Status of SuperKEKB Design: Lattice and IR

Y. Ohnishi

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KEK

"Tanabata": Festival of the Weaver ?

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Design concept

Luminosity is determined by 3 parameters in principle.

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

Lorentz factor

Beam current

Beam-Beam parameter

Geometrical reduction factors (crossing angle, hourglass effect)

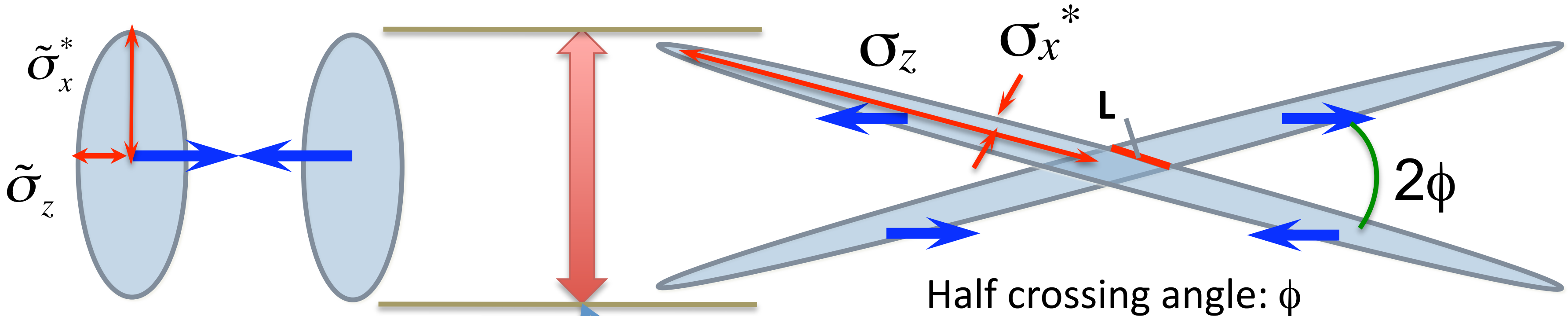
Beam aspect ratio at IP

Vertical beta function at IP

Minimum value is limited by hourglass effect

Collision scheme

High current scheme | **Nano beam scheme**



Half crossing angle: ϕ

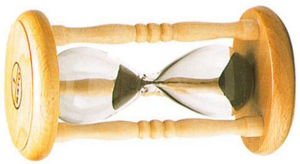
Head-on frame
(rotation and Lorentz boost)

$$\tilde{\sigma}_z = \frac{\sigma_x^*}{\phi}$$

$$\tilde{\sigma}_x^* = \sigma_z \phi$$

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

Total projected cross section is equal for each other.

	High Current	**Nano Beam**
Bunch length requirement :	$\sigma_z < \dfrac{\sigma_x^*}{\phi} \to \infty(\phi \to 0)$	$\sigma_z > \dfrac{\sigma_x^*}{\phi}$
Hourglass requirement : 	$\boxed{\beta_y^* \geq \sigma_z}$	$\boxed{\beta_y^* \geq \dfrac{\sigma_x^*}{\phi}}$
Luminosity :	$L \propto \dfrac{\boxed{N_+ N_-}}{\sigma_x^* \sigma_y^*}$	$L \propto \dfrac{N_+ N_-}{\phi \sigma_z \boxed{\sigma_y^*}}$
Beam-beam parameter :	$\xi_y \propto \dfrac{\boxed{N_+}}{\sigma_x^*}\sqrt{\dfrac{\beta_y^*}{\varepsilon_y}}$	$\xi_y \propto \dfrac{N_+}{\phi \sigma_z}\sqrt{\boxed{\dfrac{\beta_y^*}{\varepsilon_y}}}$

Strategy of Nano beam

Smaller σ_y* provides higher luminosity.

Smaller β_y* provides smaller σ_y*, however longer σ_z is OK. (less HOM, no CSR)

Hourglass (H.G) condition requires smaller σ_x*, namely smaller β_x* is necessary.

Smaller beam-beam parameter is preferable, so ε_y should be smaller in proportional to β_y*

Small β_x*, β_y* and small emittance is required.

→ **Lattice design**

Requirement: 8×10^{35} $cm^{-2}s^{-1}$

"Nano beam scheme"

LER/HER

ε_x = 2.8 nm / 2.0 nm

β_x^* = 17.8 mm / 25 mm

β_y^* = 0.26 / 0.26 mm

ξ_y = 0.079 ~ KEKB

Machine parameters

Tentative parameters:

		LER	HER	
Emittance	ε_x	2.8	2.0	nm
Coupling	$\varepsilon_y/\varepsilon_x$	0.74	1.80	%
Horizontal beta at IP	β_x^*	17.8	25.0	mm
Vertical beta at IP	β_y^*	0.26	0.26	mm
Horizontal beam size	σ_x^*	7.06	7.07	μm
Vertical beam size	σ_y^*	0.073	0.097	μm
Bunch length	σ_z	5		mm
Half crossing angle	ϕ	30		mrad
Beam Energy	E	3.5	8.0	
Beam Current	I	3.84	2.21	A
Number of bunches	n_b	2252		
Beam-beam parameter	ξy	0.079	0.079	
Luminosity	L	8×10^{35} (8.5×10^{35} with CW)		$cm^{-2}s^{-1}$

*** Luminosity is obtained from beam-beam simulations.**

Lattice design

item 1

Low emittance

LER	HER
Longer bends	Increase number of arc cells

item 2

Low beta at IP

Separated final quads
Closer to IP

item 3

Dynamic aperture for injection, Touschek lifetime

⇩

Local chromaticity correction

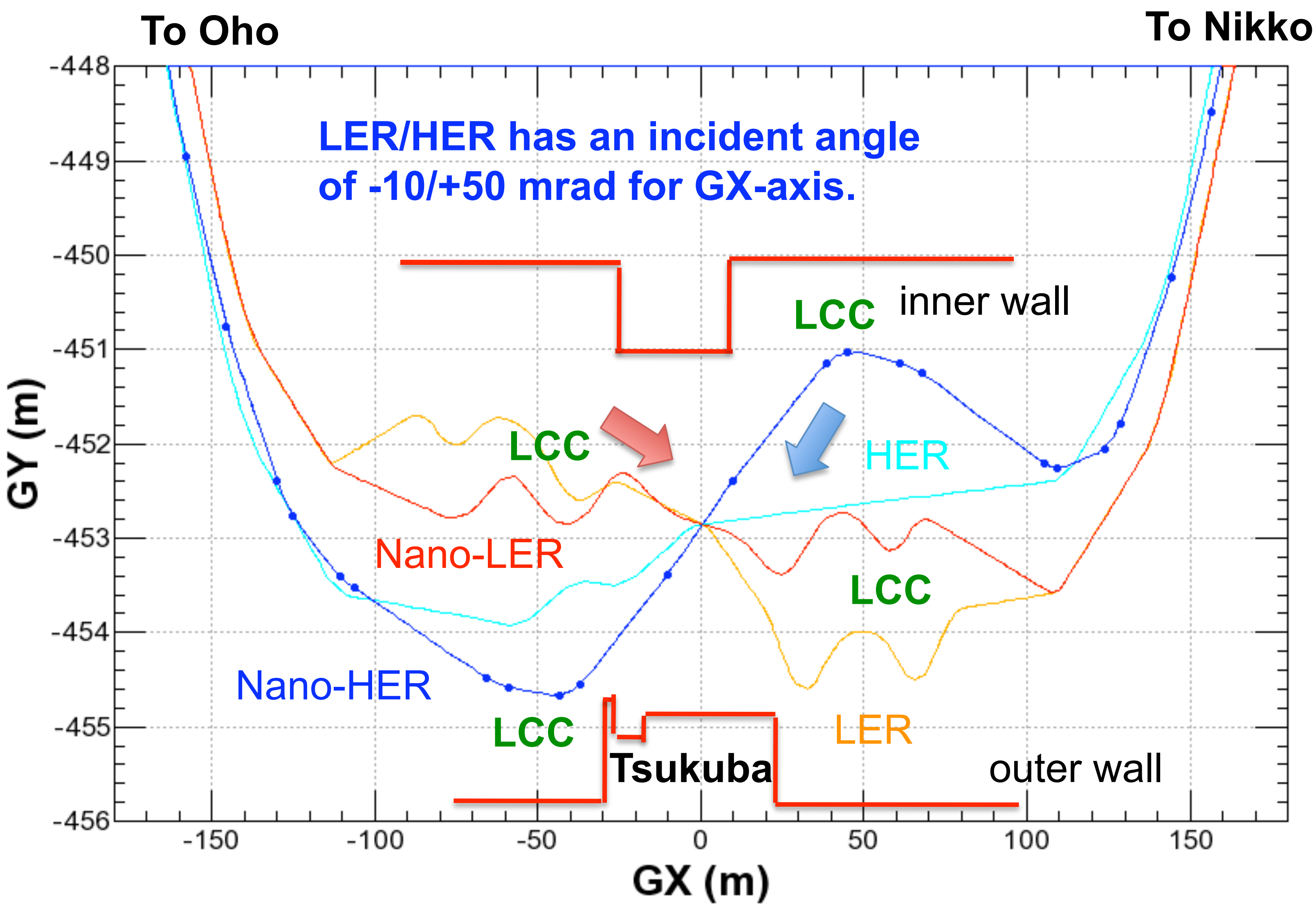
No/small emittance generation

Summary of items

	LER	HER
Low emittance	• Longer bends • 0.89 m to 4 m long	• Increase number of arc cells • Smaller dispersion in bends • 28 cells to 44 cells
Low beta at IP	• Separated final quads. • Closer to IP • Superconducting or permanent magnets	
Local chromaticity correction (LCC) (to get large DA)	• KEKB-LER type • Chicane-like (reverse bends) • Geometrical flexibility • Emittance is generated.	• ILC/SuperB type (modified to SuperKEKB) • Bending angle is necessary (no reverse bends). • Emittance can be ignored.

One of constraints is tunnel geometry.

TSUKUBA IR



To Oho
To Nikko
LER/HER has an incident angle
of -10/+50 mrad for GX-axis.
LCC
inner wall
LCC
HER
Nano-LER
LCC
Nano-HER
LCC
Tsukuba
LER
outer wall
GY (m)
GX (m)
-448
-449
-450
-451
-452
-453
-454
-455
-456
-150
-100
-50
0
50
100
150

In case of HER, large incident angle(50 mrad) makes large bending angle at LCC.

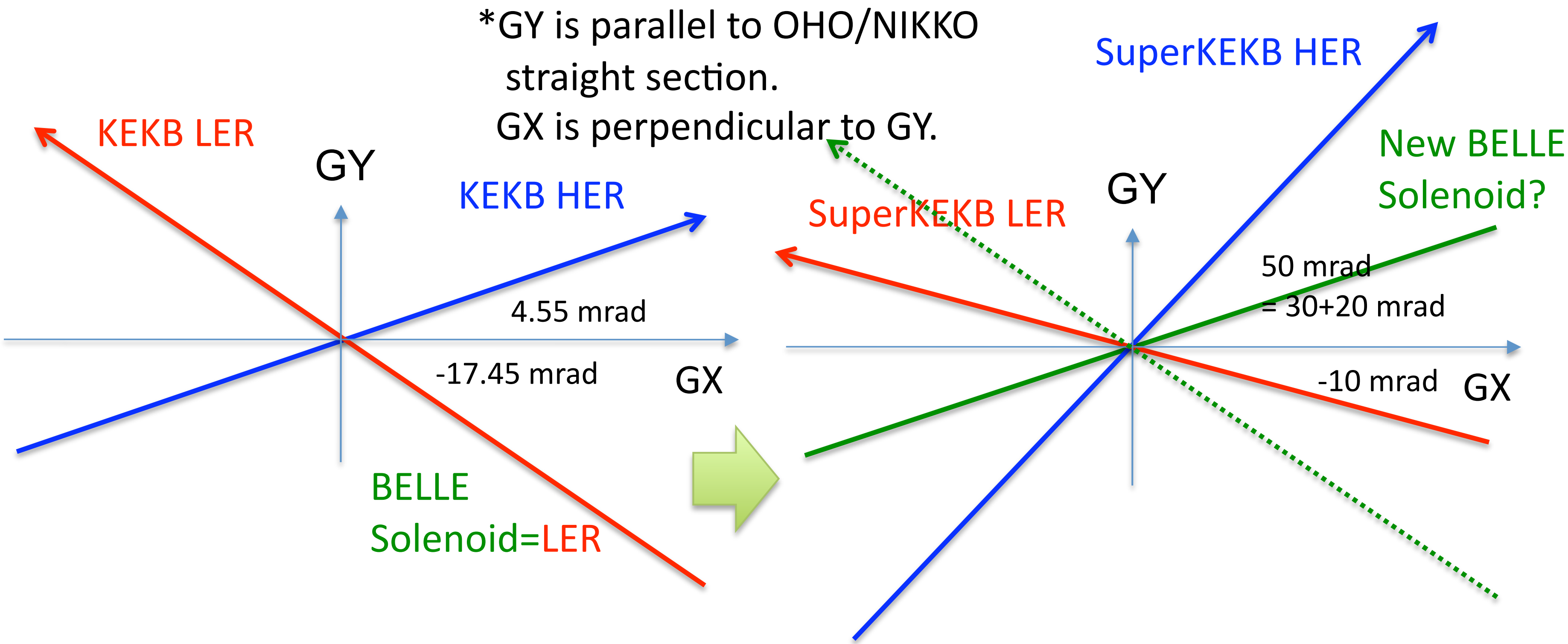
Consequently, large dispersion at LCC for HER.

Then, chromaticity correction can be done with keeping dynamic aperture.

On the other hand, LER can use KEKB-LER type for LCC since wiggler sections can control emittance.

Chicane type LCC is almost straight beam line from a global point of view although large dispersion can be made at LCC.

Beam axis and Solenoid axis



What is the Belle solenoid axis ?

Solenoid axis is:

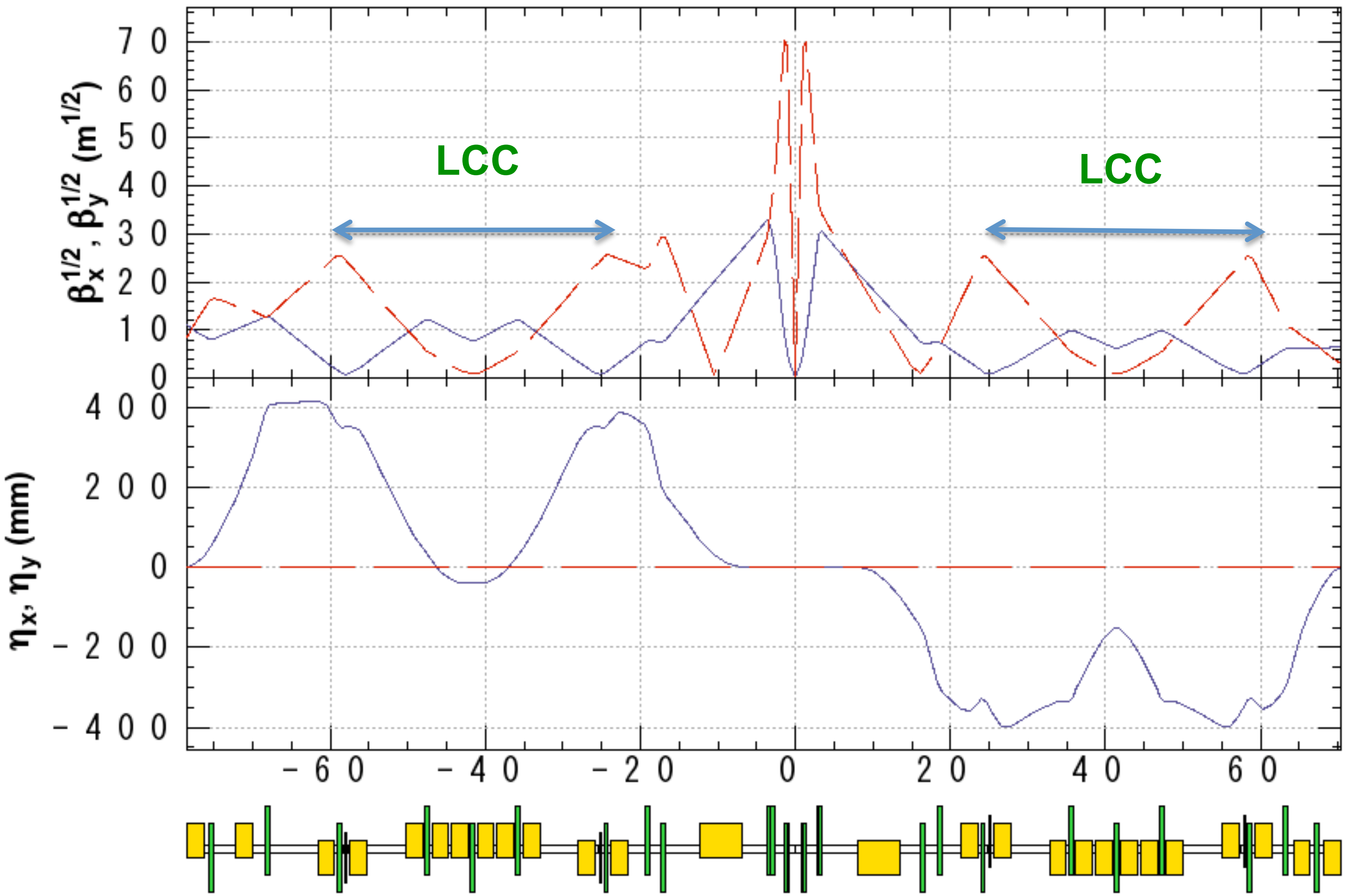
(a) LER axis -> +7.45 mrad

(b) ½ of finite-crossing angle -> +37.45 mrad

(c) or no solution to rotate BELLE

LER IR optics

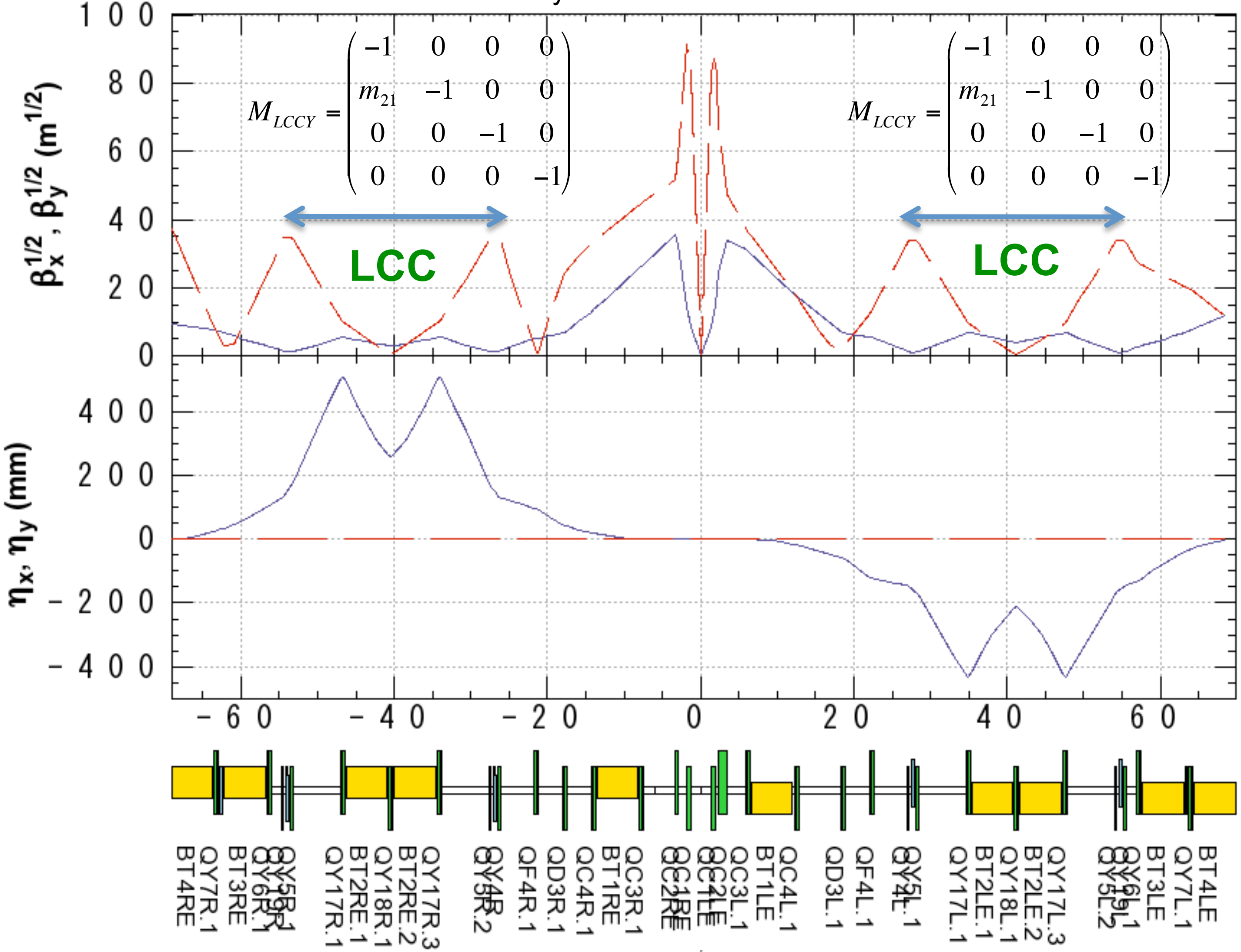
β_x^*/β_y^*=17.8 mm/0.26 mm



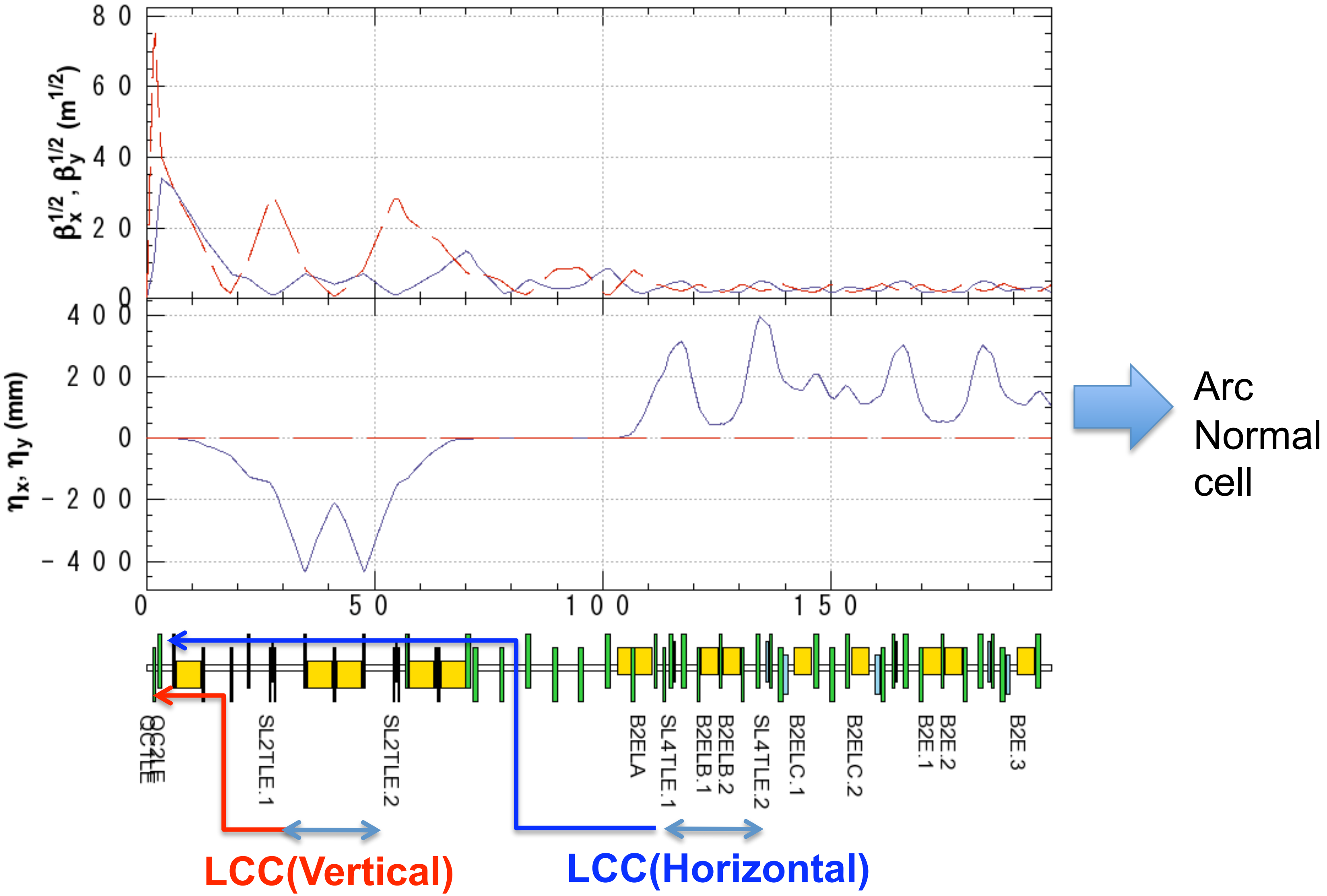
u_c = 0.44 keV

HER IR optics

β_x^*/β_y^*=25 mm/0.26 mm

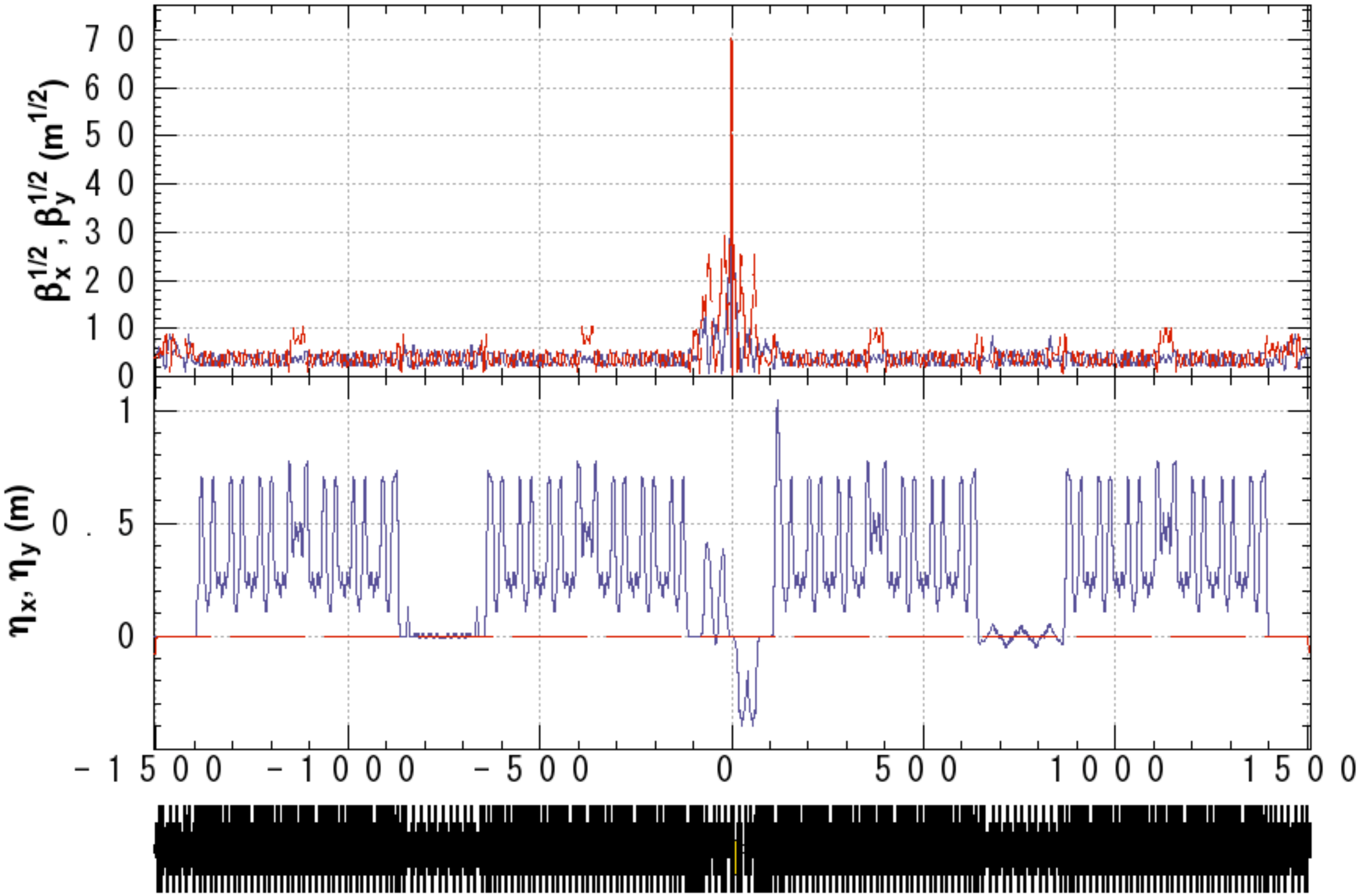


HER arc to IR optics



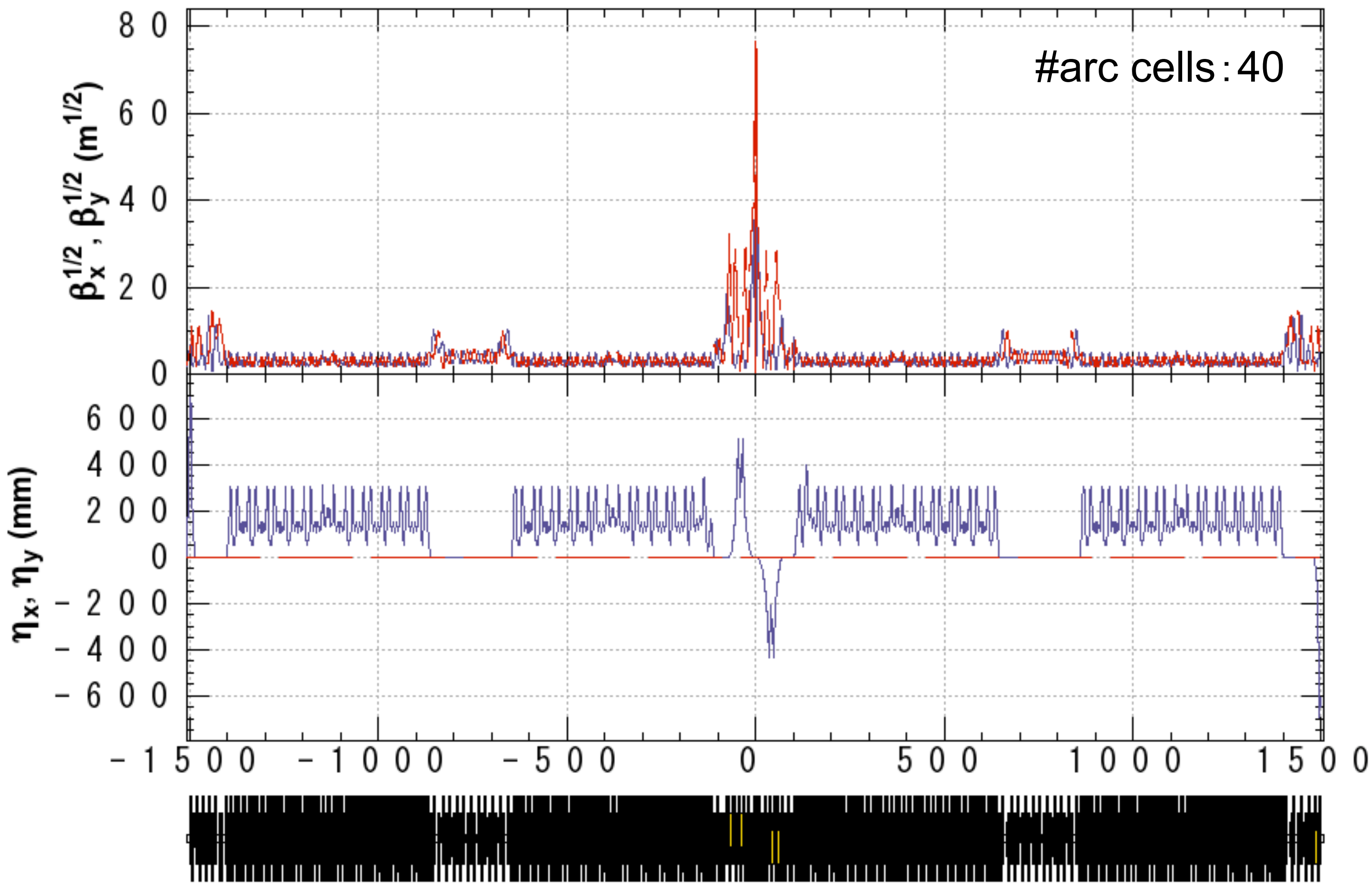
LER whole ring

C = 3016.243 m (same as KEKB-LER)

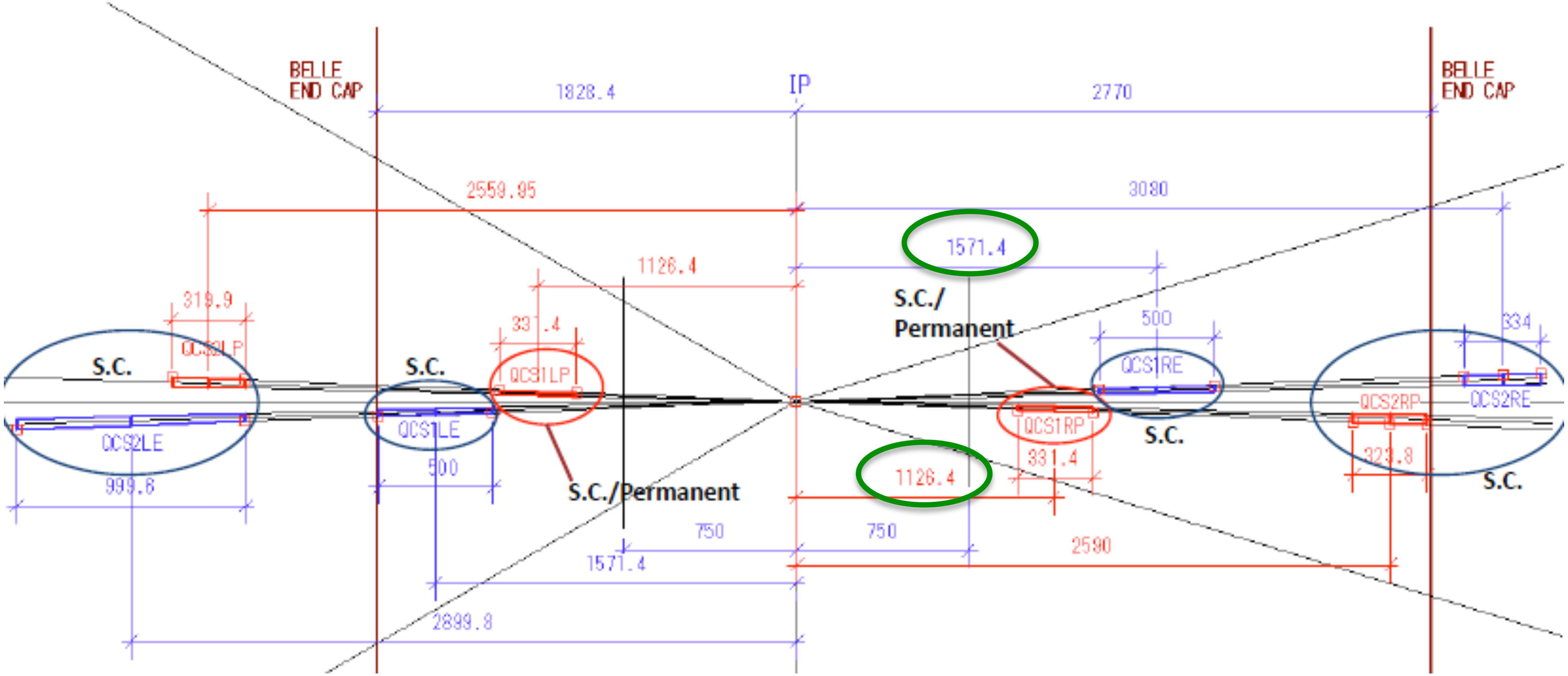


HER whole ring

C = 3016.262 m (same as KEKB-HER)



IR magnets (Preliminary)

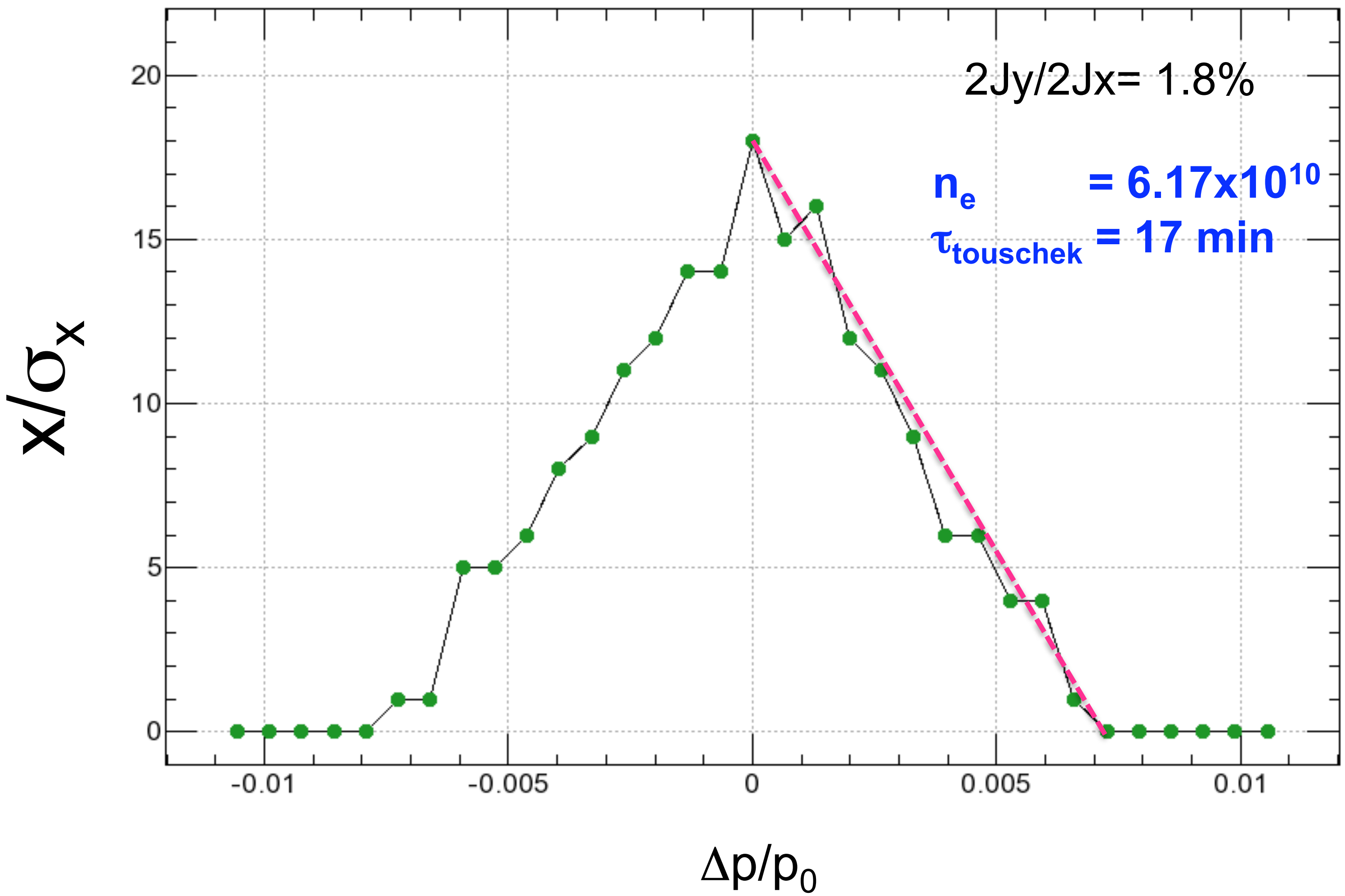


Dynamic aperture

HER dynamic Aperture (stored)

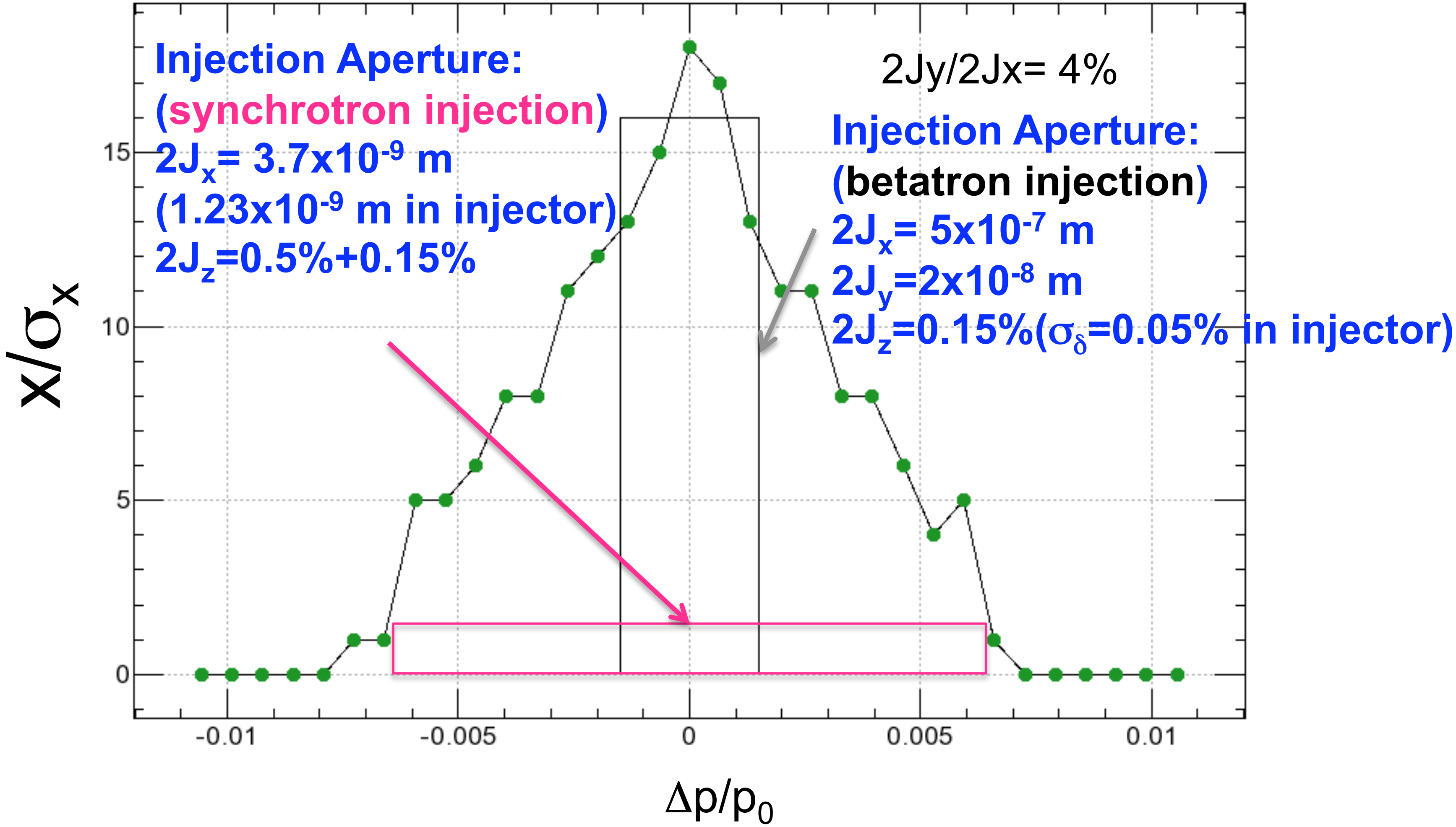
β_x^*/β_y^*=25 mm/0.26 mm

NO ERROR

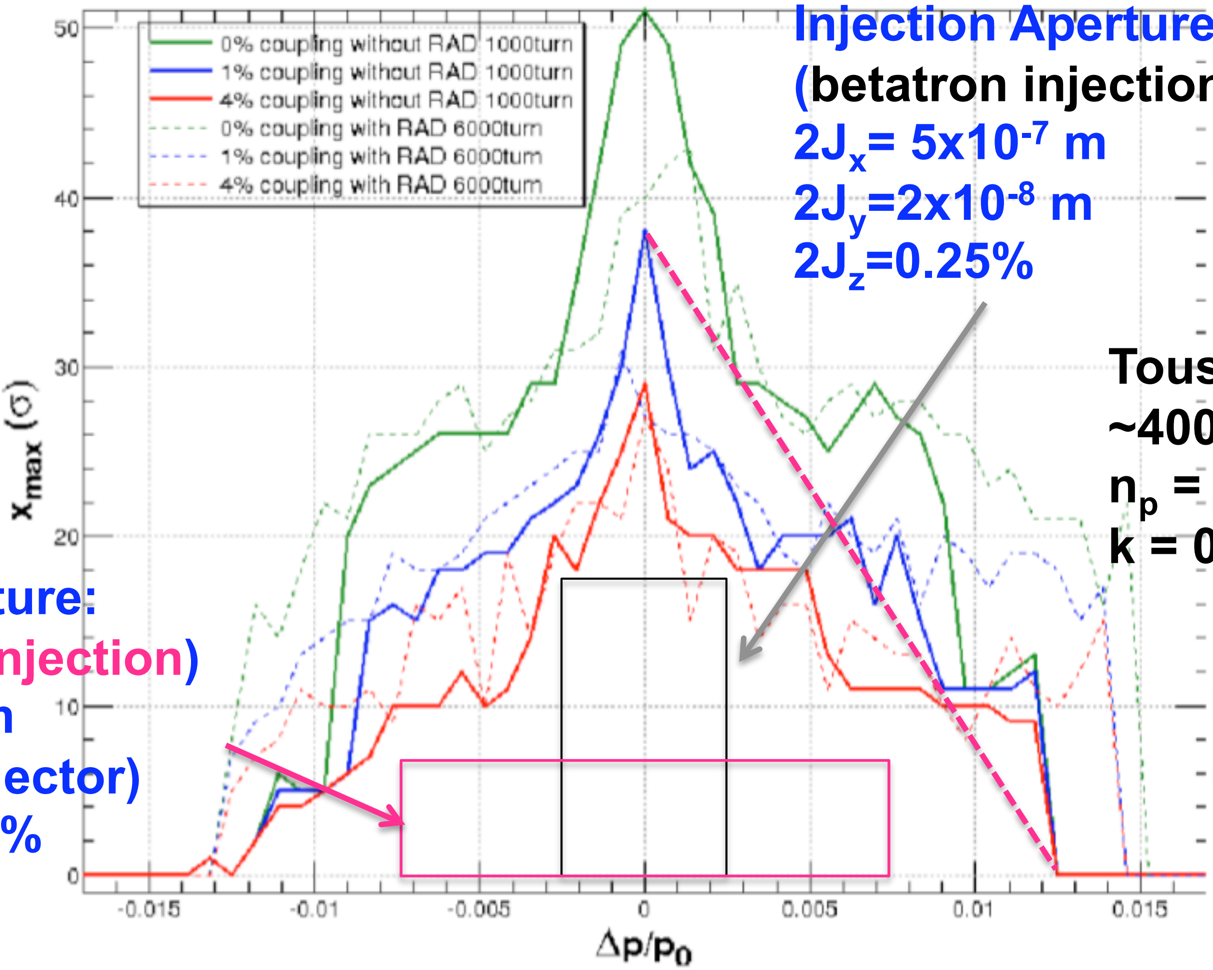


HER dynamic aperture (injection)

β_x^*/β_y^*=25 mm/0.26 mm NO ERROR



LER dynamic aperture (injection & stored)



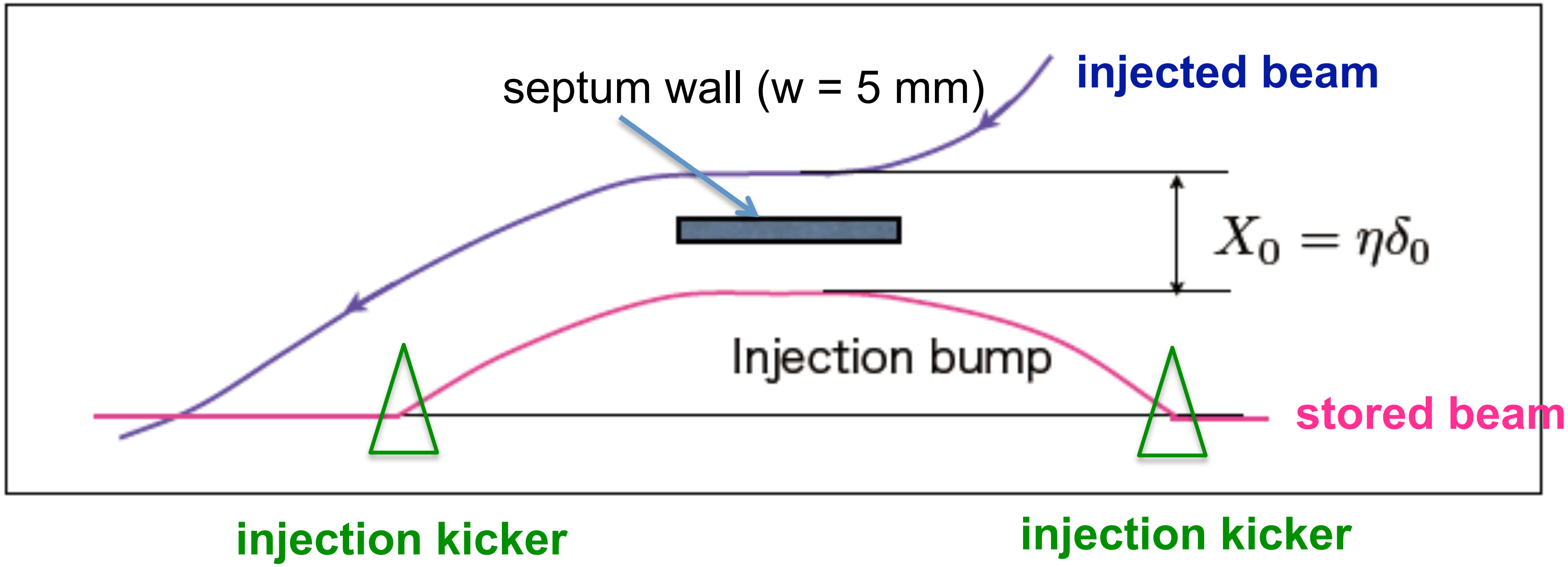
Injection Aperture:
(betatron injection)
$2J_x$= 5x10^{-7} m
$2J_y$=2x10^{-8} m
$2J_z$=0.25%

Touschek lifetime
~400 sec
n_p = 10.7x10^{10}
k = 0.74 %

Injection Aperture:
(synchrotron injection)
$2J_x$= 1.2x10^{-8} m
(4x10^{-9} m in injector)
$2J_z$=0.5%+0.25%

$\varepsilon_x \sim$ 1.8nm(without INTRA)
4% coupling Acceptance 1.1 μm @ on-momentum

Synchrotron injection



*This scheme is applied in LEP.

1) Energy of injected beam is shifted by δ_0, then an injection orbit is adjusted to be a closed orbit of the ring. $(X_0, X_0') = (\eta, \eta')\delta_0$
2) The coherent betatron oscillation due to the injection error should be zero since the betatron oscillation is transformed to the synchrotron oscillation.

$X0 = 2.5\,\sigma_{inj} + 3\,\sigma_{ring} + w = 6\sim6.5$ mm
$\eta = 1.28$ m (LER) / 1.2 m (HER) for $\delta_0 = 0.5$ %

To make this possible, the injection point will be moved from the FUJI straight section to the arc section.

-> Remodel the BT lines

Good quality of injected beam is quite necessary.

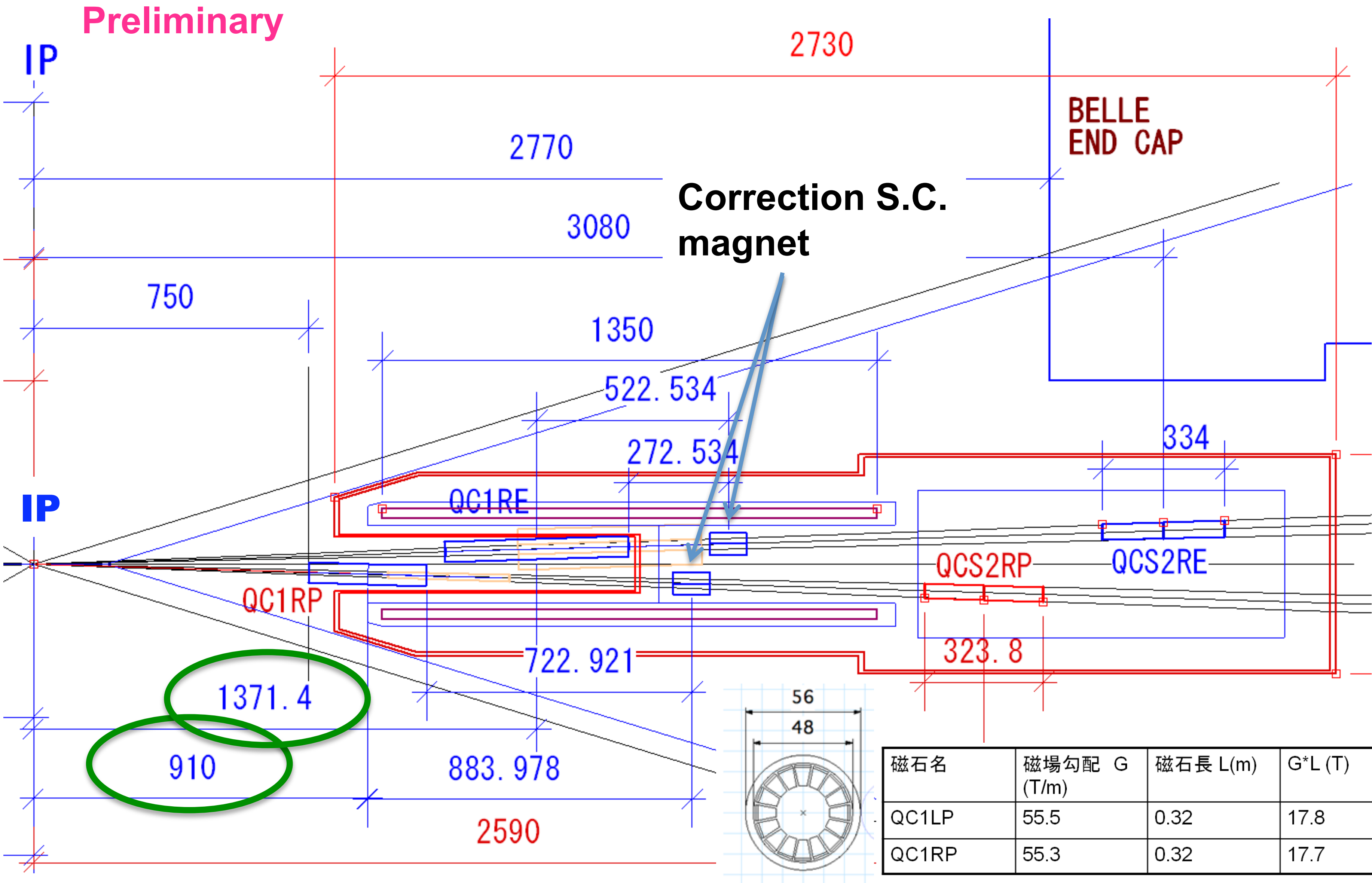
e- low emittance RF gun
and
e+ DR

IR magnet configuration: Permanent magnet + S.C. corrector (alternative)

Final focus quadrupoles(QC1) can be closer to IP than S.C. magnets only.

This makes larger dynamic aperture.

QC1P/E(Permanent Magnet)



磁石名	磁場勾配　G (T/m)	磁石長 L(m)	G*L (T)
QC1LP	55.5	0.32	17.8
QC1RP	55.3	0.32	17.7

Summary

The lattice of "Nano beam scheme" is still being developed.

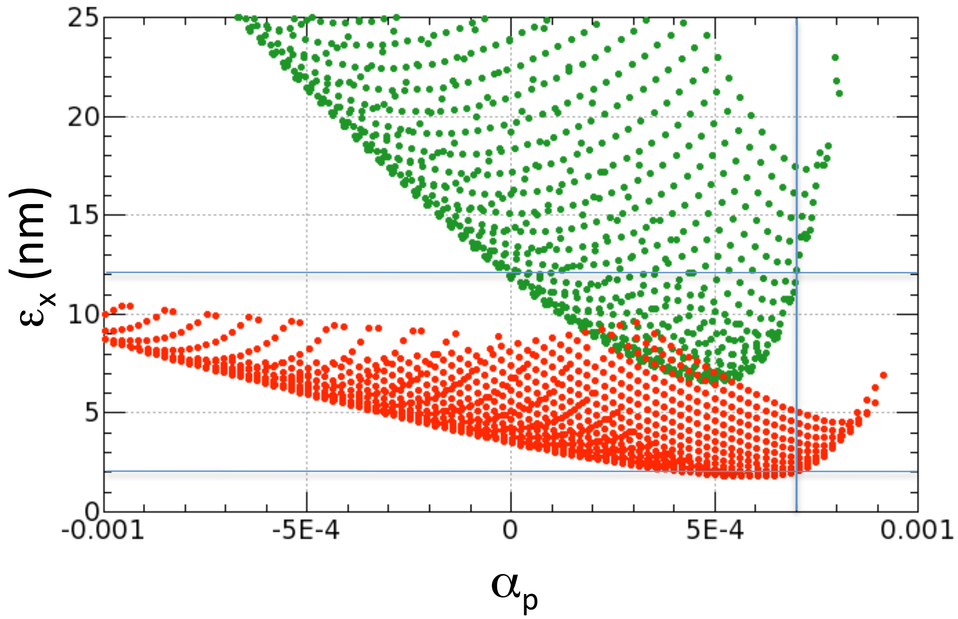
Dynamic aperture is not enough so far for injection/Touschek lifetime. It strongly depends on IR magnet configuration.

We are considering both permanent and superconducting magnets.

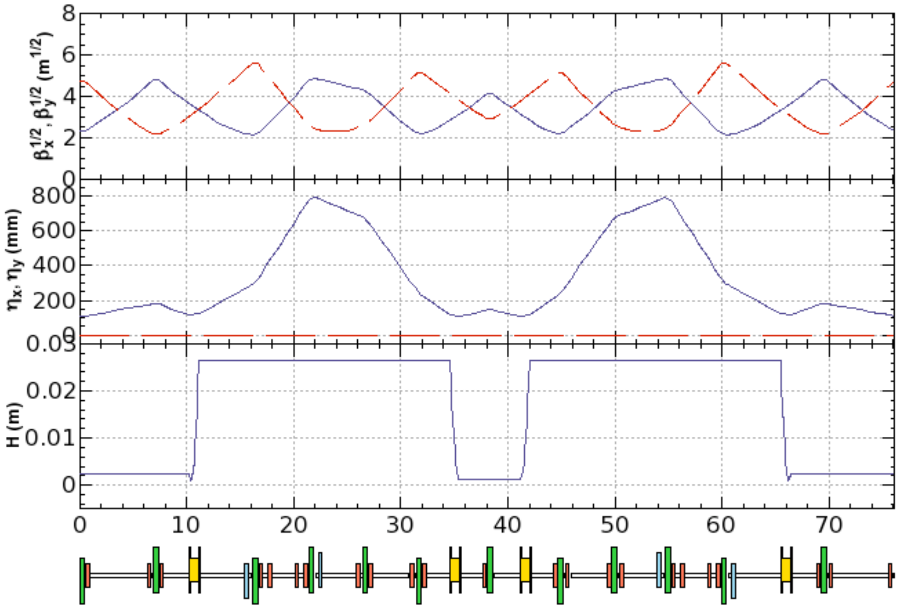
Appendix

LER Arc Cell

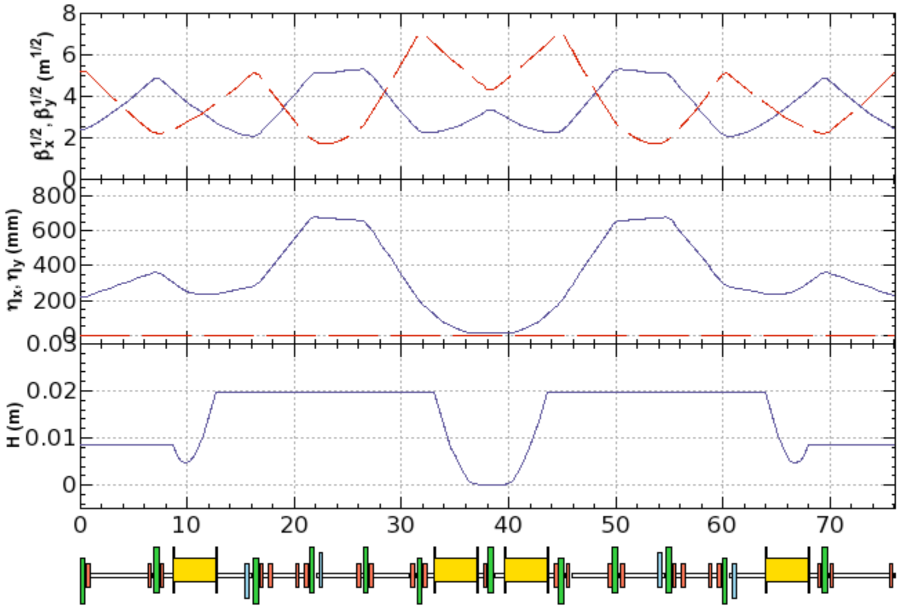
L= 0.89 m → 4 m



ε_x = 8.8 nm α_p = 3.3x10^{-4}

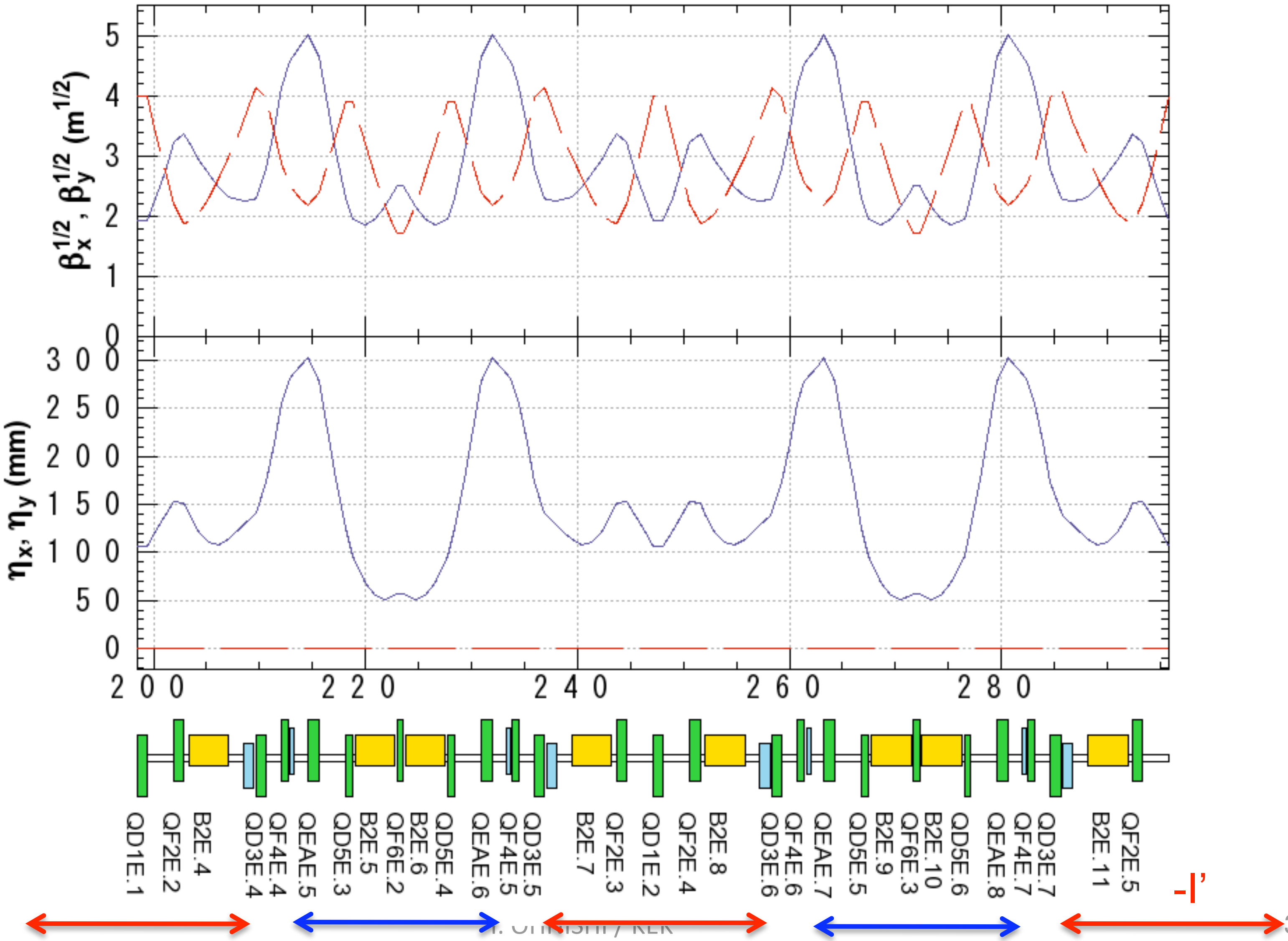


ε_x = 2 nm α_p = 4.4x10^{-4}

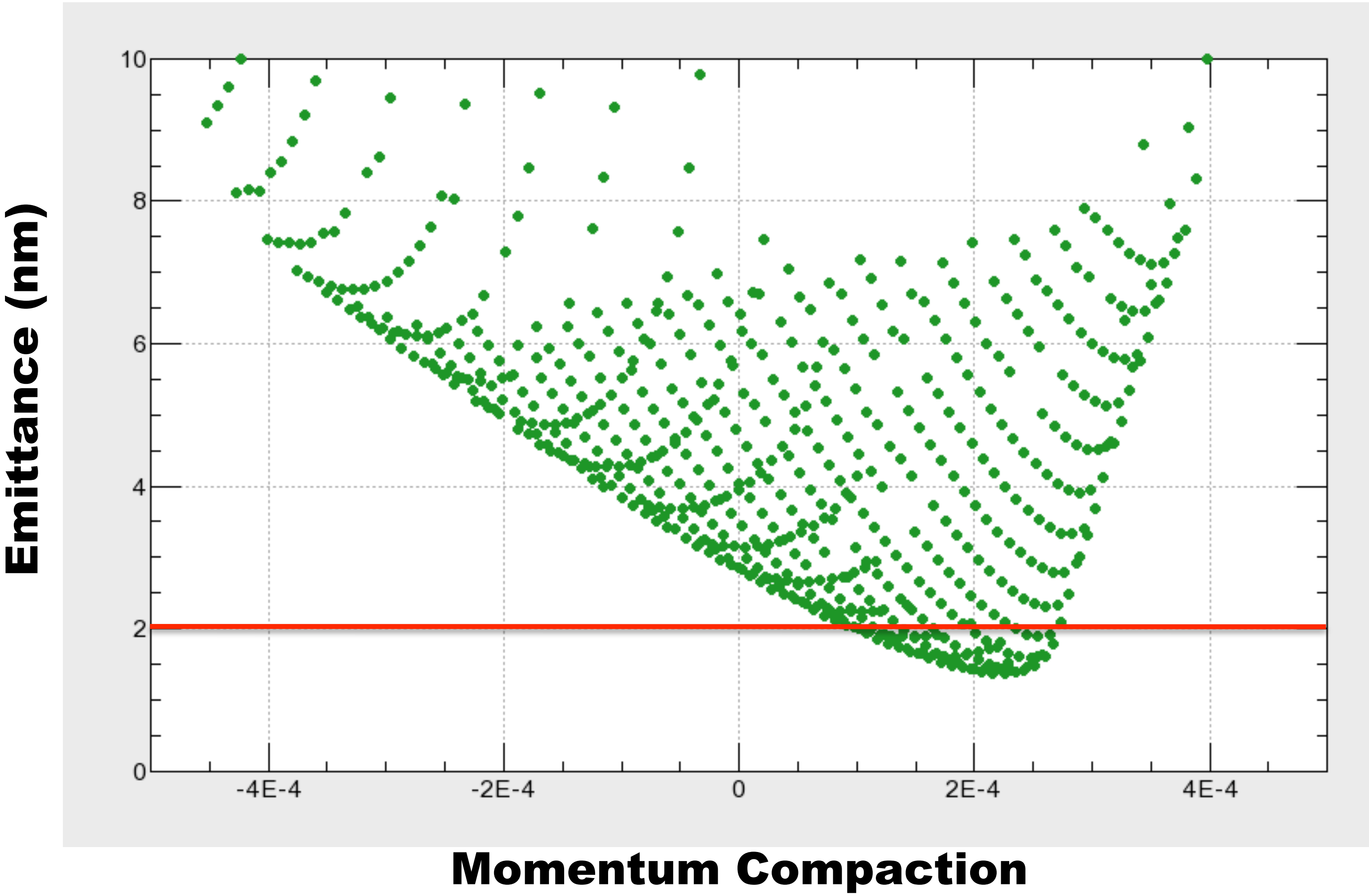


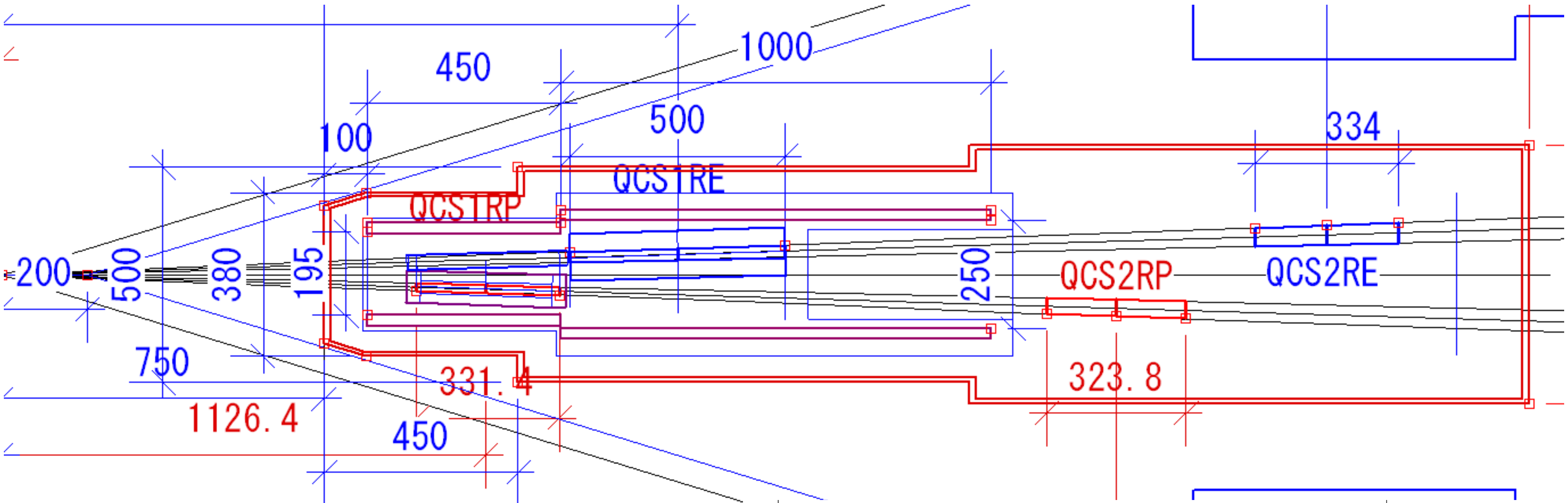
HER arc cell

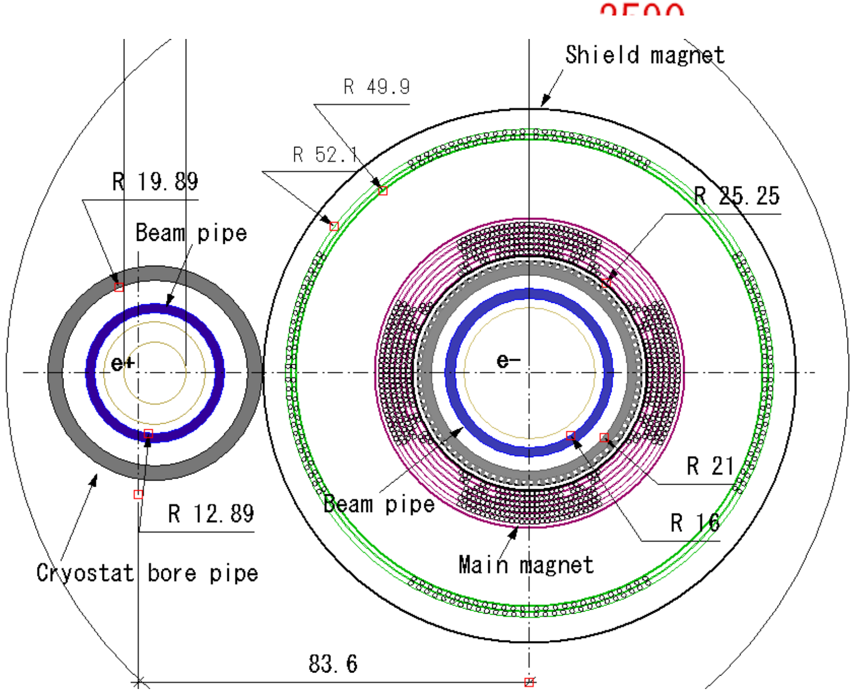
2.5π non-interleaved sextupole chromaticity correction

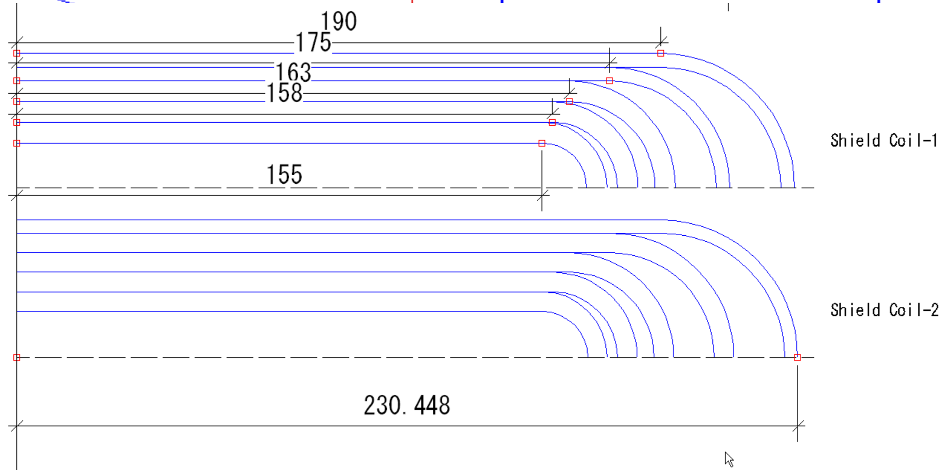


HER arc cell
#magnets increases by 60%



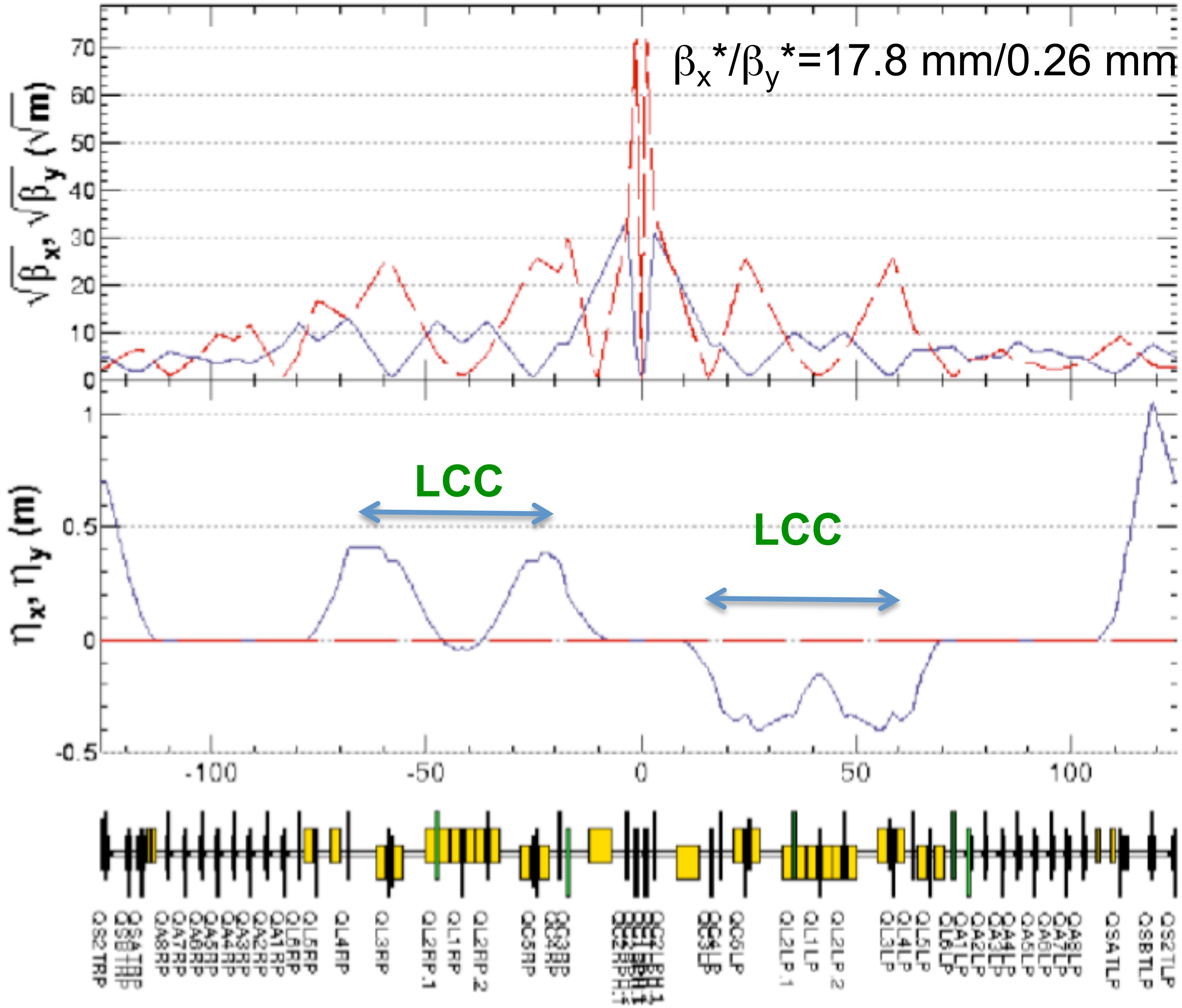






QCS1Pコイル長：305.93mm [磁石長370mm]
QCS1Eコイル長：460.896mm [磁石長500mm]
磁石位置（IPから）
QCS1P＝1126.4mm　(910mm : 5/1 optics)
QCS1E＝1571.4mm　(1460 mm)

LER IR optics



$\beta_y \sim$ 600m, $\eta_x \sim \pm$350mm @ L.C.C. Sextupole