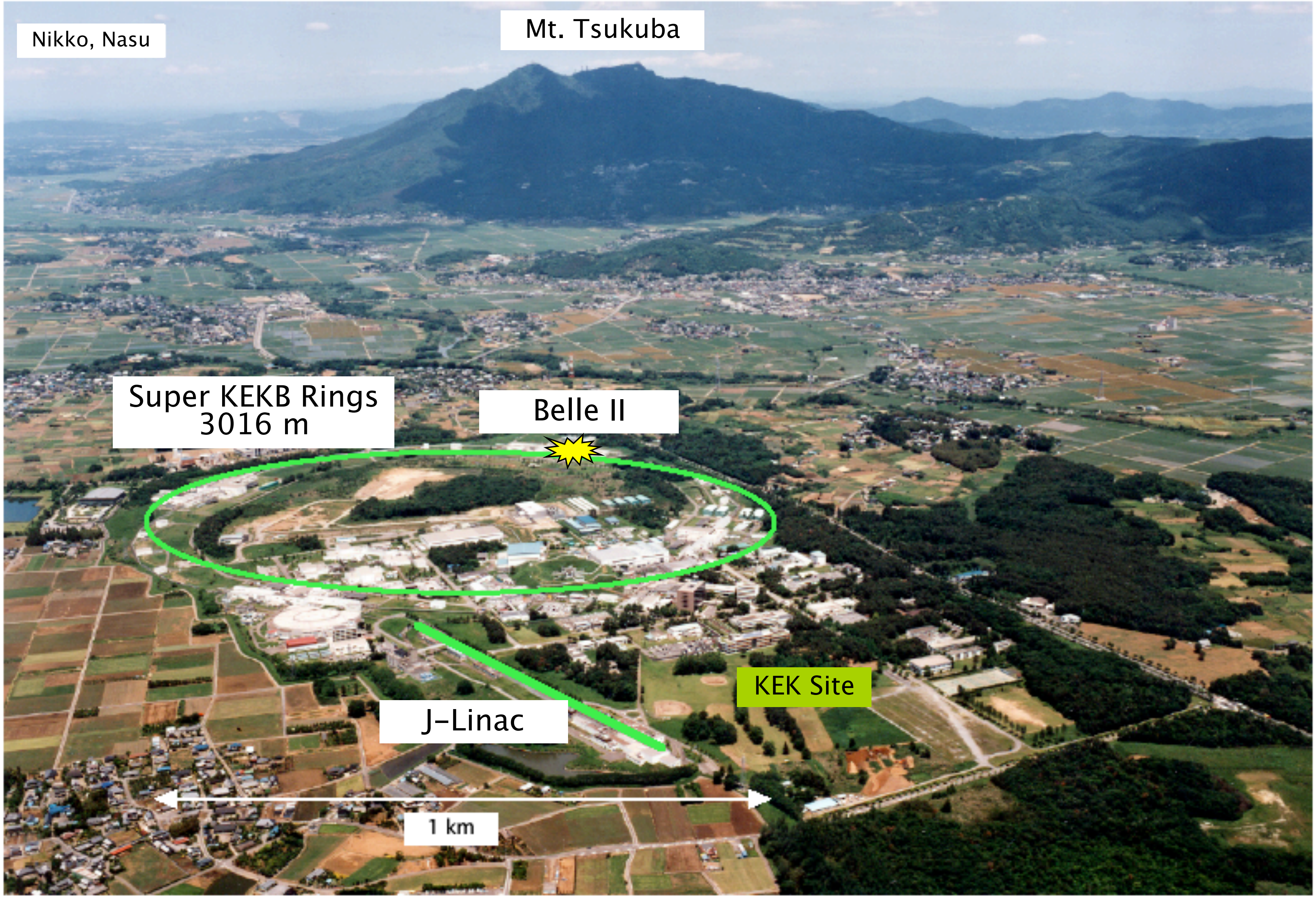
SuperKEKB Design Overview

16th KEKB Accelerator Review
Feb. 7, 2011

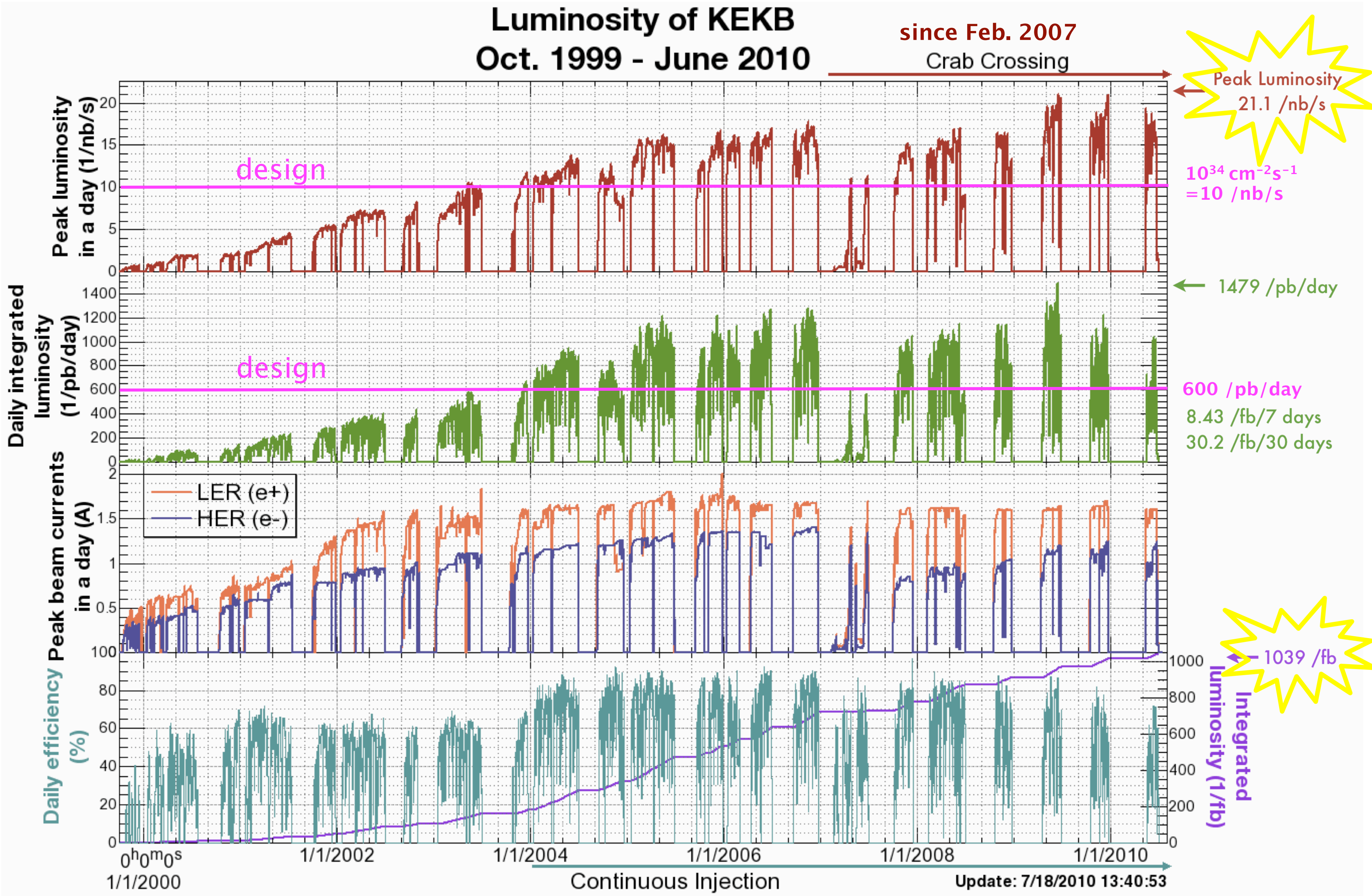
Haruyo Koiso

http://kekb.jp

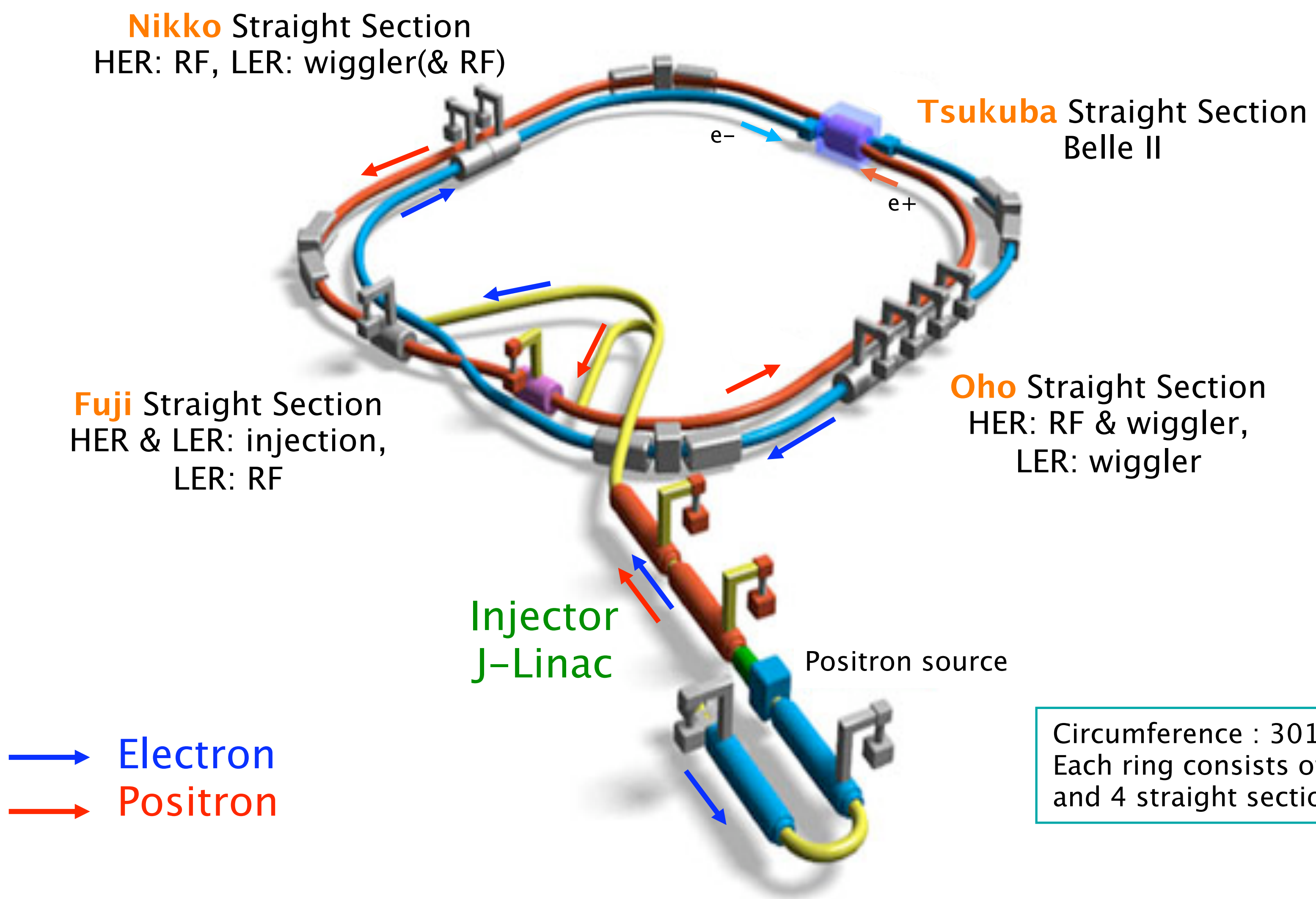


Nikko, Nasu
Mt. Tsukuba
Super KEKB Rings
3016 m
Belle II
KEK Site
J-Linac
1 km

KEKB History



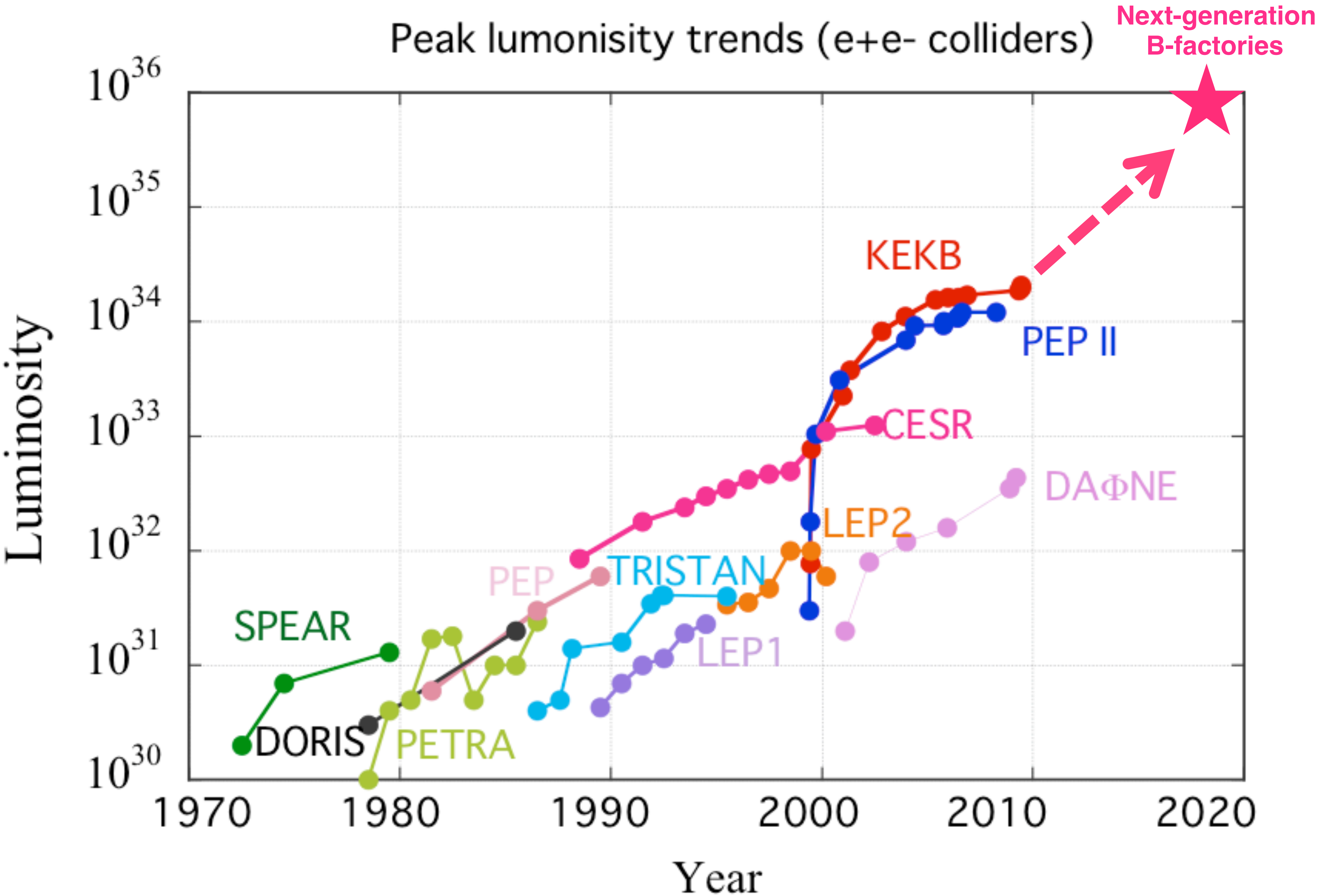
SuperKEKB



Circumference : 3016 m
Each ring consists of 4 arcs and 4 straight sections.

HER (8->7GeV e-) + LER (3.5->4GeV e+) + J-Linac

e^+e^- Colliders



Design Concept of SuperKEKB

- Increase the luminosity by 40 times based on "Nano-Beam" scheme, which was first proposed for SuperB by P. Raimondi.

Luminosity Gain

- Vertical β function at IP: 5.9 → 0.27/0.30 mm (× 20)
- Beam current: 1.7/1.4 → 3.6/2.6 A (× 2)
- Beam-beam parameter: .09 → .09 (× 1)

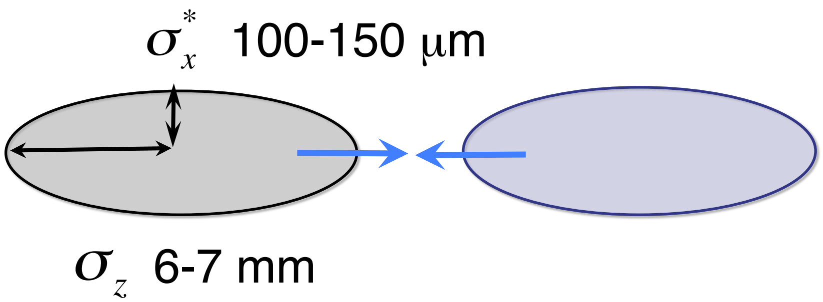
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right) = 8 \times 10^{35}\ \mathrm{cm^{-2}s^{-1}}$$

- Beam energy: 3.5/8.0 → 4.0/7.0 GeV

LER : Longer Touschek lifetime and mitigation of emittance growth due to the intra-beam scattering
HER : Lower emittance and lower SR power

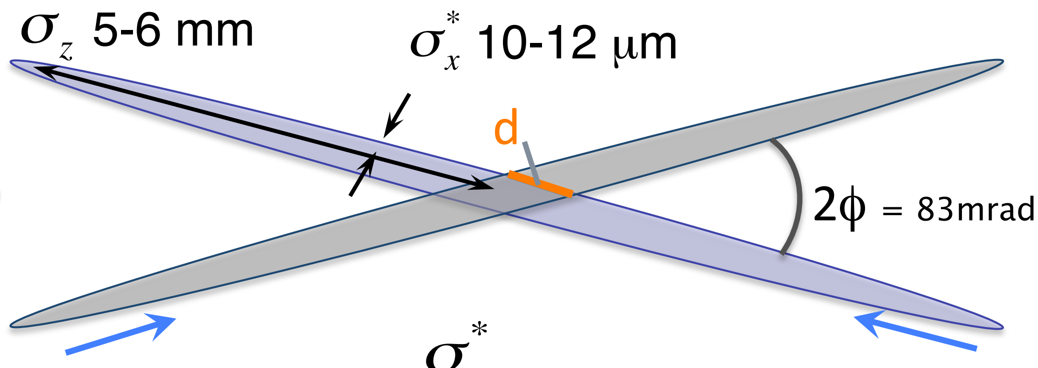
Collision Scheme

KEKB head-on (crab crossing)



overlap region = bunch length

Nano-Beam 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.

Y. Ohnishi et al.

Design Concept of SuperKEKB

- Use the KEKB tunnel.
  - We have no option for polarization at present.

- Use the components of KEKB as much as possible.
  - Preserve the present cells in HER.
    - Major change since the 15th KEKB Review.
  - Replace dipole magnets keeping other main magnets in LER arcs.

Comparison of Parameters

	KEKB Design	KEKB Achieved : with crab	SuperKEKB Nano-Beam
Energy (GeV) (LER/HER)	3.5/8.0	3.5/8.0	4.0/7.0
β_y^* (mm)	10/10	5.9/5.9	0.27/0.30
β_x^* (mm)	330/330	1200/1200	32/25
ε_x (nm)	18/18	18/24	3.2/5.3
$\varepsilon_y/\varepsilon_x$ (%)	1	0.85/0.64	0.27/0.24
σ_y(μm)	1.9	0.94	0.048/0.062
ξ_y	0.052	0.129/0.090	0.09/0.081
σ_z (mm)	4	6 - 7	6/5
I_{beam} (A)	2.6/1.1	1.64/1.19	3.6/2.6
$N_{bunches}$	5000	1584	2500
Luminosity (10^{34} cm^{-2} s^{-1})	1	2.11	80

Y. Ohnishi et al.

Lattice

- Low beta

	LER	HER	
β_x^*	32	25	mm
β_y^*	0.27	0.30	mm

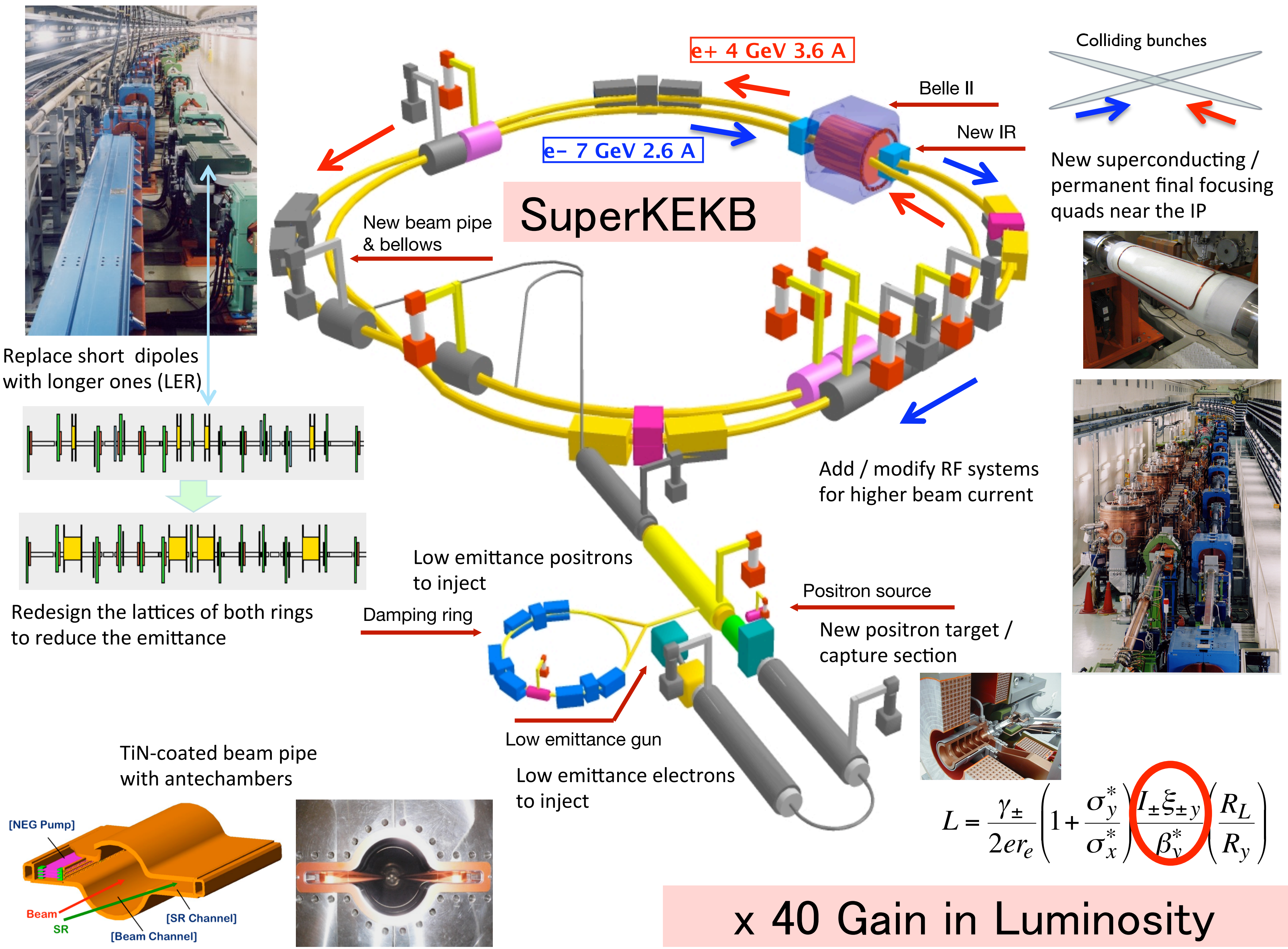
- Low emittance

	LER	HER	
ε_x	3.2	4.3*- 5.3	nm
ε_y	< 8.64 (0.27%)	< 10.32 (0.24 %)	pm

* : with full wigglers

- Ensure a sufficient dynamic aperture for
  - Touschek lifetime > 600 sec
  - Injection acceptance: A_x $707_{(LER)}$ / $377_{(HER)}$ nm

-> Morita, Iida


SuperKEKB
e+ 4 GeV 3.6 A
e− 7 GeV 2.6 A
Belle II
New IR
Colliding bunches
New superconducting / permanent final focusing quads near the IP
New beam pipe & bellows
Replace short dipoles with longer ones (LER)
Redesign the lattices of both rings to reduce the emittance
Add / modify RF systems for higher beam current
Low emittance positrons to inject
Damping ring
Positron source
New positron target / capture section
Low emittance gun
Low emittance electrons to inject
TiN-coated beam pipe with antechambers
[NEG Pump]
Beam
SR
[SR Channel]
[Beam Channel]
$L = \frac{\gamma_\pm}{2 e r_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$
x 40 Gain in Luminosity

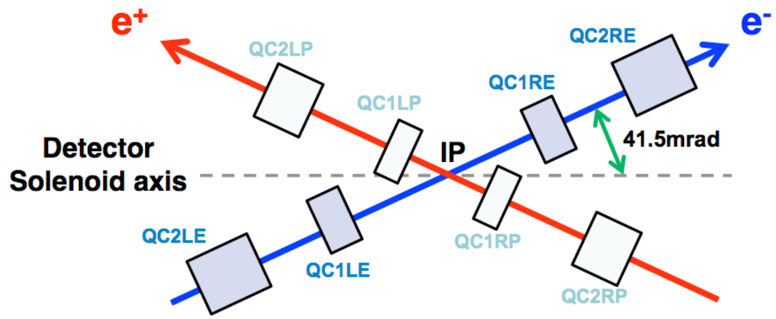
Main Items to Upgrade

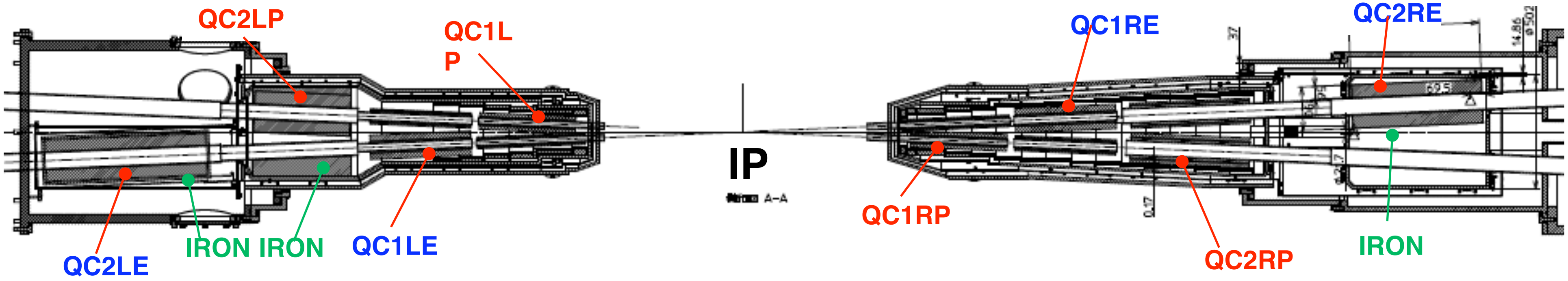
- Rebuild the IR and Tsukuba straight section
- Improve optics in the arcs and wiggler sections
- Change the beam pipes
- Strengthen and reconfigure the RF system
- Upgrade Linac, including the construction of a positron damping ring, strengthening the positron source, and installation of a low-emittance gun for electrons
- Implement speed and resolution improvements to the beam diagnostics and control system
- Strengthen the cooling facilities

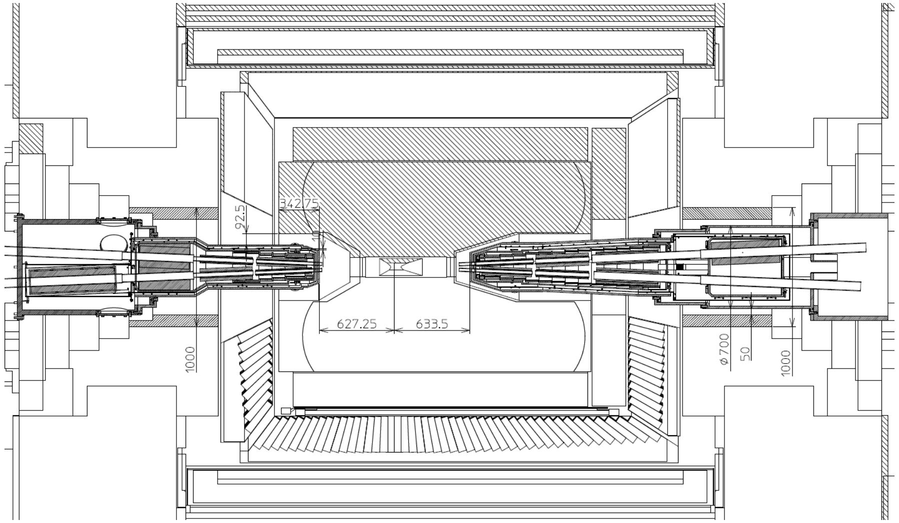
KEK's Roadmap Revised April 30, 2010, http://www.kek.jp/Roadmap/pdf/100430roadmap-E.pdf

Interaction Region

New superconducting magnets around IP

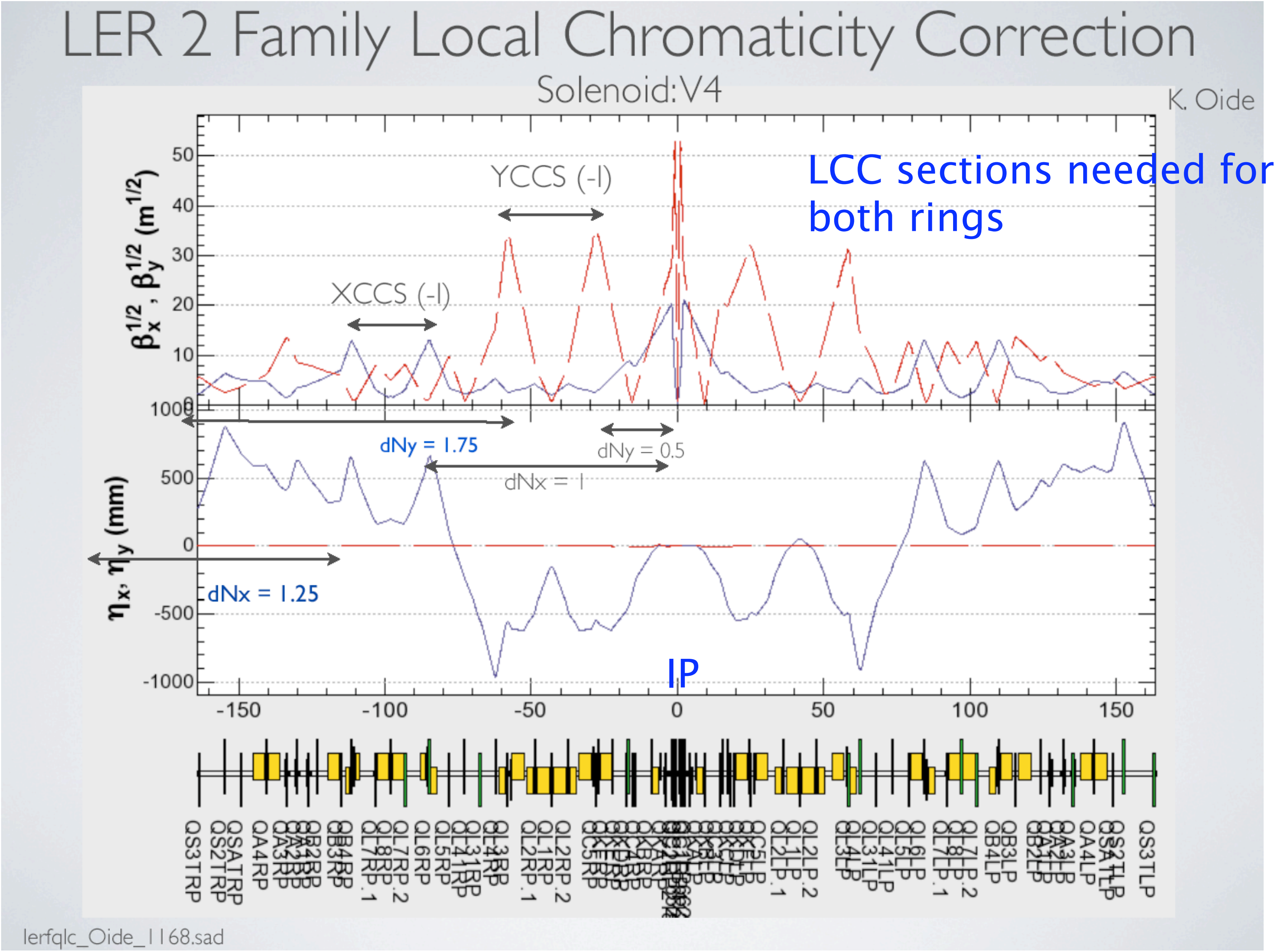






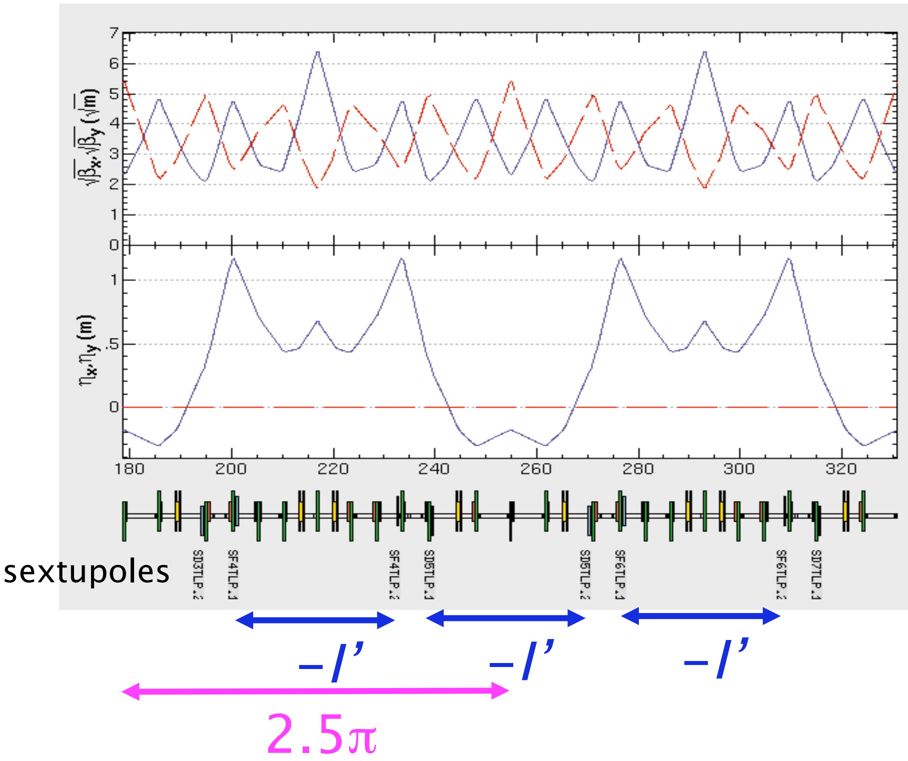
-> N. Ohuchi

IR with local chromaticity correction



2.5 π cell structure

KEKB LER

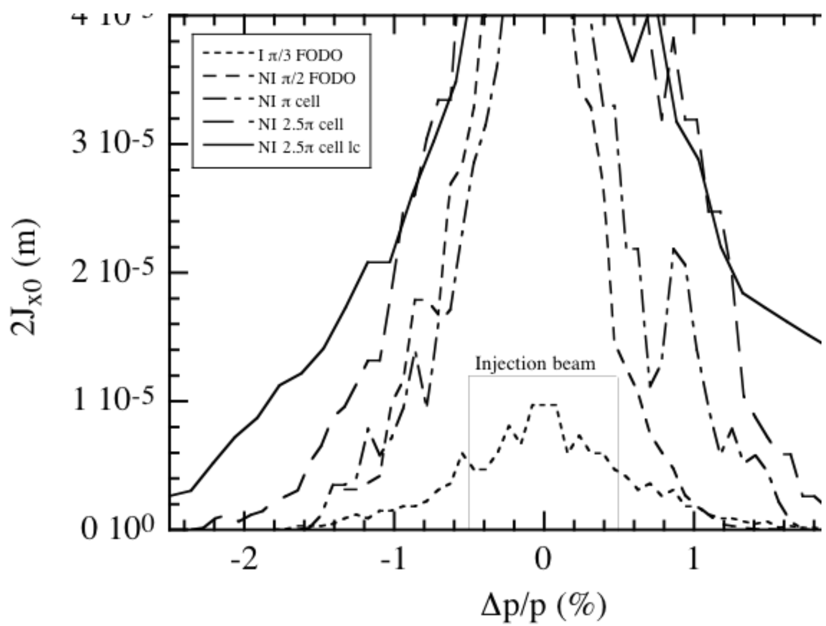


•Chromaticity correction with non-interleaved pairs of sextupoles which are connected with a −*I'* transformer.

•Major non linearity is cancelled within each pair.

•52-54 pairs / ring.

KEKB LER dynamic aperture

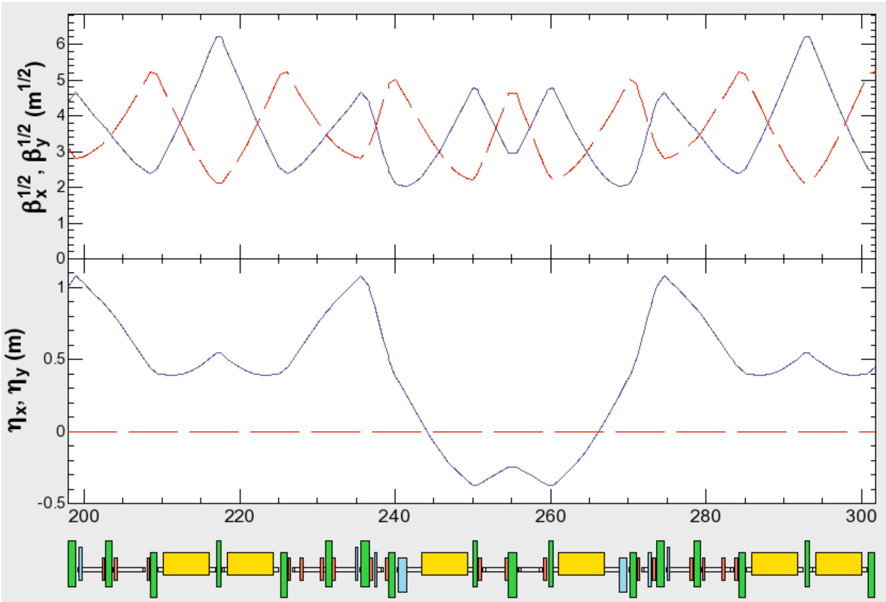


•Large dynamic aperture.

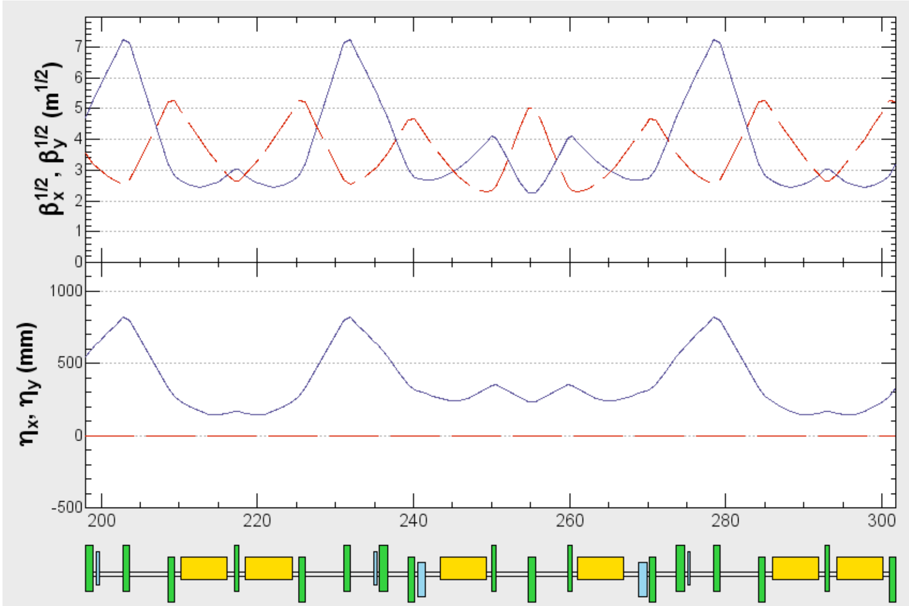
•Large tuning range of the horizontal emittance and the momentum compaction factor.

HER arc

HER emittance can be decreased to ~5 nm
preserving the KEKB cell structure



Present KEKB
24 nm @ 8 GeV

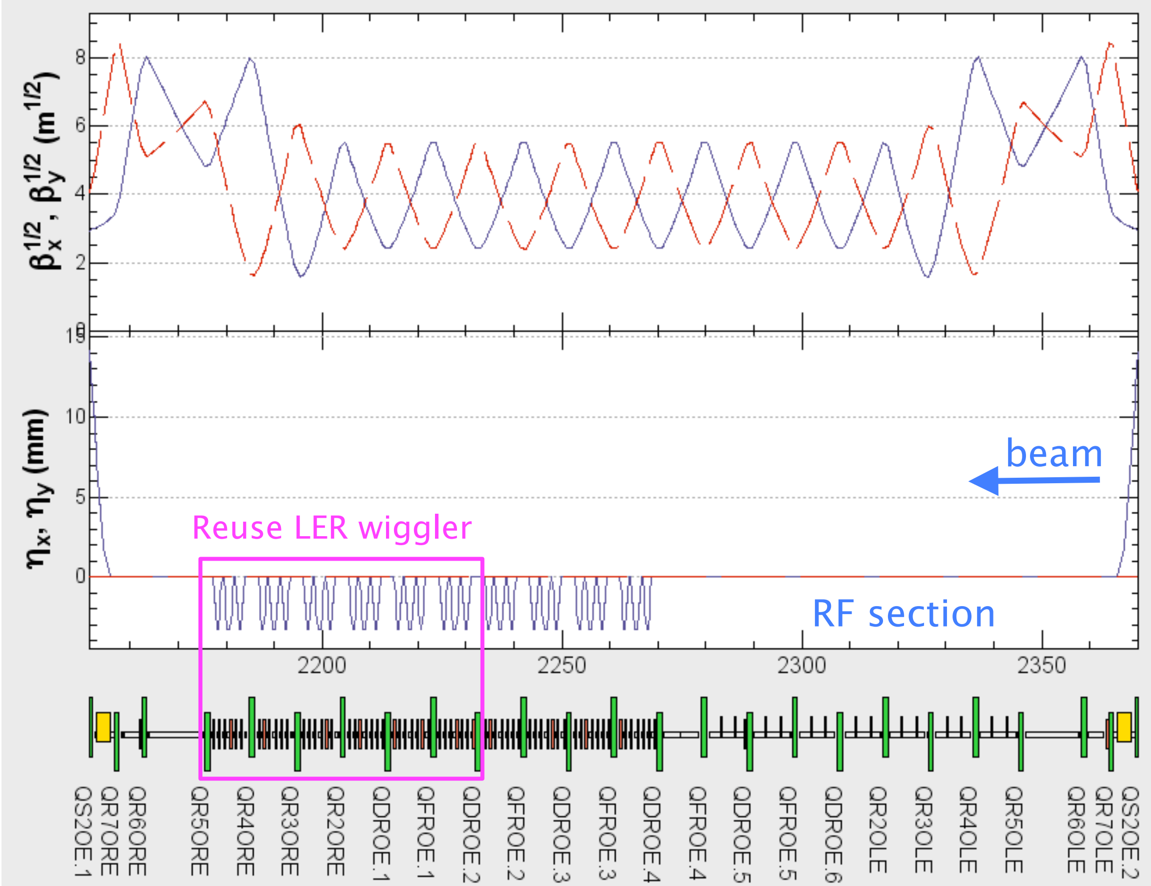


SuperKEKB
5.2 nm @ 7 GeV

-> Morita

HER Wiggler Section

Oho Straight Section



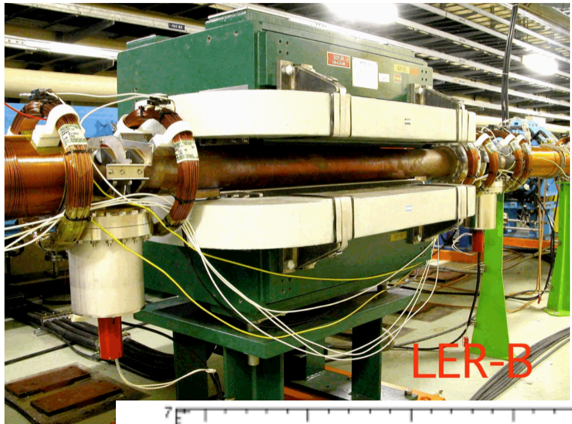
- Decrease the horizontal emittance with wigglers.
- Reuse LER wiggler magnets. (60%)
- Install more wigglers if possible. (+40%)

-> Morita

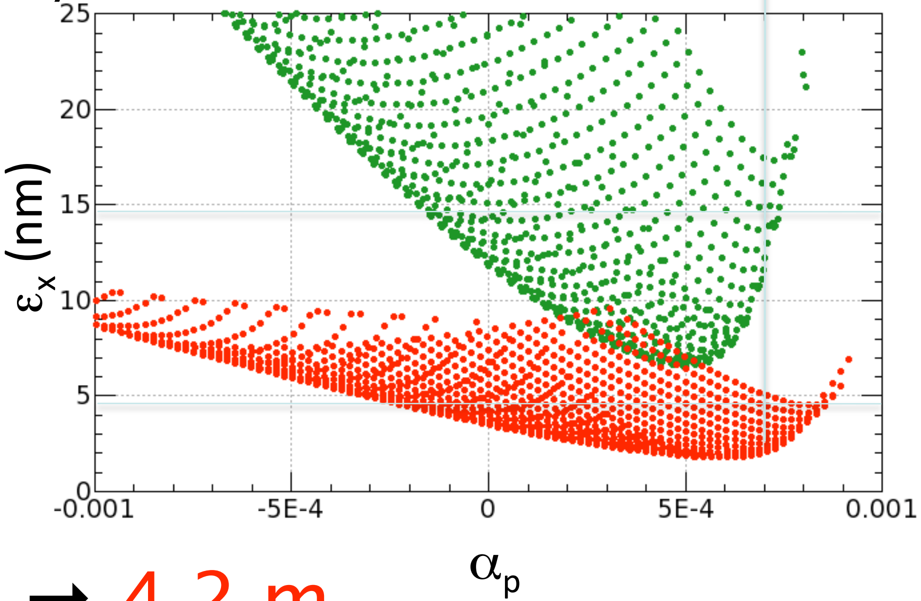
LER arc

A. Morita, Y. Ohnishi, et al

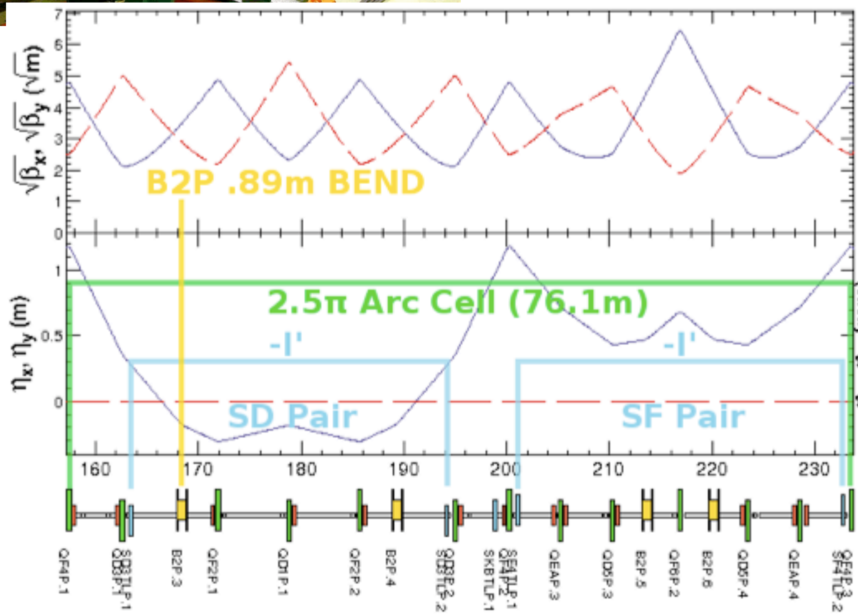
Replace ~100 dipole magnets in the arc sections to longer dipoles



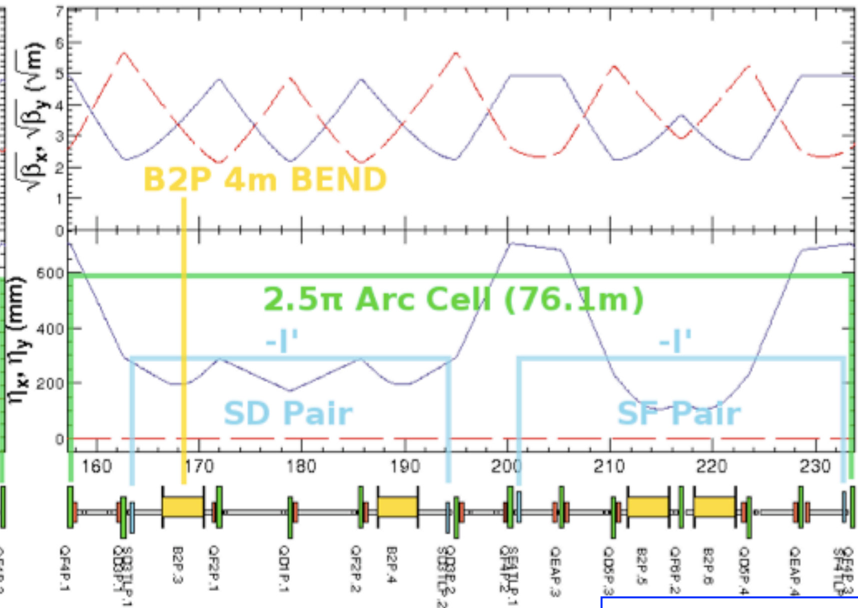
Tunability of the LER cell



L= 0.89 m → 4.2 m



KEKB LER

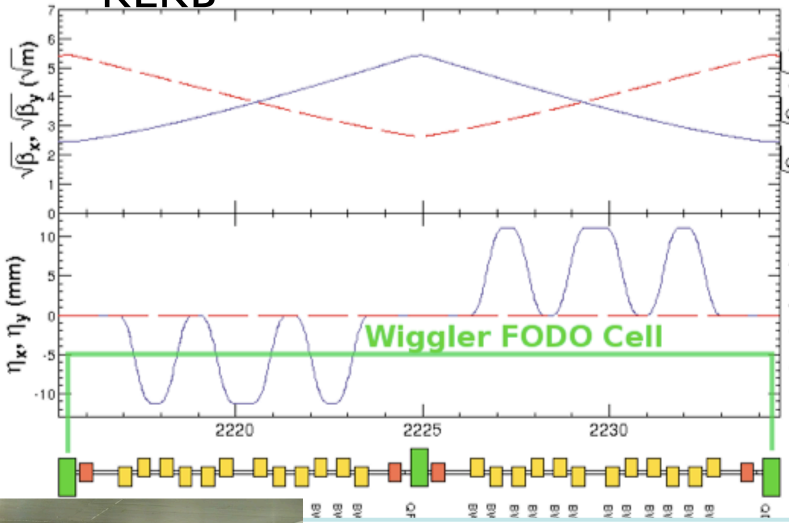


SuperKEKB LER

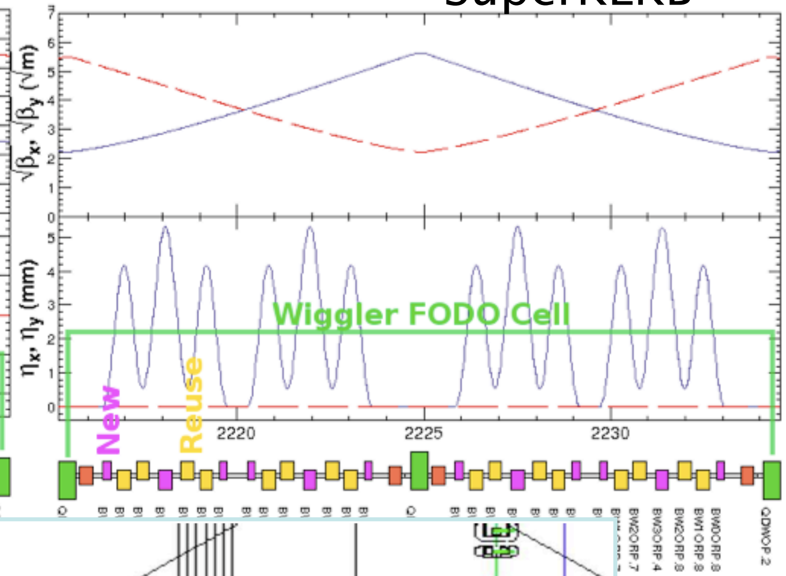
-> Morita

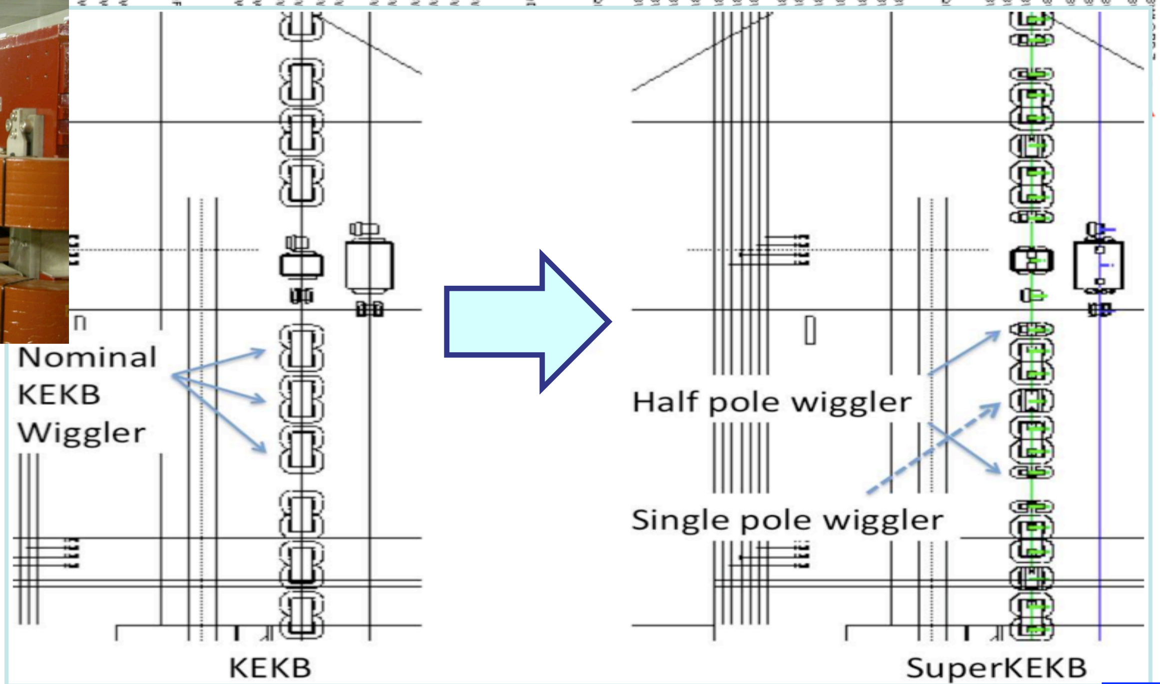
LER wiggler section

KEKB



SuperKEKB





Shorten wiggler period by ½ for lower emittance

-> Morita

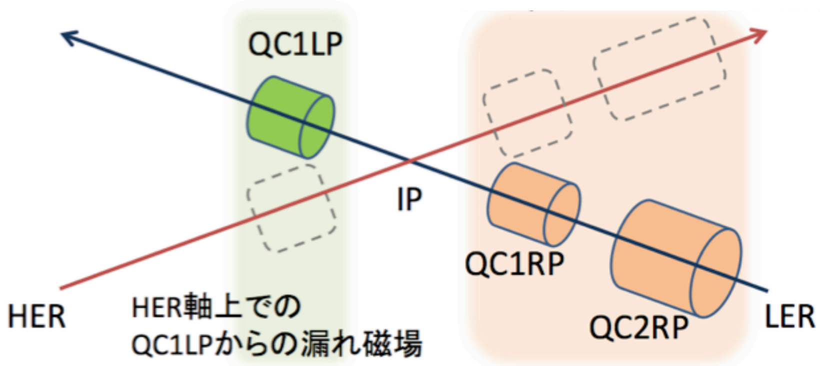
Dynamic Aperture

- Dynamic apertures of both rings are limited by nonlinear leakage fields of IR magnets for counter-rotating beams. More serious in LER.

- Physical apertures need sufficient clearances.

Leakage fields from QC1LP, QC1RP, & QC2RP

Example:
LER->HER



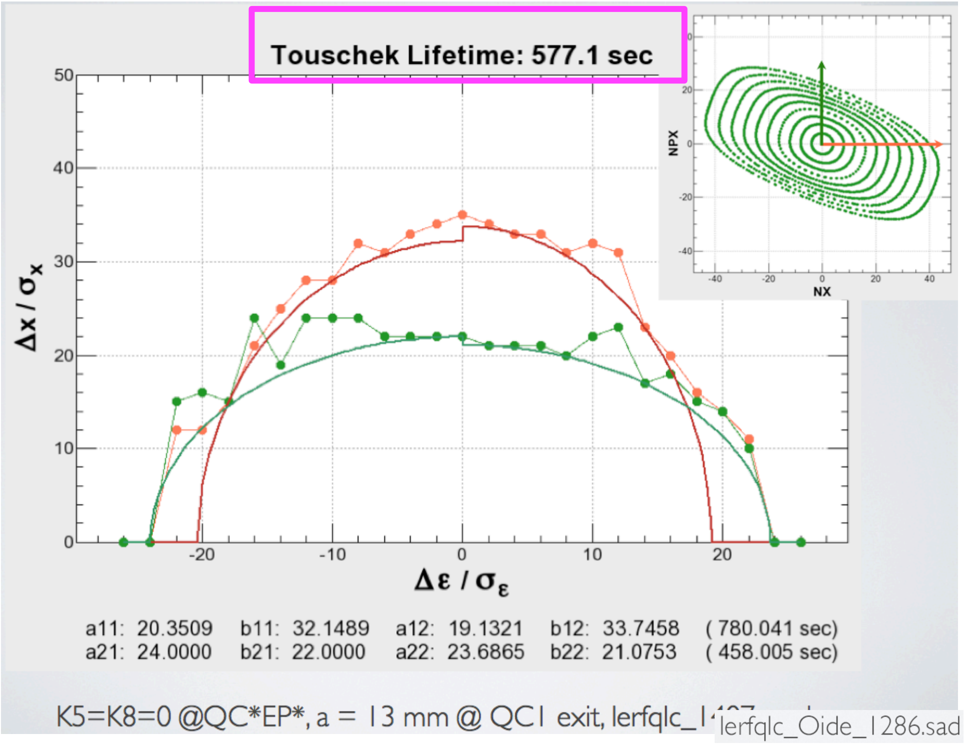
M. Iwasaki, N. Ohuchi

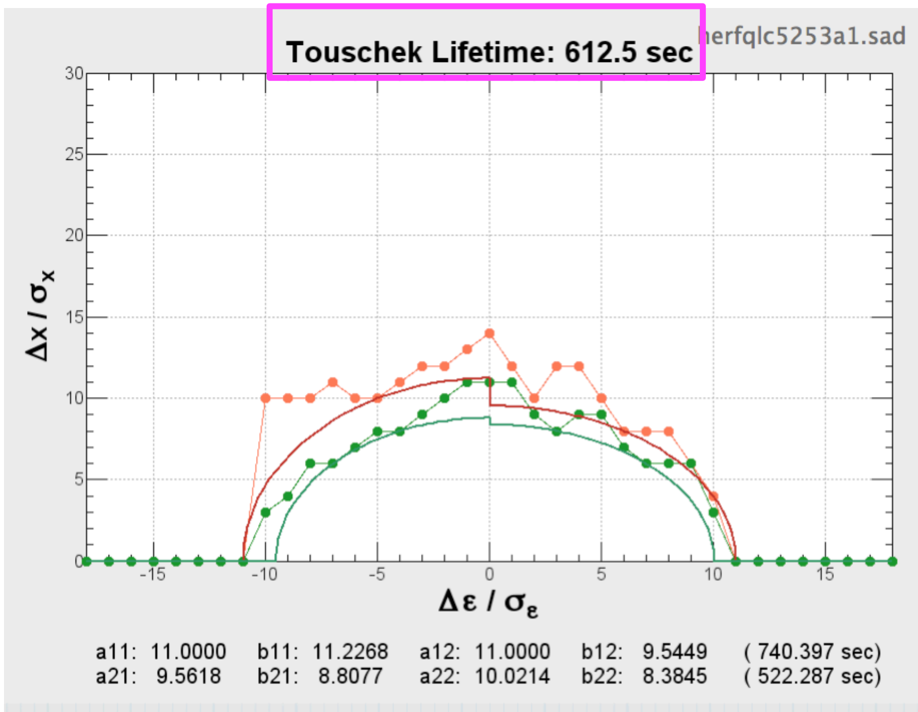
- Optimization of magnetic fields and physical apertures is being in progress.

->Morita, Ohuchi

Dynamic Aperture

LER





Max injection rate :
LER: 4 nC/bunch, 2 bunches/pulse, 25 Hz
HER: 5 nC/bunch, 2 bunches/pulse, 25 Hz

Lower limit of lifetime:

LER >181 sec, HER > 105 sec

-> Morita

K. Oide, Y. Ohnishi, A. Morita

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.

Machine Parameters

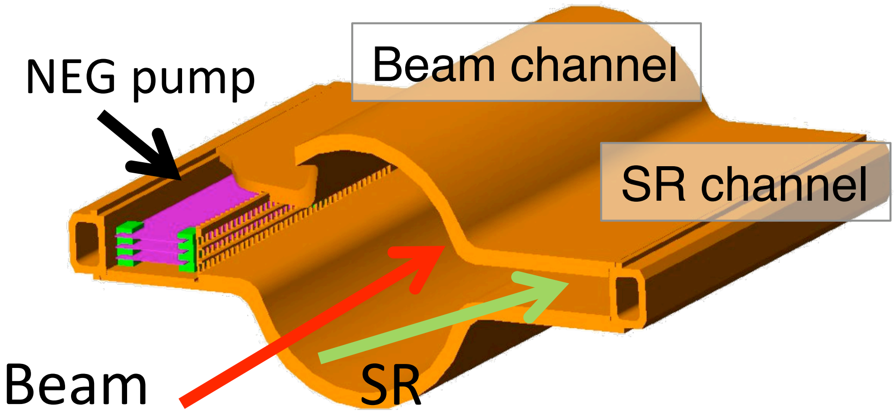
2010/Sept/8	LER	HER	HER	HER	unit
wiggler	Full	None	6/10	Full	
E	4.000	7.007	7.007	7.007	GeV
I	3.6	2.6	2.6	2.6	A
Number of bunches	2,500	2,500	2,500	2,500	
Bunch Current	1.44	1.04	1.04	1.04	mA
Circumference	3,016.3700	3,016.3700	3,016.3704	3,016.3707	m
$\varepsilon_x/\varepsilon_y$	3.2(1.9)/(2.8)	5.3(5.2)/(4.2)	4.6(4.5)/(3.6)	4.3(4.1)/(3.2)	nm/pm
β_x^*/β_y^*	32/0.27	25/0.30	25/0.30	25/0.30	mm
α_p	3.49×10^{-4}	4.55×10^{-4}	4.55×10^{-4}	4.54×10^{-4}	
σ_δ	$8.00(7.66)\times10^{-4}$	$5.85(5.78)\times10^{-4}$	$6.35(6.29)\times10^{-4}$	$6.59(6.54)\times10^{-4}$	
V_c	9.4	12.4	14.7	15.8	MV
σ_z	6.0(5.0)	5.0(4.9)	5(4.9)	5(4.9)	mm
ν_s	-0.0256	-0.0254	-0.0277	-0.0287	
ν_x/ν_y	44.53/43.57	45.53/43.57	45.53/43.57	45.53/43.57	
U_0	1.87	2.07	2.43	2.67	MeV
$\tau_{x,y}/\tau_s$	43.0/21.5	68.2/34.1	58.0/29.0	52.8/26.4	msec
	lerfqlc1351	herfqlc5210	herfqlc5214	herfqlc5215	

Values in () : without the effect of intra-beam scattering

Y. Ohnishi

New Ante-chamber beam pipe

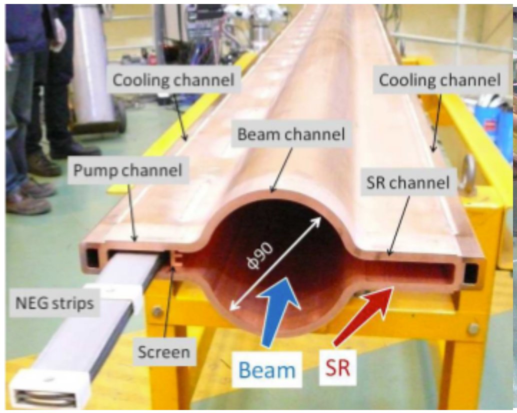
TiN-coated beam pipes with ante-chambers
to suppress – Heating of components : HOM and SR
– Electron cloud instability



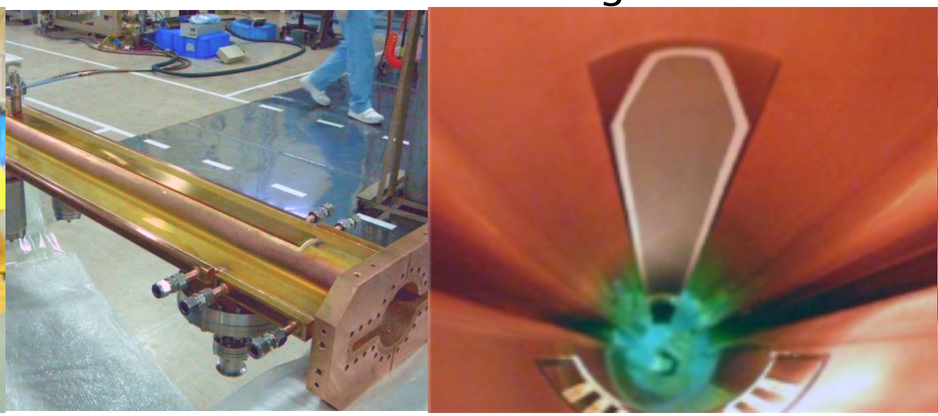
-> Suetsugu

- Low SR power density
- Less photoelectrons
- Low beam impedance

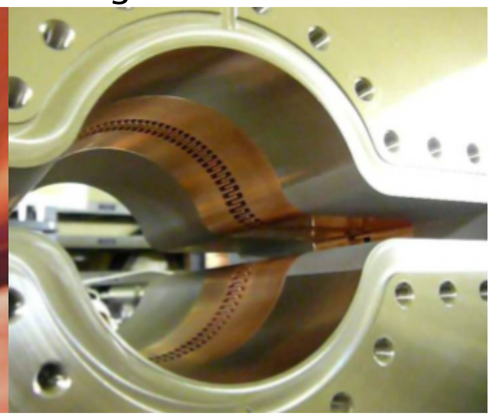
Ante-chamber



Ante-chamber with clearing electrodes



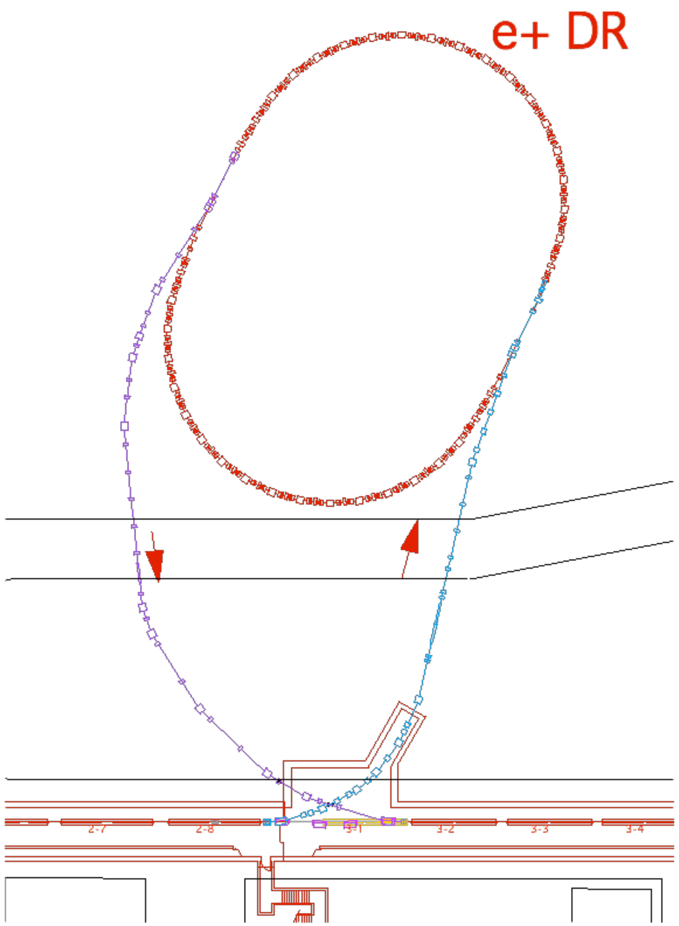
Comb-type RF shield
For gate valve



Positron Damping Ring

The injected beam should have very low emittance
because of poor dynamic aperture of the main rings

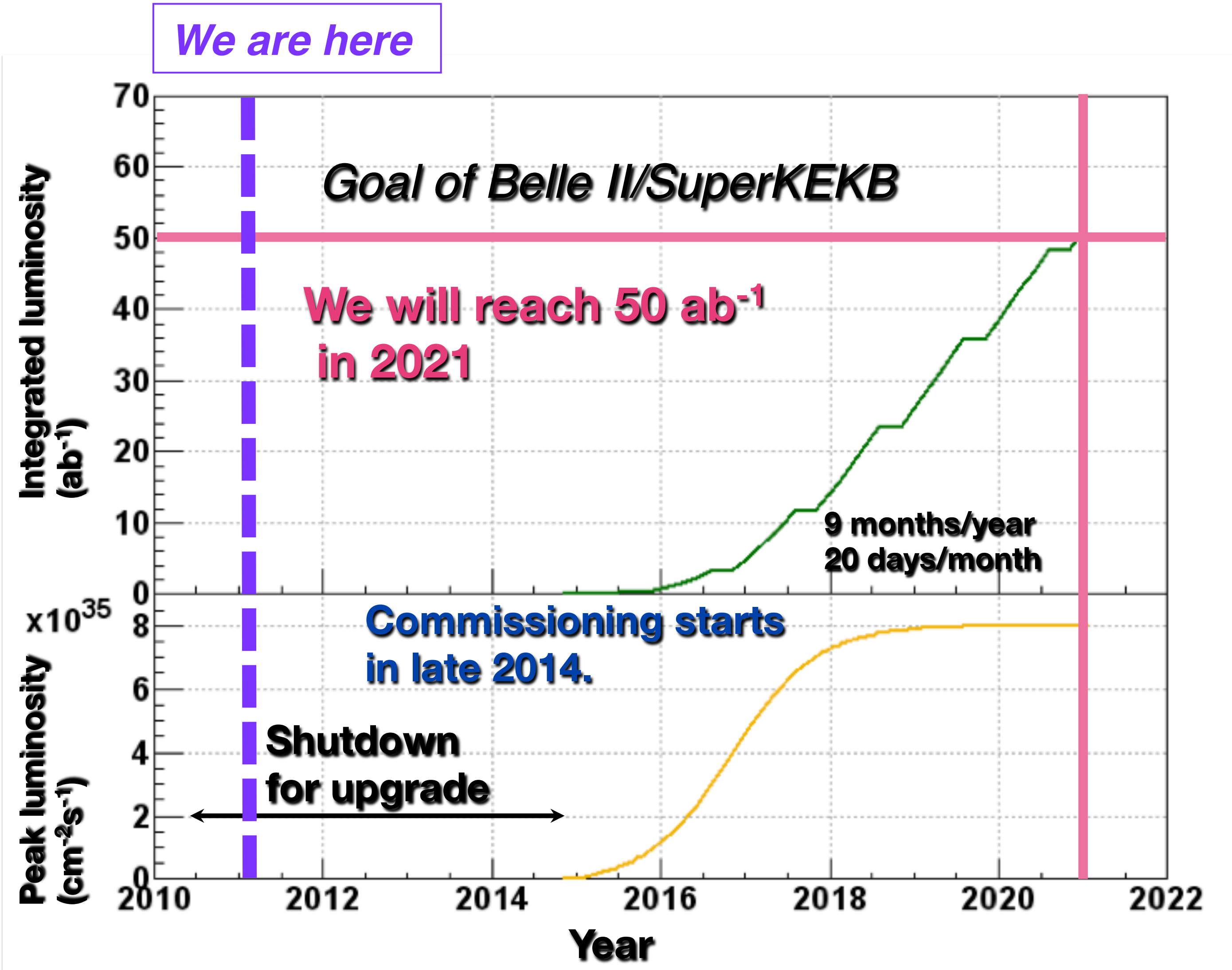
-> Kikuchi



Beam energy (GeV)	1.1		
Circumference (m)	135		
# of train	2		
# of bunches/train	2		
Maximum stored current (mA)	70.8		
Horizontal damping time (ms)	11		
Injected-beam emittance (μm)	1.7		
Emittance @ extraction (H/V) (nm)	42.5 / 2.07		
Cavity voltage (Vc) (MV)	0.5	1.0	1.4
Bunch length (mm)	11.1	7.7	6.5
Momentum compaction (α)	0.0141		
Energy spread (%)	0.055		

Electron cloud will be mitigated by TiN coating and solenoid windings.
Founded for some components such as magnets.

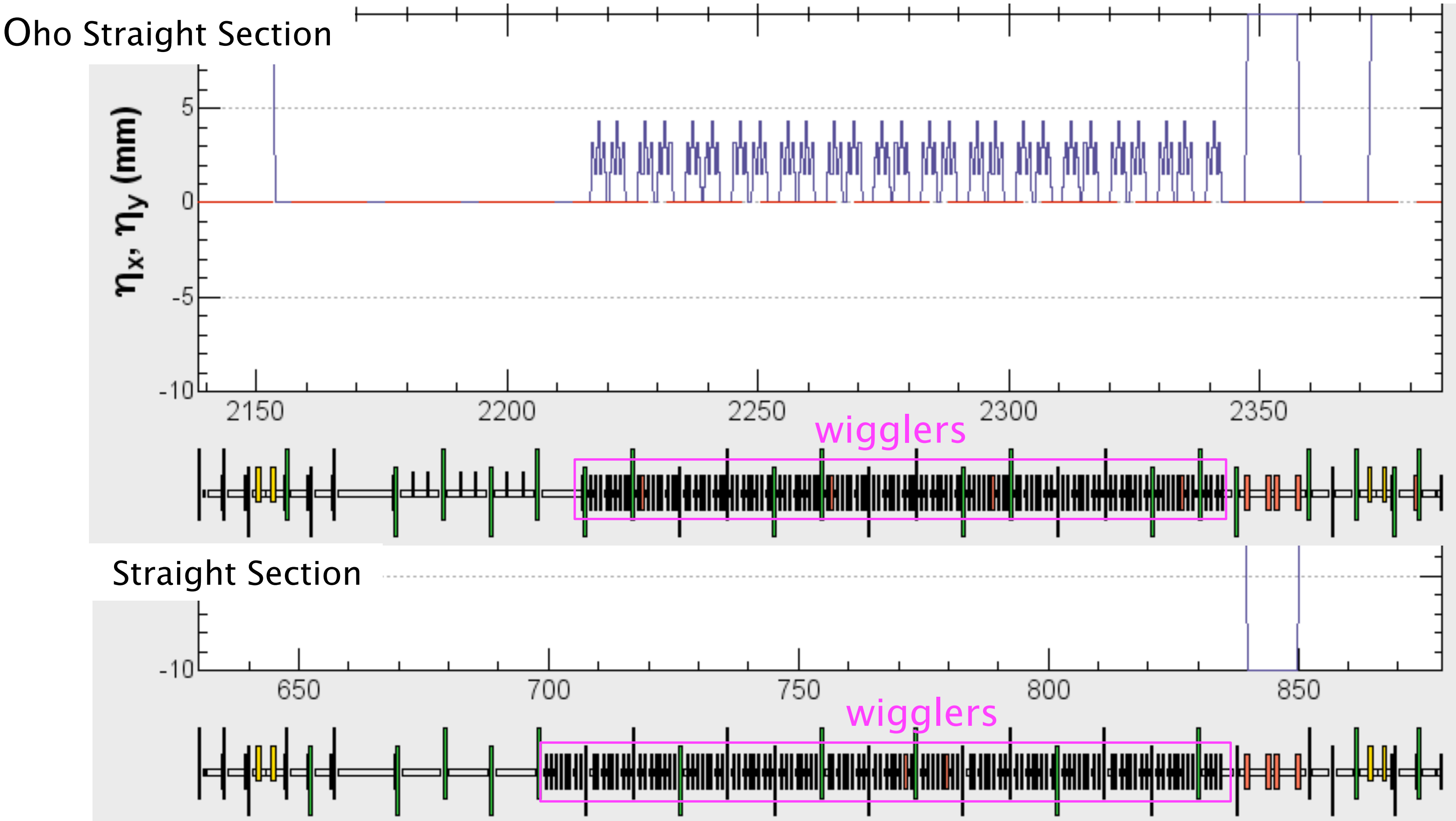
SuperKEKB luminosity projection



Y. Ohnishi

backup

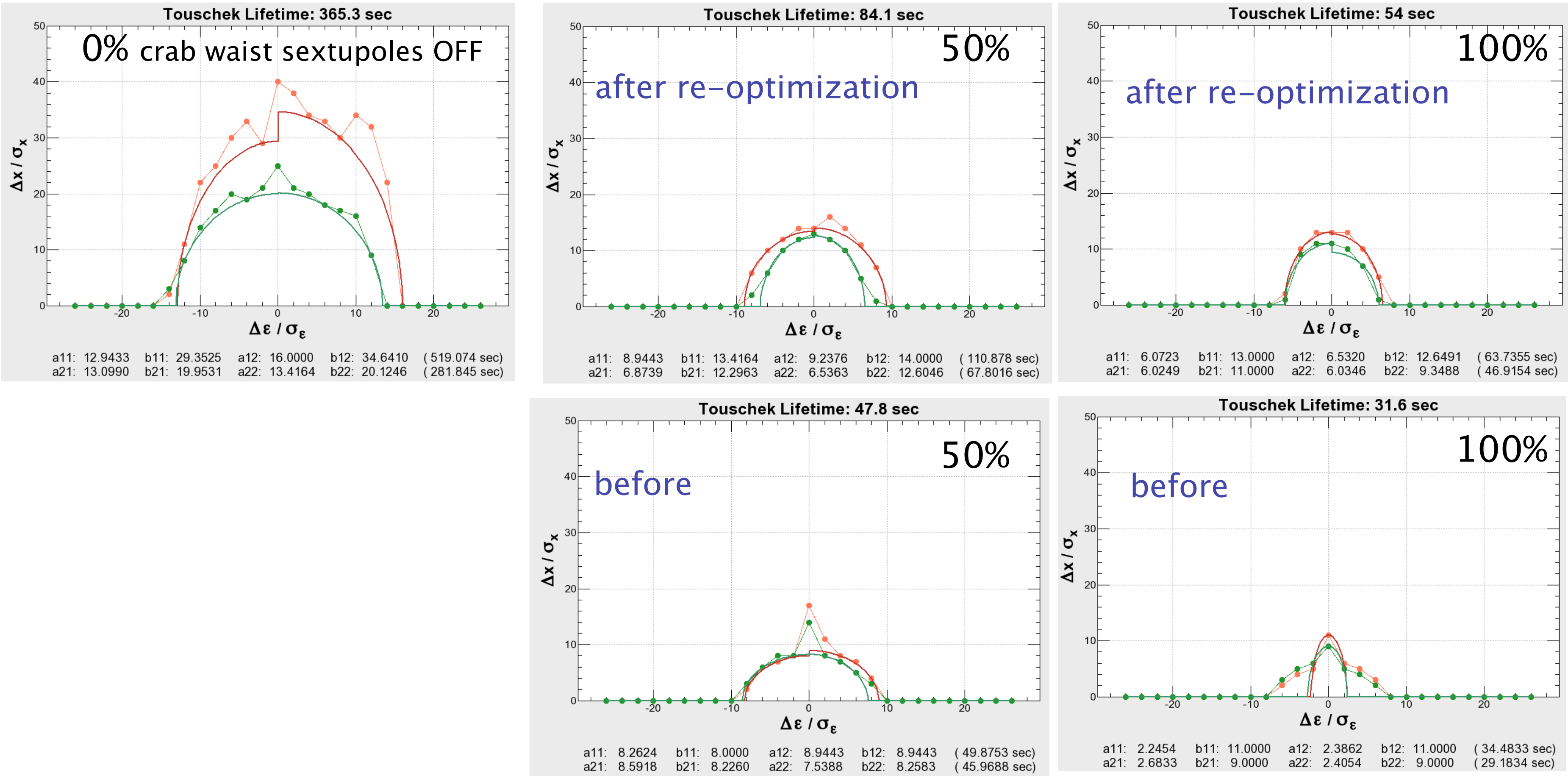
LER wiggler section



Half pole wigglers (new) : 112
Single pole wigglers (new) : 56
KEKB two pole wigglers (reuse): 112

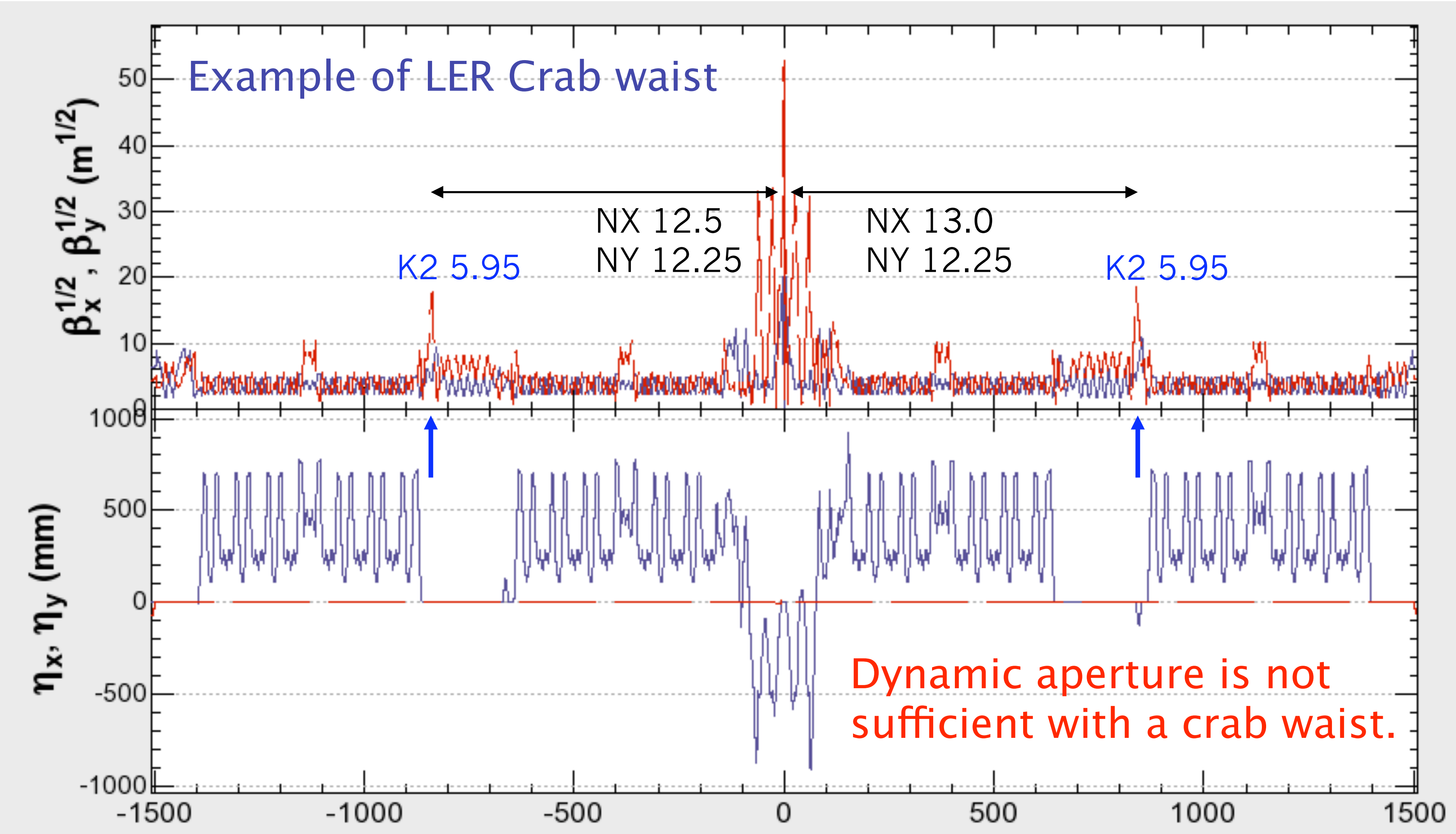
Total effective length: 120.8 m
(Total pole length: 84 m)

Crab waist scheme



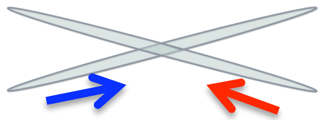
Crab waist sextupoles have decreased the dynamic aperture in both transverse and momentum directions.

Crab waist scheme



Nano-beam Scheme (15-th KEKB Review)

- The scheme proposed by P. Raimondi and SuperB Group.



- Squeeze β_y^* as small as possible: 0.27/0.41 mm.

- Assume beam-beam parameter = 0.09 which has been already achieved at KEKB.

- Change beam energies 3.5 / 8 -> 4 /7 GeV to achieve longer Touschek lifetime and mitigate the effect of intra-beam scattering in LER.