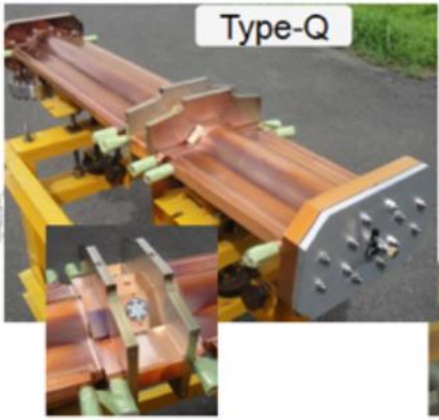
Beam pipes

Measures for e- cloud issues:

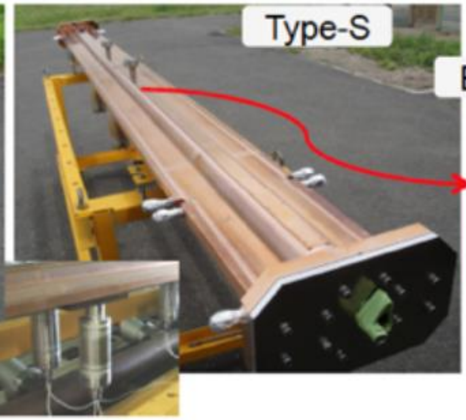
- Antechamber + TiN coating
- + electrode (wiggler sections)
- + groove (bent pipes)
- + solenoids

Copper beam pipes for LER and HER wigger sections



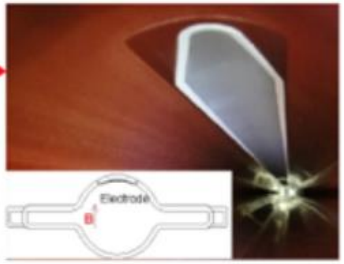


Type-Q



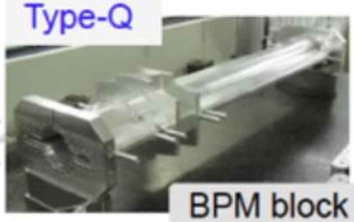
Type-S

Electrode



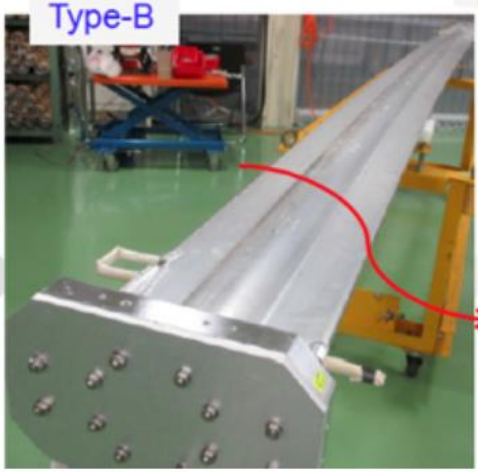
Aluminum antechamber beam pipes for LER arc sections

Type-Q



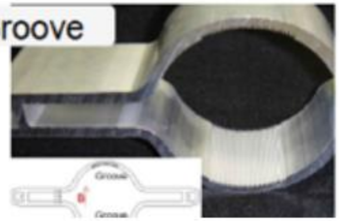
BPM block

Type-B

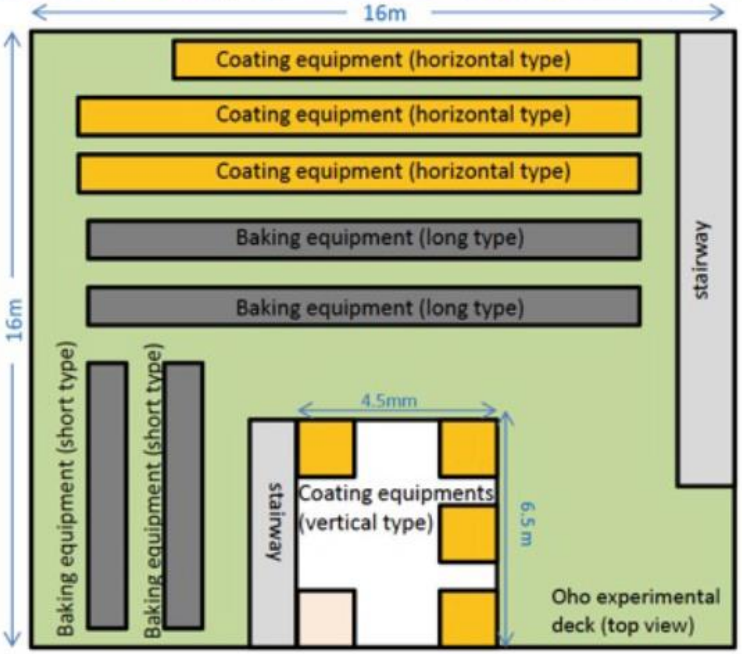


Aluminum-alloy flange

Groove

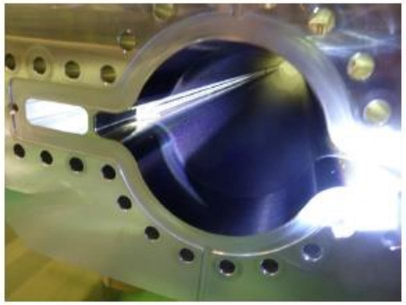


TiN Coating and Baking at OHO Lab.



Visual check
on the beam pipe

TiN Coating
(LER pipe)

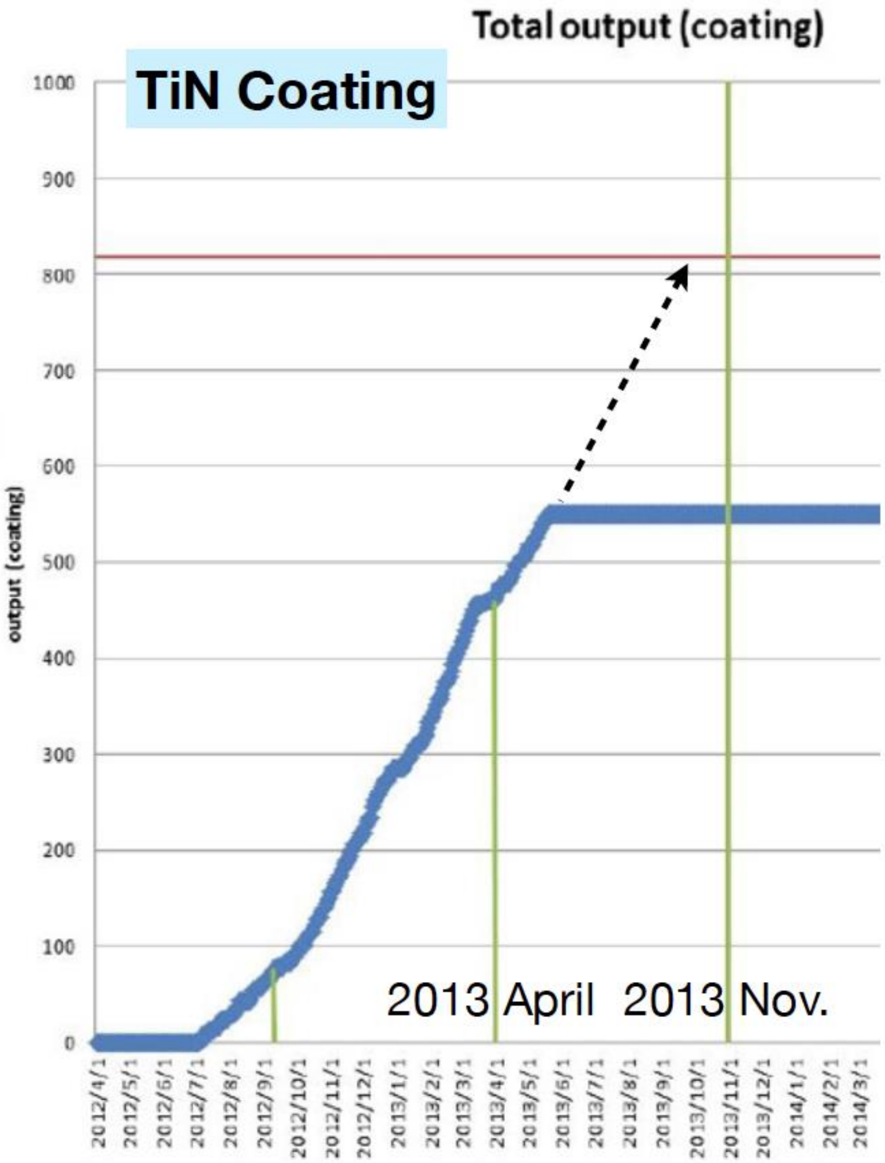


After TiN coating
before baking

Assembling
(NEG pump and BPM electrode)

Baking process

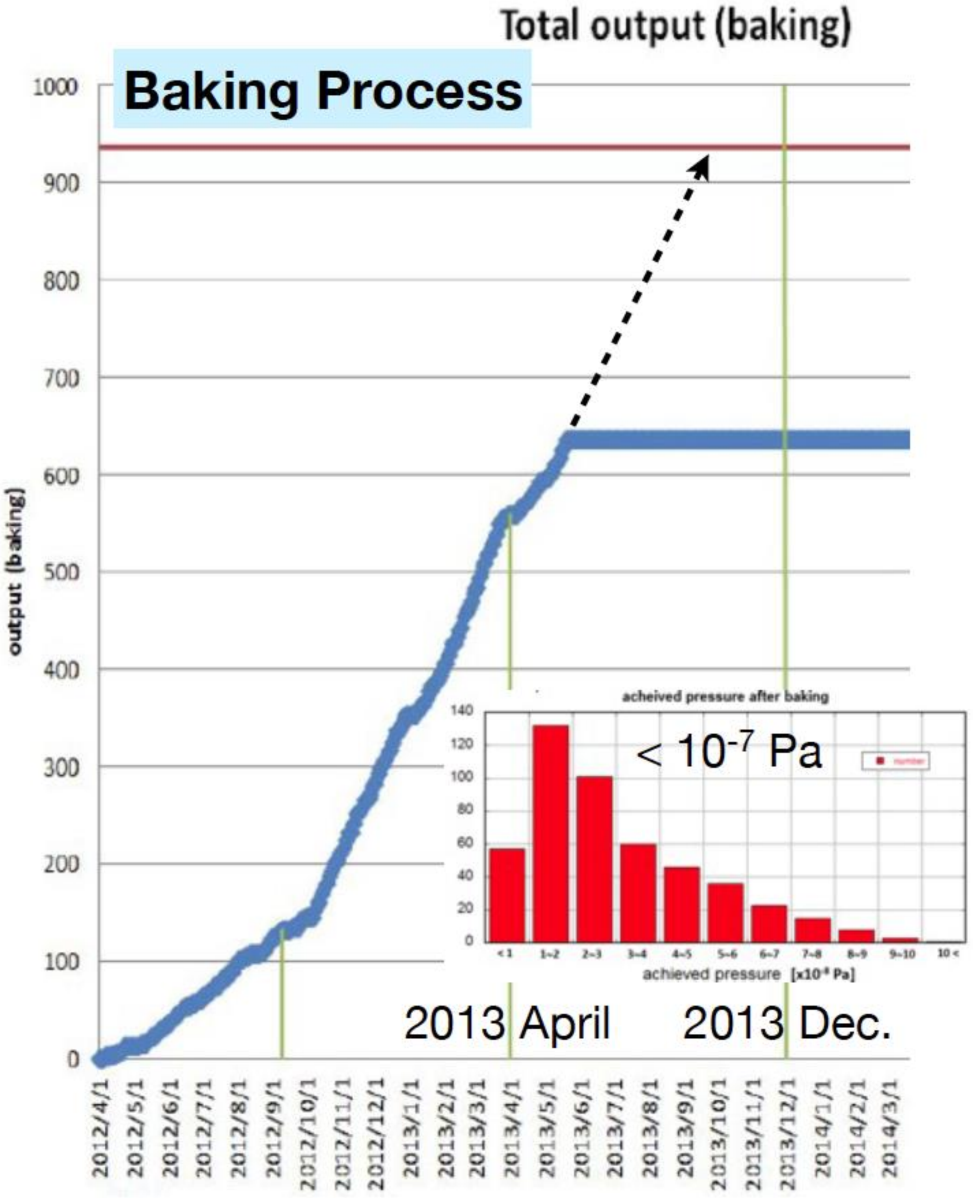
TiN and Baking for Beam Pipes (MR)



TiN Coating

Total output (coating)

2013 April 2013 Nov.



Baking Process

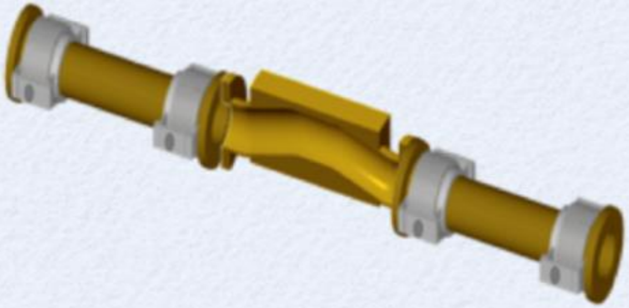
Total output (baking)

2013 April 2013 Dec.

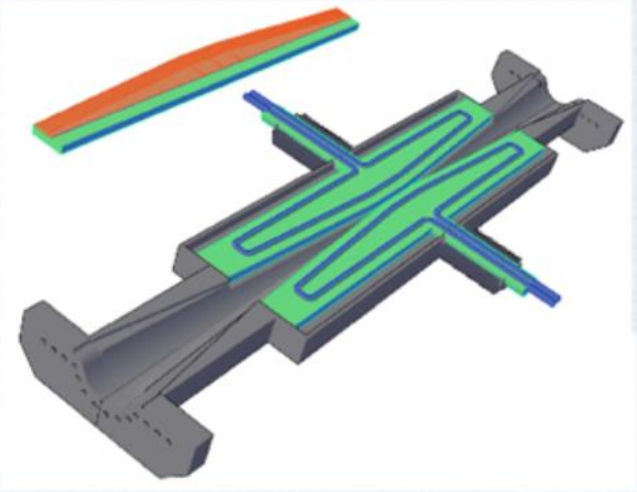
< 10^{-7} Pa

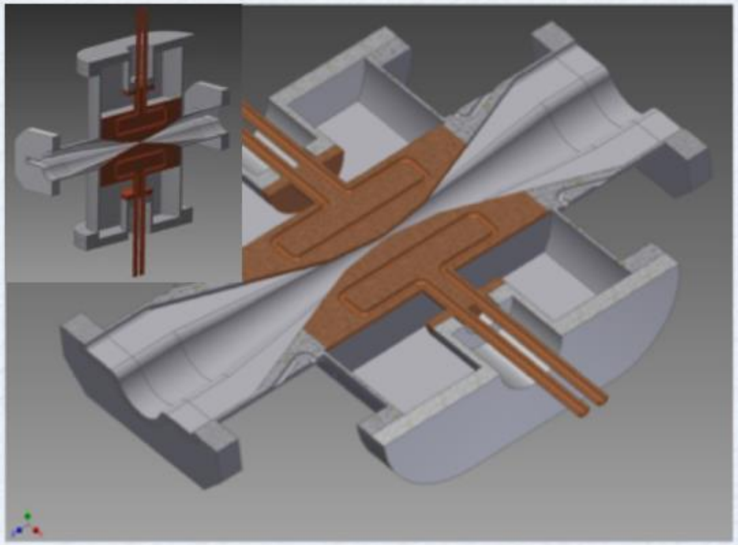
Movable Masks

Ver.4: KEKB type



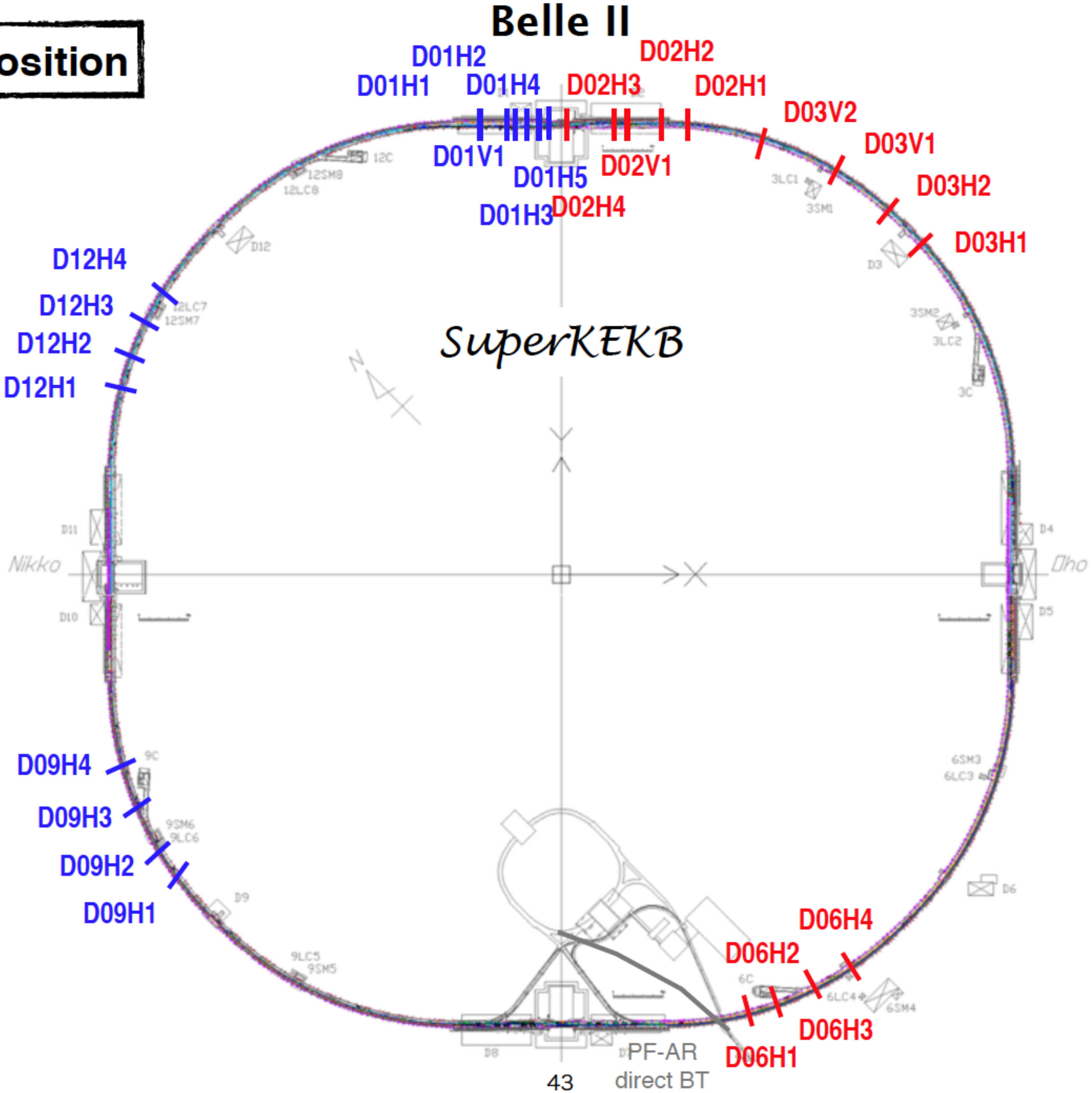
Ver.5: Fit antechambers. The loss factor is smaller by a factor of 2 compared with Ver.4. Total length ~1500 mm.





Ver.6: The latest version. Part of the movable heads are placed in the antechambers. The total length is shorten with the same loss factor as Ver.5.
Total length ~ 1000 mm.

Mask Position



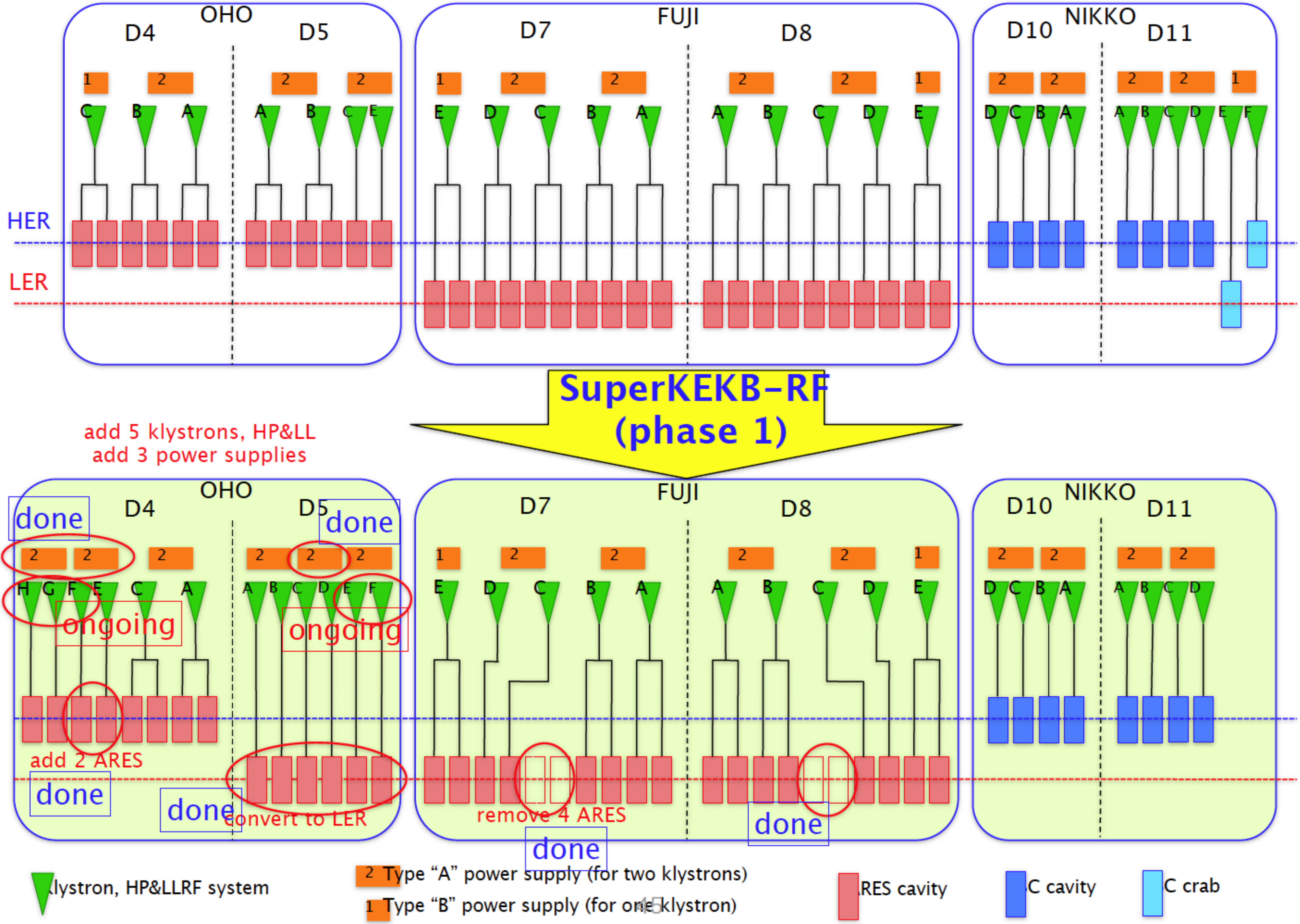
PMD01H5
PMD01H4
PMD01H3
PMD01V1
PMD01H2
PMD01H1
PMD12H4
PMD12H3
PMD12H2
PMD12H1
PMD09H4
PMD09H3
PMD09H2
PMD09H1

PMD06H1
PMD06H2
PMD06H3
PMD06H4
PMD03H1
PMD03H2
PMD03V1
PMD03V2
PMD02H1
PMD02H2
PMD02V1
PMD02H3
PMD02H4

RF System

- Upgrade of RF for twice beam currents and 2.5 times beam power
- 1 klystron to 1 ARES cavity scheme
  - KEKB: 1 klystron to two ARES cavities
- HOM power in SCC
- New low level RF control system

KEKB-RF



SuperKEKB-RF (phase 1)

add 5 klystrons, HP&LL
add 3 power supplies

done

ongoing

add 2 ARES

convert to LER

remove 4 ARES

Klystron, HP&LLRF system

2 Type "A" power supply (for two klystrons)

1 Type "B" power supply (for one klystron)

ARES cavity

SC cavity

SC crab

Damping Ring

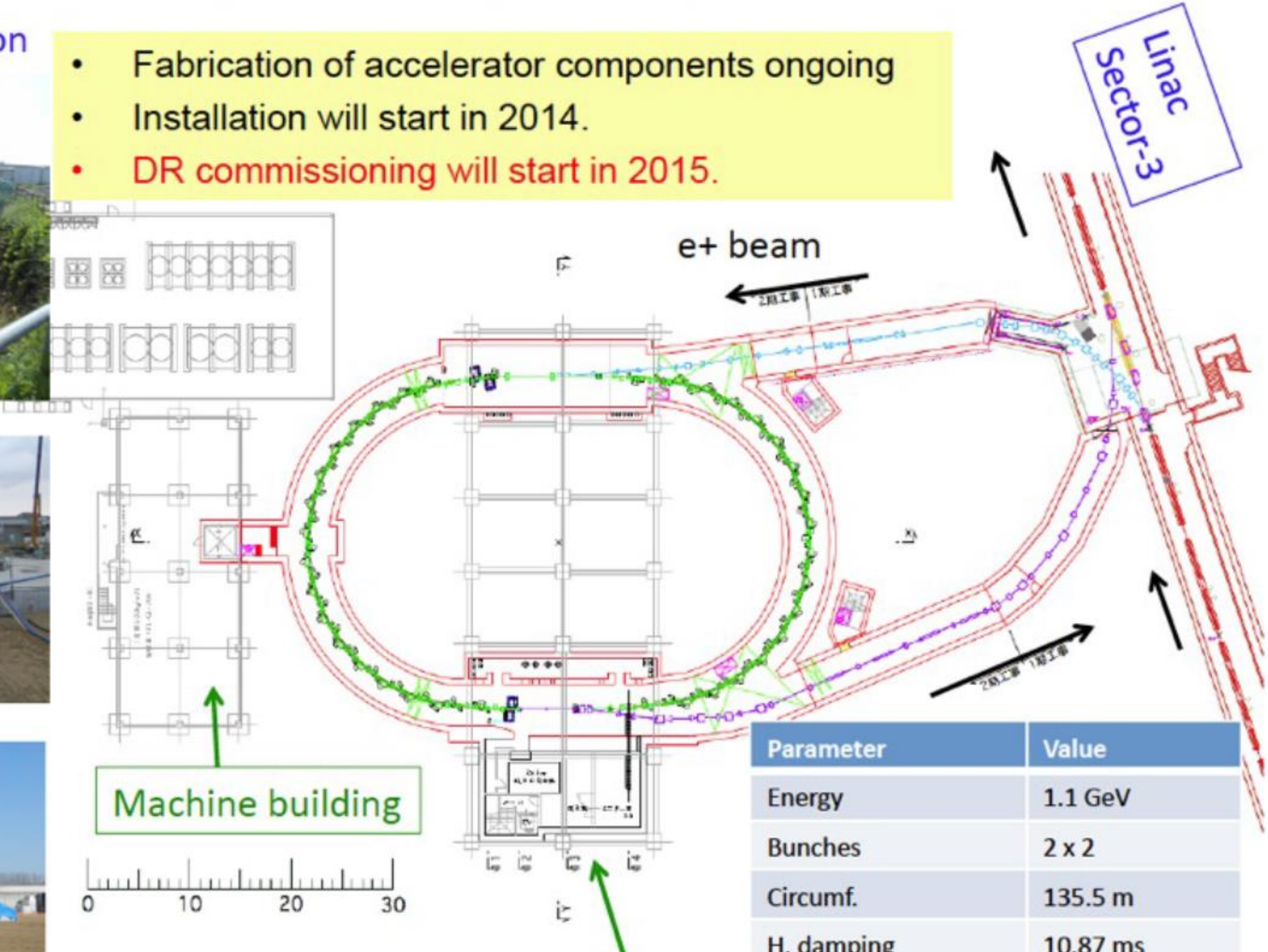
DR tunnel construction


Jun. 2012


Dec. 2012


Mar. 2013
Completed

- Fabrication of accelerator components ongoing
- Installation will start in 2014.
- DR commissioning will start in 2015.



Parameter	Value
Energy	1.1 GeV
Bunches	2 x 2
Circumf.	135.5 m
H. damping	10.87 ms
Ext. emittance (H/V)	42.5/3.15 nm
Max. current	70.8 mA

M. Kikuchi, N. Iida

Linac Schedule

Winter 2013	DR switchyard DR tunnel	construction
Spring 2013	RF gun (A1)	alignment
Summer 2013	ECS, FC(2nd), DC solenoid, klystron modulators, wire scanners, etc.	installation
Autumn 2013	e-/e+ commissioning (half linac, current is limited.)	Day: construction Night: commissioning
Spring 2014	pulsed steering	installation and alignment
Summer 2014	cooling water, FC(3rd), BPM, pulsed magnets, new PF-AR BT, etc	installation
Autumn 2014	e-/e+ commissioning (full)	
Winter 2015	MR injection at Phase-1	

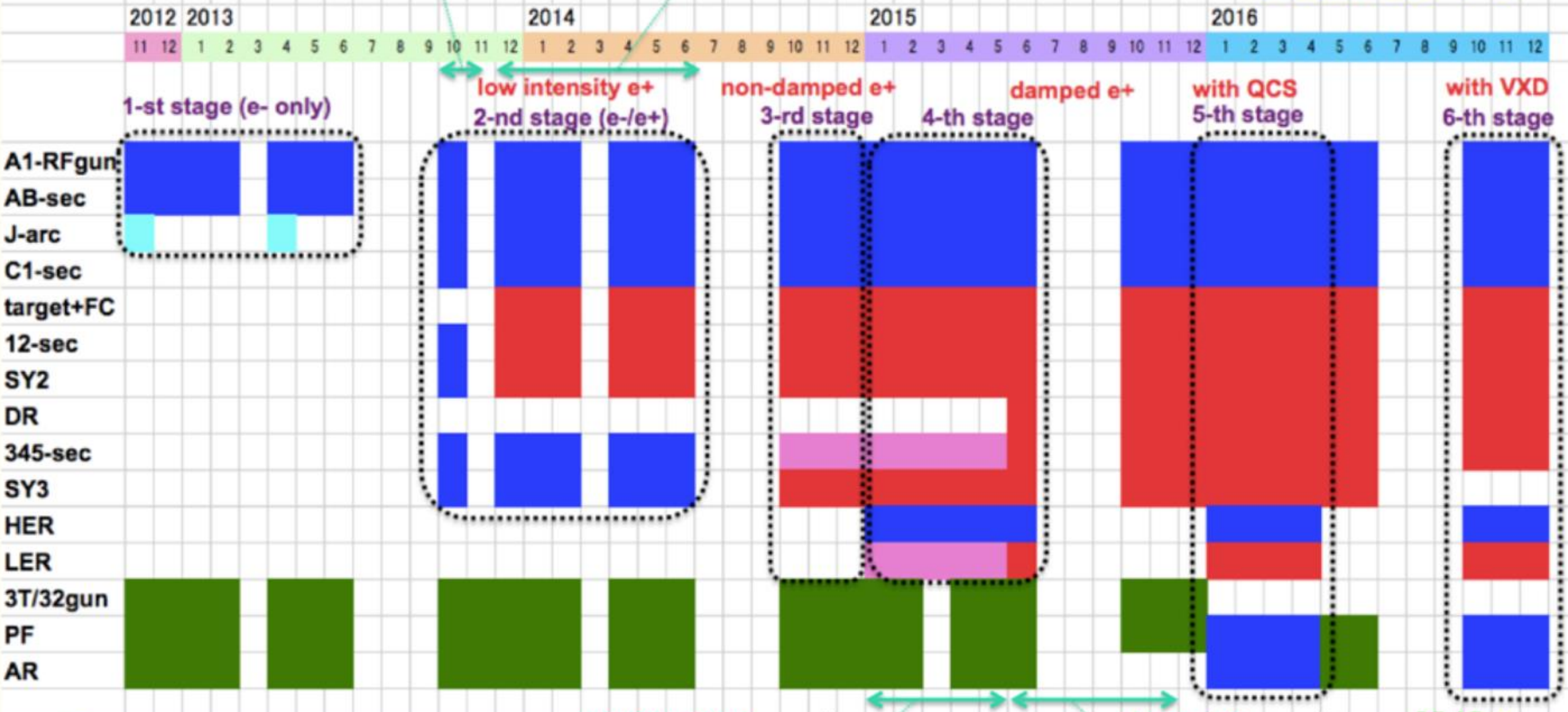
Linac Schedule Overview

RF-Gun e- beam commissioning at A,B-sector
Qe- = 5nC

e- commiss.
at A,B,J,C,1
Qe- = 5nC

e+ commiss.
at 1,2 Qe+ = 0.5nC (FC, DCS, Qe- 50%)
e- commiss.
at 1,2,3,4,5 Qe- = 5nC

Kamitani + α



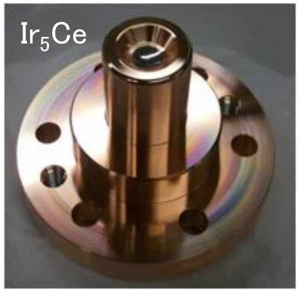
🟦 : Electron
🟥 : Positron
🟩 : Low current electron

non damped e+ commiss.
at 1,2, 3,4,5 Qe+ = 4nC
e- commiss. pulse-switch
at A→5 Qe- = 5nC

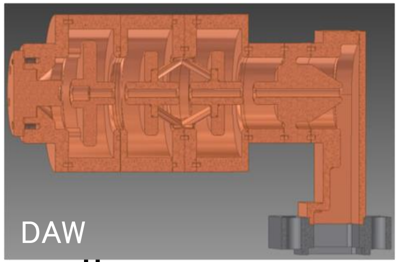
damped e+ commiss.
at 1→5 Qe+ = 4nC
e- commiss.
at A→5 Qe- = 5nC

PF-AR e- commiss.

RF Gun Development

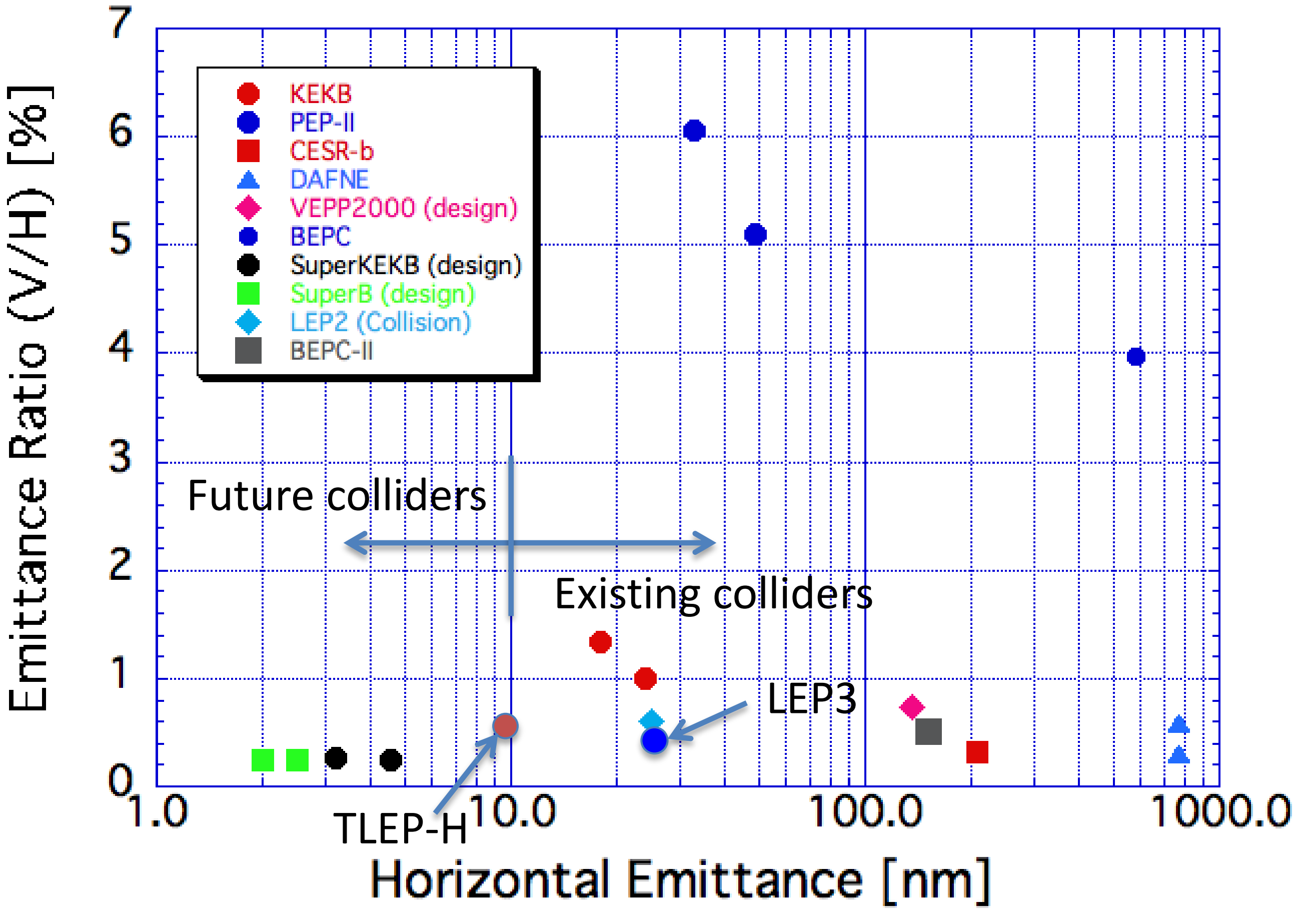


- Photo cathode : stability, longer life, efficiency
  - At first LaB_6, then Ir_5Ce → 5nC / bunch
- Laser : higher power, pulse width control
  - Nd:YAG medium, LD excitation → ~1.5mJ / 30ps / pulse at 266nm
  - Polarization control for slant irradiation
  - In parallel, fiber laser is under development



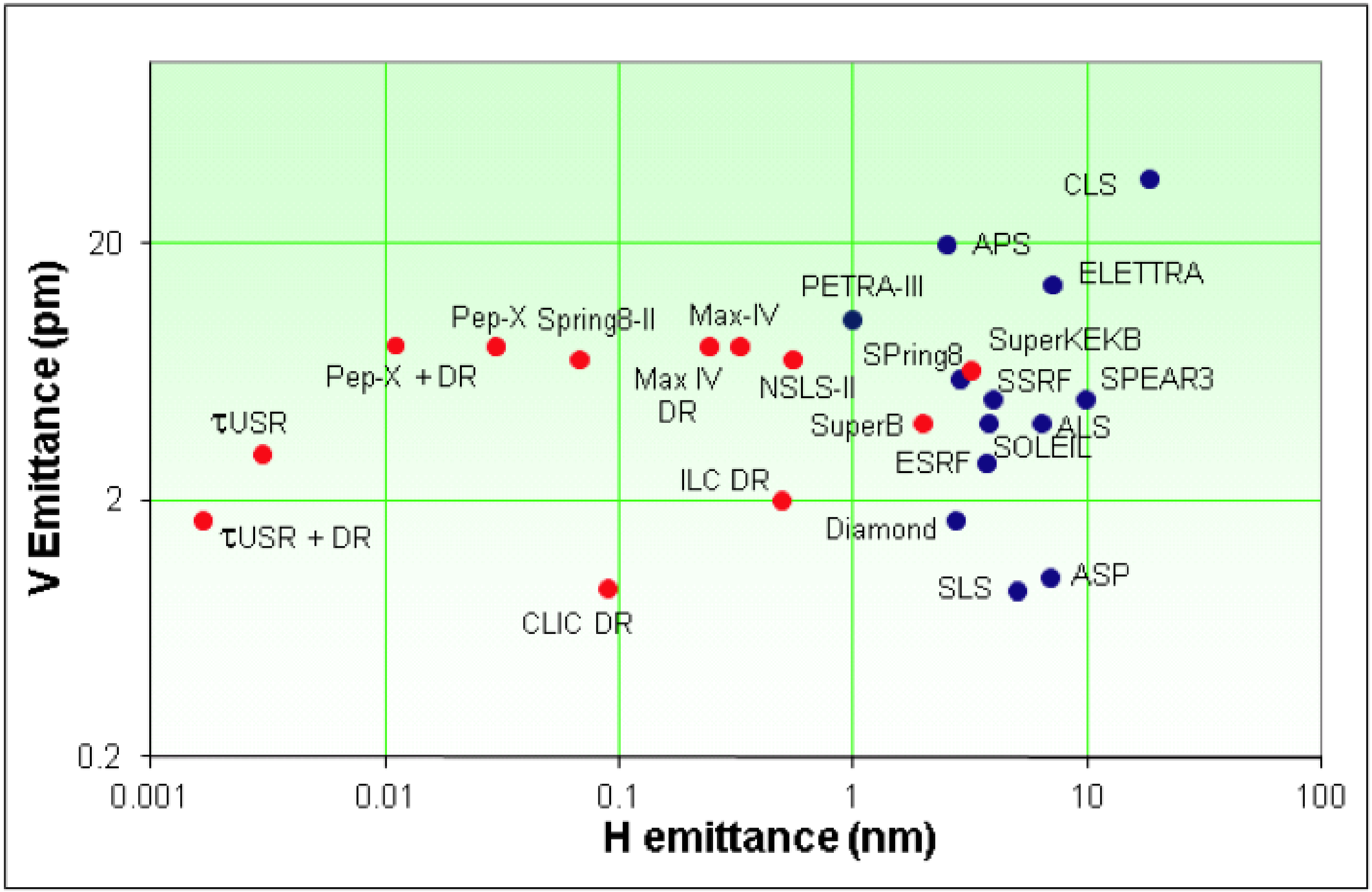
- Cavity : better focusing field, higher gradient
  - DAW (Disk and washer) type cavity
  - Development of quasi-travelling-wave side-coupled cavity as well
- Test stands
  - RFgun at A-1 will be constructed this autumn for SuperKEKB
  - RFgun at 3-2 was used to inject into PF with proper synchronization
  - Long-period demonstration will be carried during this autumn

Comparison of emittances of colliders [cont'd]



R. Bartolini

Emittance in 3rd GLS, DR and B-factories

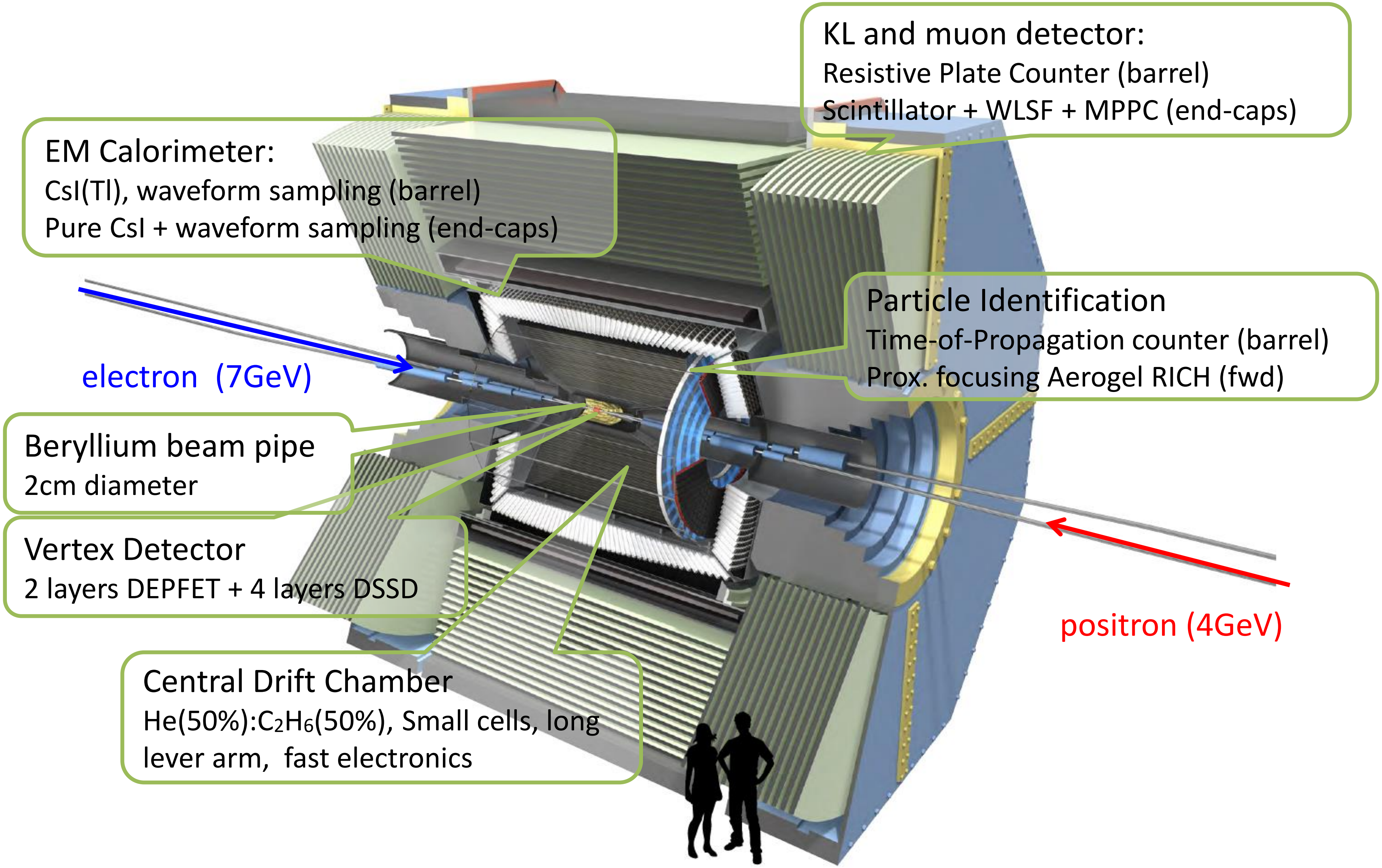


~ 2012

Difference between SR rings and colliders

- IR
  - Detector solenoid and its compensation
  - Low beta insertion
  - Local chromaticity correction
- Size of rings
  - In larger rings, orbit drift tends to be large.
    - Accuracy of optics measurement with orbit drifts
- Beam-beam interaction
  - Beam-beam blowup
  - Restriction on choice of working point

Belle II Detector



KL and muon detector:
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC (end-caps)

EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)

Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)

electron (7GeV)

Beryllium beam pipe
2cm diameter

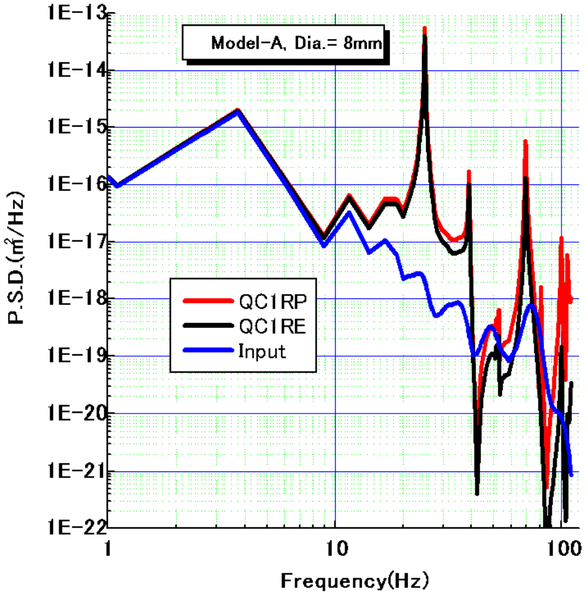
Vertex Detector
2 layers DEPFET + 4 layers DSSD

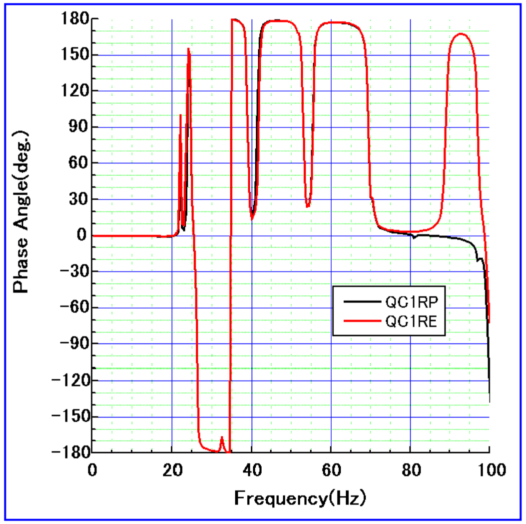
Central Drift Chamber
He(50%):C_2H_6(50%), Small cells, long lever arm, fast electronics

positron (4GeV)

Model-A

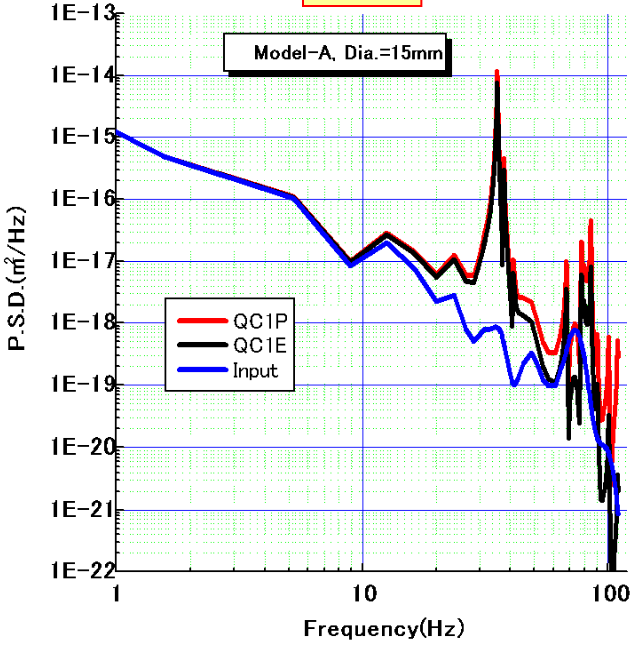
R側

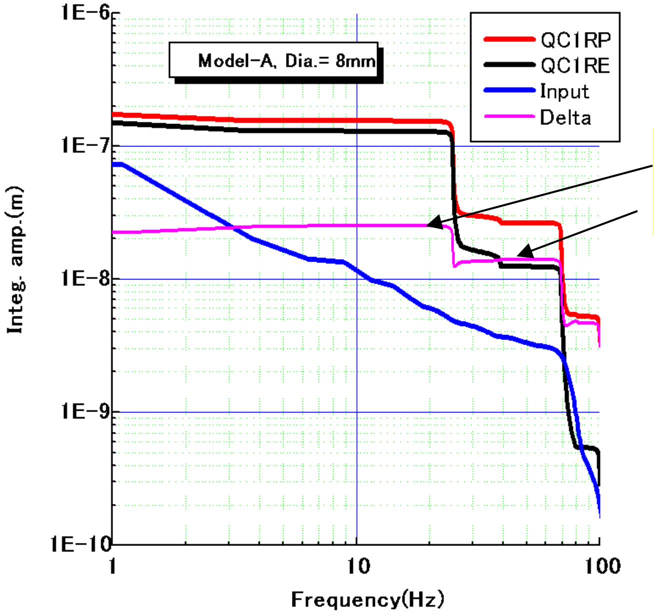




Oscillation phases of QC1RP and QC1RE.

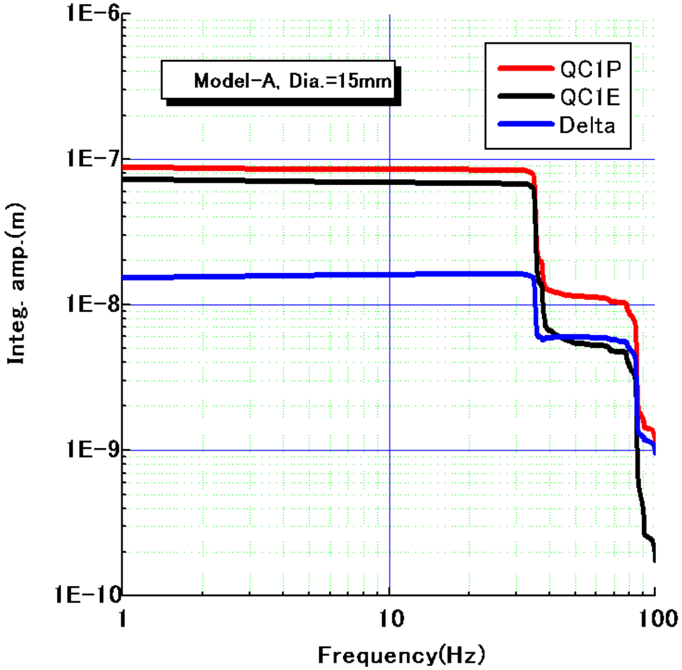
L側





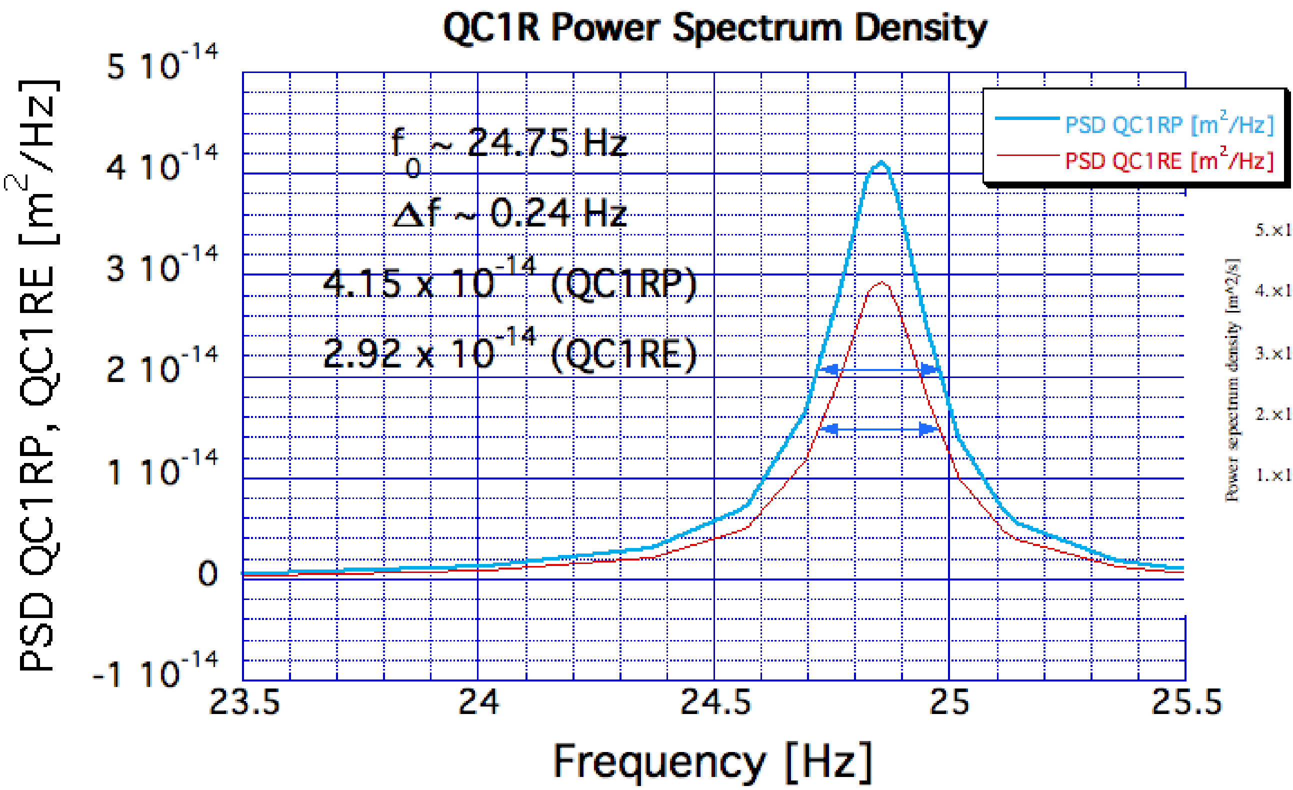
25nm@20Hz

14nm@50Hz



山岡

f =24.75Hz (Model F)

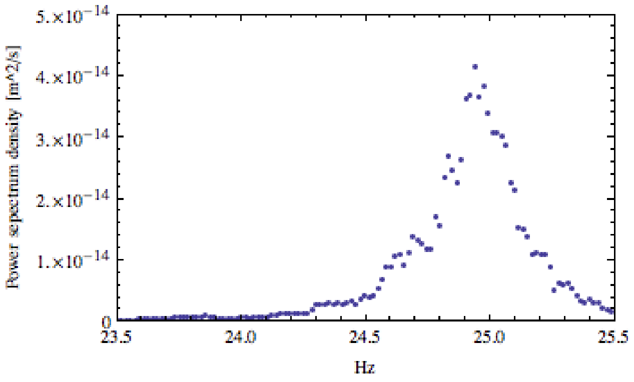


$f_0 \sim 24.75$ Hz

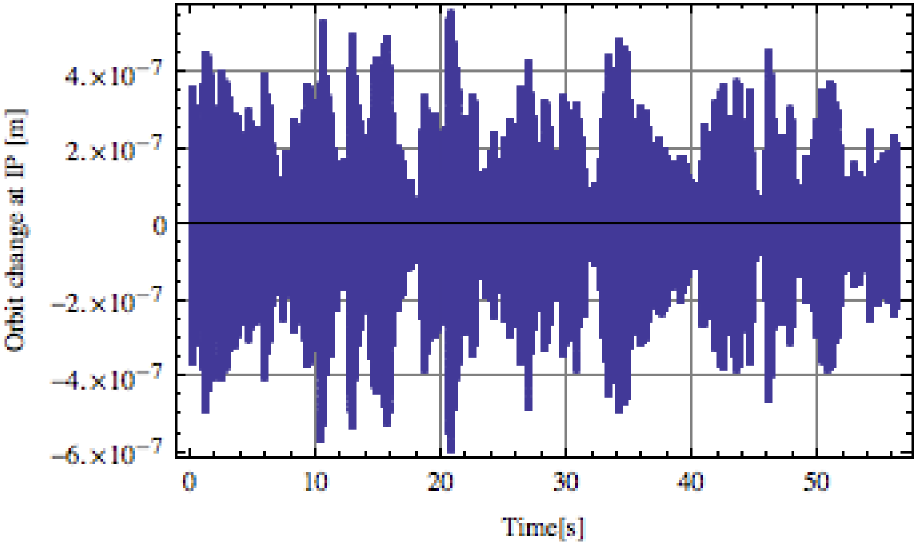
$\Delta f \sim 0.24$ Hz

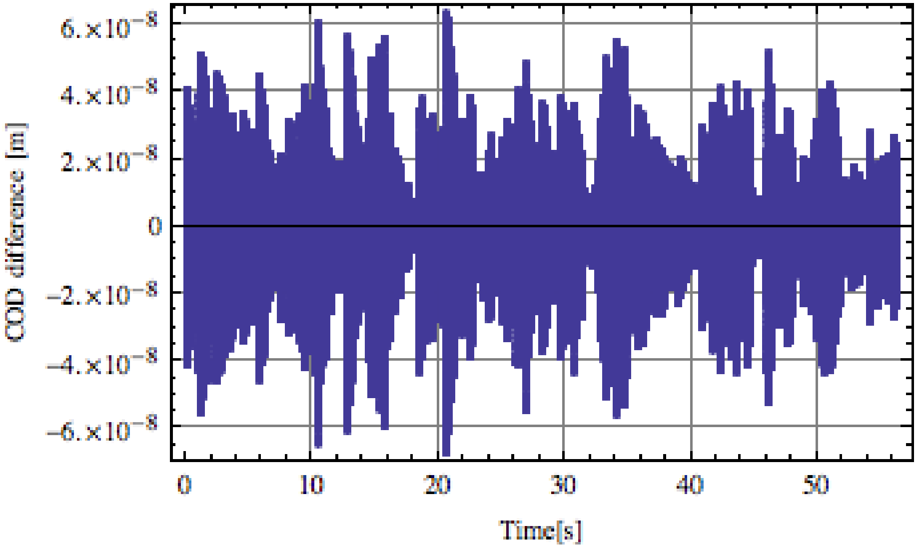
4.15×10^{-14} (QC1RP)

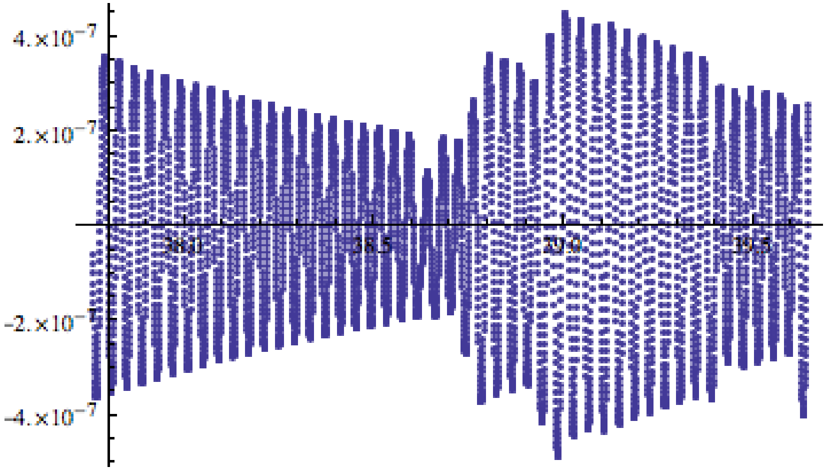
2.92×10^{-14} (QC1RE)



24.75Hz (Model A)







The average luminosity is about 95.4% of the case w/o QCS vibration.

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	
$\sigma_x'^*$	120μrad	120μrad	450μrad	320μrad	
σ_y^*	0.94 μm	0.94μm	48nm	56nm	~1/20
$\sigma_y'^*$	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?	

Facilities

- Storage and staging areas needed for magnet and vacuum components.
- Need increased cooling water for klystrons and magnets:
  - 24 klystrons for ARES cavities, 8 klystrons for SCC
  - Magnet cooling water needs double (4 plants -> 8)
- Electricity:

Electricity Consumption: June-09

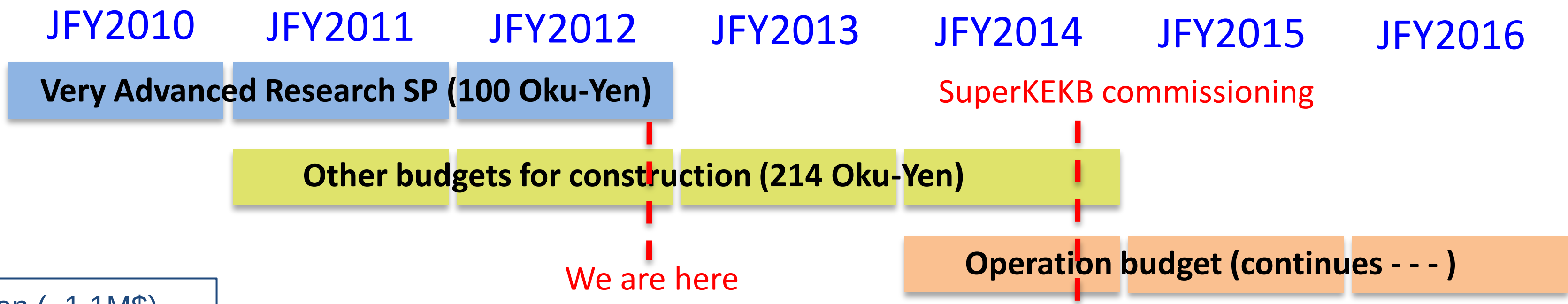
KEKB/KEK total

(Design option)	KEKB:MW	ΔMW	KEK:MW	ΔMW
Present(Average)	45		64	
Nano Beam: June-09	70.7	24.3	96	32
Upgrade: Feb.-09	94.8	49.8	120	56
Super: ‘07-July	102.6	57.6	128	64

Recent Design(Feb.-10): Add 2 ARES units--> +(3~4)MW

Overall budget (original)

- Budget
  - Total construction budget is 314 Oku-Yen for Rings, Injector, and Belle-II.
  - Most of the budget comes year-by-year based.
  - Operation budget is expected in FY2014 and later.



JFY2010 JFY2011 JFY2012 JFY2013 JFY2014 JFY2015 JFY2016

Very Advanced Research SP (100 Oku-Yen)

SuperKEKB commissioning

Other budgets for construction (214 Oku-Yen)

We are here

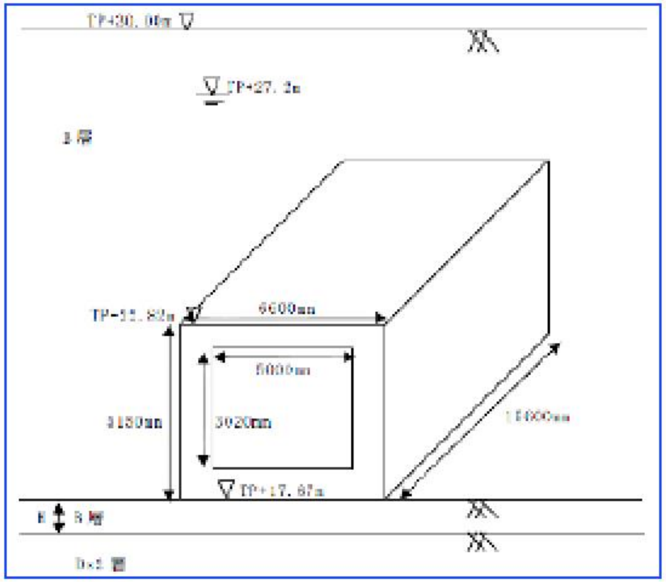
Operation budget (continues - - -)

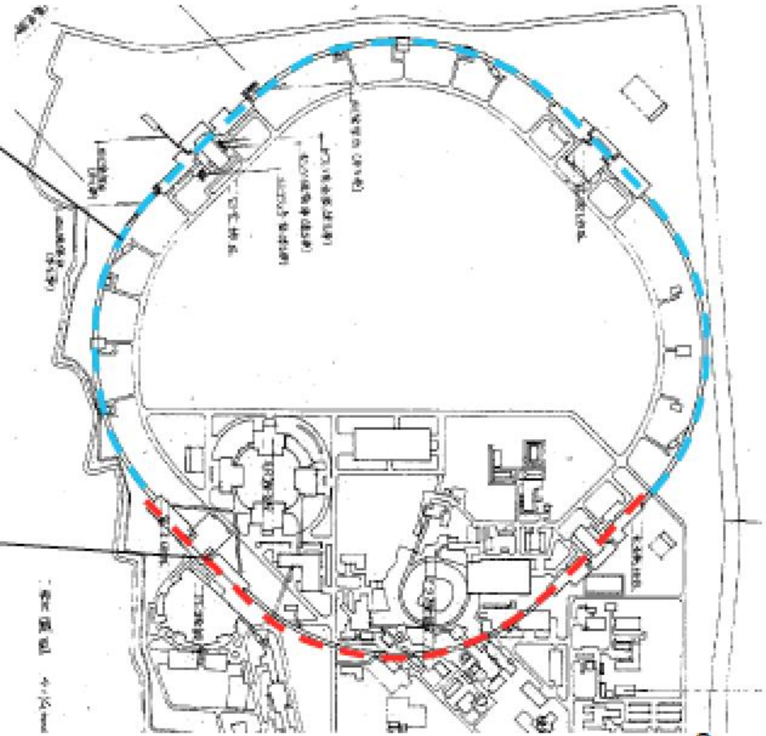
Unit: Oku-Yen (~1.1M$)

	JFY2010	JFY2011	JFY2012	JFY2013	JFY2014	Total
VARSP	75.0	10.5	14.5	0	0	100.0
Others	0	41.6	40.2	61.6	46.7	190.0
Buildings	0	4.5	12.4	7.2	0	24.1
Total	75.0	56.6	67.1	68.8	46.7	314.1
Status	Supplied	Supplied	Supplied			

Configuration of the KEKB tunnel

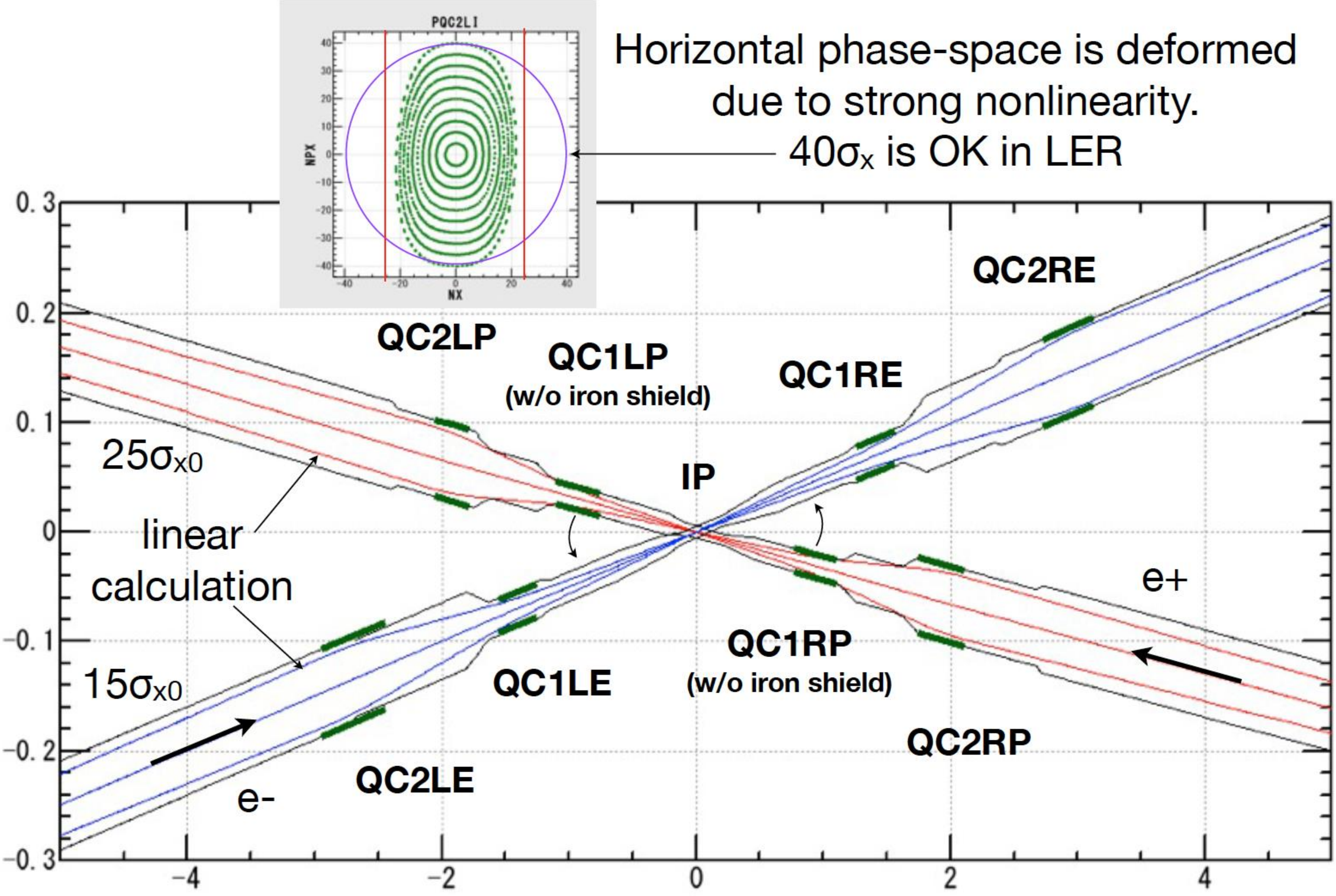
- No piling under the floor at arc-section.
- Refilled soil after complete the tunnel.





Walls to prevent a landslide .

Beam Envelope for Design Parameters



Horizontal phase-space is deformed due to strong nonlinearity. $40\sigma_x$ is OK in LER

IR Design Features

- Natural chromaticity:

	SuperKEKB		KEKB	
	LER	HER	LER	HER
ξ_{x0}	**−105**	**−171**	−72	−70
ξ_{y0}	**−776**	**−1081**	−123	−124

- Approximately *80 %* of the natural chromaticity in the vertical direction is induced in the Final Focus. A "*local chromaticity correction*" is adopted to correct it.

- The angle between Belle II Solenoid(1.5 T) and beam-axis is 41.5 mrad. Anti-solenoids are overlaid with QC1 and QC2 to compensate the Belle II solenoid field. The vertical emittance (about 1.5 pm) is generated due to the solenoid fringe field. To reduce them, skew coils and/or rotation of QC1 and QC2 are used.

SC correctors by BNL

Revised corrector scheme in the right side: