July, 2015

Status of SuperKEKB Project

Accelerator Design and Construction Progress

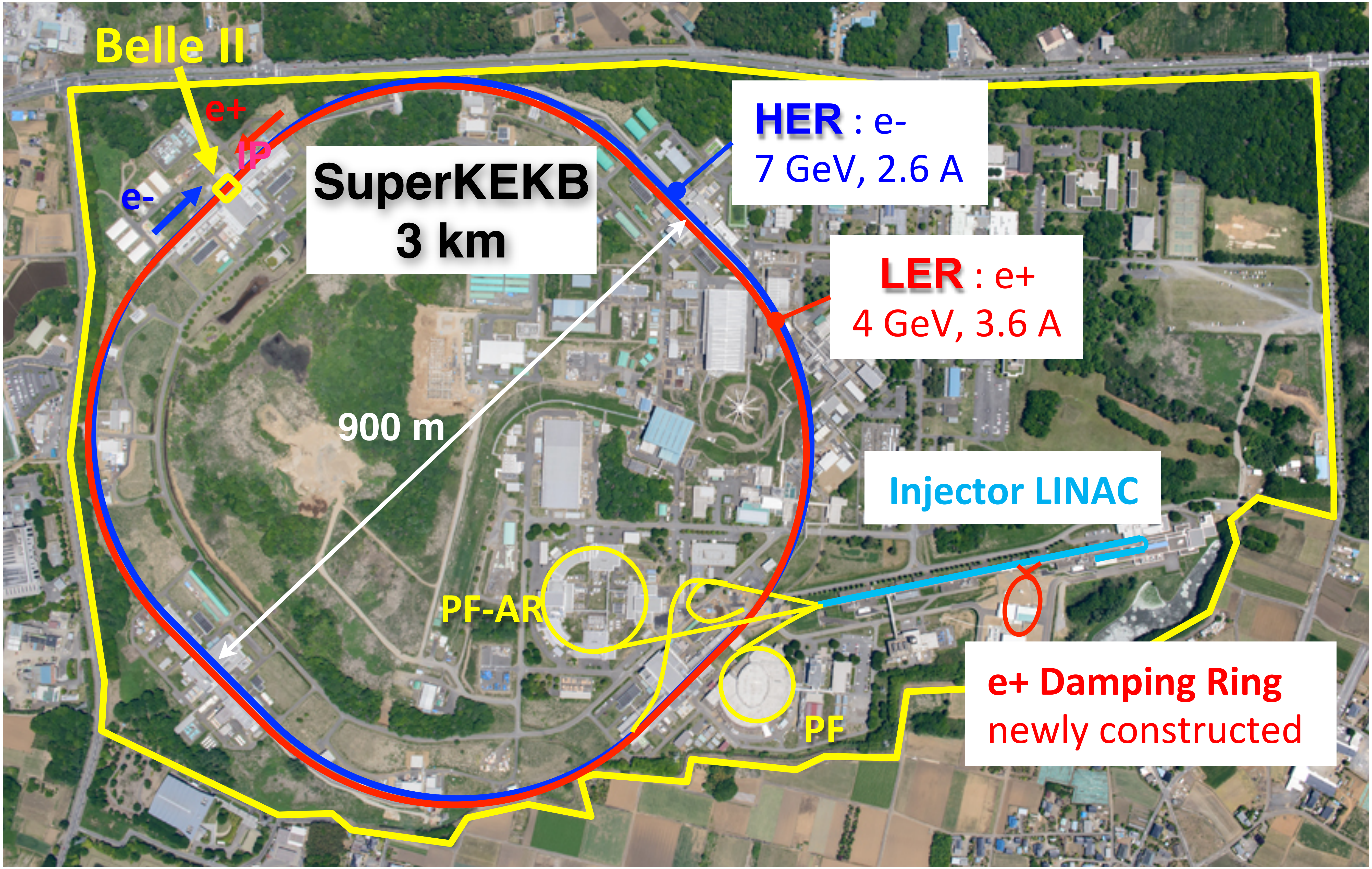
Y. Ohnishi / KEK

Where is KEK ?

Terrestrial globe by G. J. Blaeuw (1571-1638) in Vatican Museum

SuperKEKB Accelerator

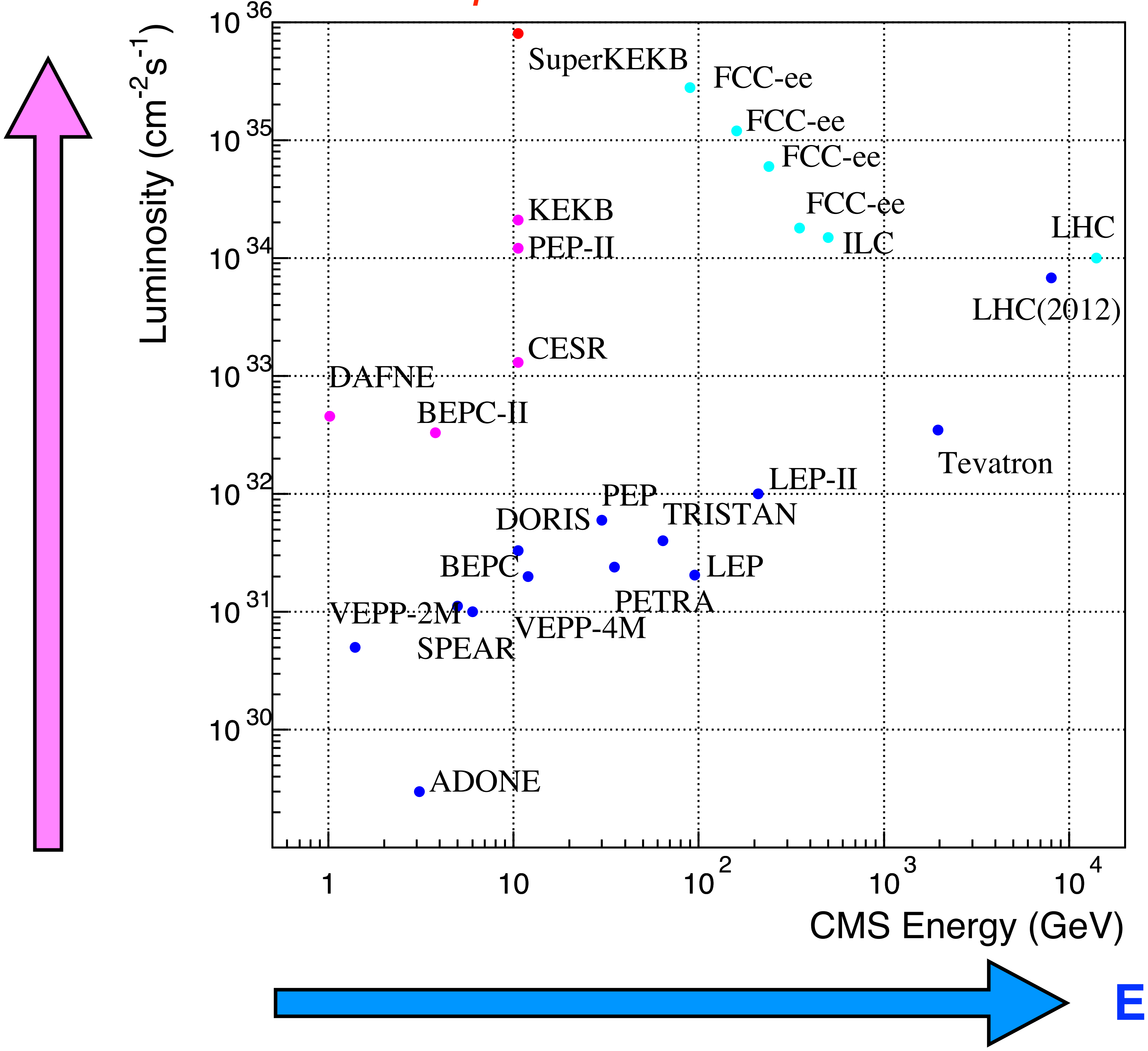
Target peak luminosity: 8 x 10^{35} cm^{-2} s^{-1}



Luminosity VS CMS Energy

Luminosity Frontier

SuperKEKB

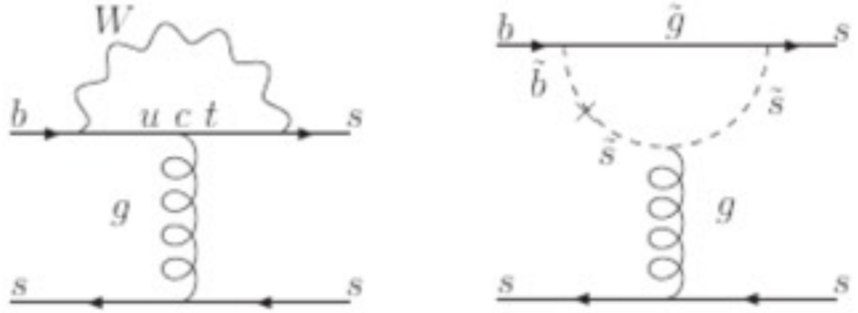


Energy Frontier

Why Luminosity Frontier ?

Number of physics events:

$$N = \int_0^T L\sigma dt$$



σ: Cross section determined by nature's law
L: Luminosity which we can improve with many efforts
T: Experimental period << human life-span

In the case of B meson production, σ is ~1 nb.
New physics will be much smaller than 1/10 - 1/100.

☞ 10 - 100 times luminosity larger than KEKB is necessary to explore new physics.

Origin of flavor structure
Naturalness
Dark matter and dark energy
Baryon symmetry in Universe
...

Strategy of Luminosity Upgrade

Beam-Beam parameter in the vertical direction:

$$\xi_{y\pm} = \frac{r_e}{2\pi\gamma_\pm} \frac{\beta^*_{y\pm} N_\mp}{\sigma^*_{y\mp}(\sigma^*_{x\mp} + \sigma^*_{y\mp})} R_{\xi y\pm}$$

Luminosity is expressed by using Beam-Beam parameter:

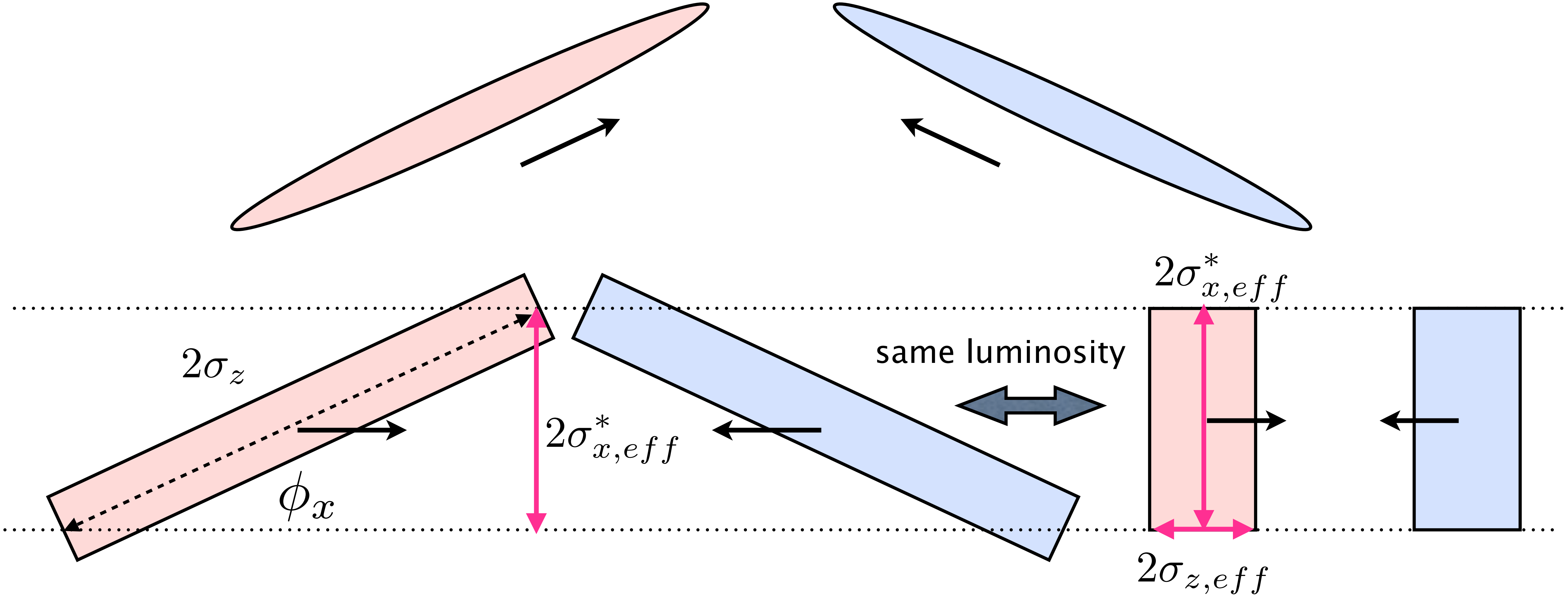
$$L = \frac{\gamma_\pm}{2er_e}(1+a)\boxed{\frac{\xi_{y\pm} I_\pm}{\beta^*_{y\pm}}}\left(\frac{R_L}{R_{\xi y}}\right) \qquad a = \frac{\sigma^*_y}{\sigma^*_x}$$

In order to get higher luminosity,

higher Beam-Beam parameter
higher beam current
smaller vertical beta function at IP

Nano-Beam Scheme

Laboratory frame to head-on frame with Lorentz boost: P. Raimondi et al.



Effective horizontal beam-spot size

$$\sigma_{x,eff} = \sigma_z \sin\phi_x$$

Effective bunch length

$$\sigma_{z,eff} = \frac{\sigma^*_x}{\sin\phi_x}$$

~300 μm in SuperKEKB

1/20 of KEKB

Hourglass Effect

The beta function at IP is restricted by hourglass effect:

$$\beta_y^* > \sigma_z$$

In the case of the nano-beam scheme, the bunch length is replaced with the effective bunch length:

$$\beta_y^* > \sigma_{z,eff} = \frac{\sigma_x^*}{\sin \phi_x}$$

~300 μm in SuperKEKB

1/20 of KEKB

$$2\phi_x = 83\ mrad$$

$$\sigma_x^* = \sqrt{\varepsilon_x \beta_x^*}$$

< 10 μm

Horizontal beam-spot is important.

$$\beta_x^* = 25 \sim 30\ mm \longrightarrow \varepsilon_x = 3 \sim 5\ nm$$

The beta function can be squeezed independent of the bunch length. Low emittance lattice is necessary.

Luminosity in Nano-Beam Scheme

Luminosity and Beam-Beam parameter formulae are modified as:

$$L = \frac{N_+ N_-}{4\pi\sigma^*_{x,eff}\sigma^*_y} f \qquad \xi_{y\pm} = \frac{r_e}{2\pi\gamma_\pm} \frac{\beta^*_{y\pm} N_\mp}{\sigma^*_y(\sigma^*_{x,eff} + \sigma^*_y)}$$

$$L = \frac{N_+ N_-}{4\pi\sigma_z \sin\phi_x \sigma^*_y} f \propto \frac{1}{\sin\phi_x \sqrt{\boxed{\varepsilon_y \beta^*_y}}}$$

σ_y^* = 48 - 62 nm in SuperKEKB

When the vertical emittance and beta at IP are same for each:

$$\varepsilon_y = \varepsilon_{y+} = \varepsilon_{y-}$$

$$\beta^*_y = \beta^*_{y+} = \beta^*_{y-}$$

$$\xi_{y\pm} \simeq \frac{r_e}{2\pi\gamma_\pm} \sqrt{\frac{\beta^*_y}{\varepsilon_y}} \frac{N_\mp}{\sigma_z \sin\phi_x} \propto \frac{1}{\sin\phi_x} \sqrt{\boxed{\frac{\beta^*_y}{\varepsilon_y}}} \qquad (15)$$

If we make ε_y and β_y^* small with keeping the ratio of β_y^* to ε_y, the luminosity increases with a constant Beam-Beam parameter.

Horizontal Beam-Beam Parameter

On the other hand,

$$\xi_{x\pm} = \frac{r_e}{2\pi\gamma_\pm} \frac{\beta^*_{x\pm} N_\mp}{\sigma^*_x(\sigma^*_x + \sigma^*_y)}$$

In the case of the nano-beam scheme:

$$\xi_{x\pm} \simeq \frac{r_e}{2\pi\gamma_\pm} \frac{\beta^*_{x\pm} N_\mp}{(\sigma_z \sin\phi_x)^2}$$

When we make emittance small, the horizontal Beam-Beam parameter does not increase.

$$\xi_x \sim 0.001 - 0.003$$

The dynamic effect such as beta-beat due to Beam-Beam effect becomes very small.

Strategy of Luminosity Upgrade

	KEKB		SuperKEKB		Luminosity gain
	LER	HER	LER	HER	
ξ_y	0.129	0.09	0.088	0.081	x 1
β_y^* [mm]	5.9	5.9	0.27	0.30	x 20
I [A]	1.64	1.19	3.6	2.6	x 2
L [$\mathrm{cm^{-2}s^{-1}}$]	2.1×10^{34}		8×10^{35}		x 40

Key Items

- **Final focus system**
  - Superconducting magnets
  - Small dynamic aperture: Shorter Touschek lifetime
- **Low emittance lattice**
  - Arc cells and wigglers
  - Shorter Touschek lifetime: **Powerful injector** is necessary.
- Very small vertical emittance, less than ~10 pm with including Beam-Beam effect, electron cloud, and machine error.
  - $\varepsilon_y/\varepsilon_x$ = 0.27 - 0.28 %
- **Reinforcement of RF system**
- **Ante-chamber to suppress electron cloud in positron ring**

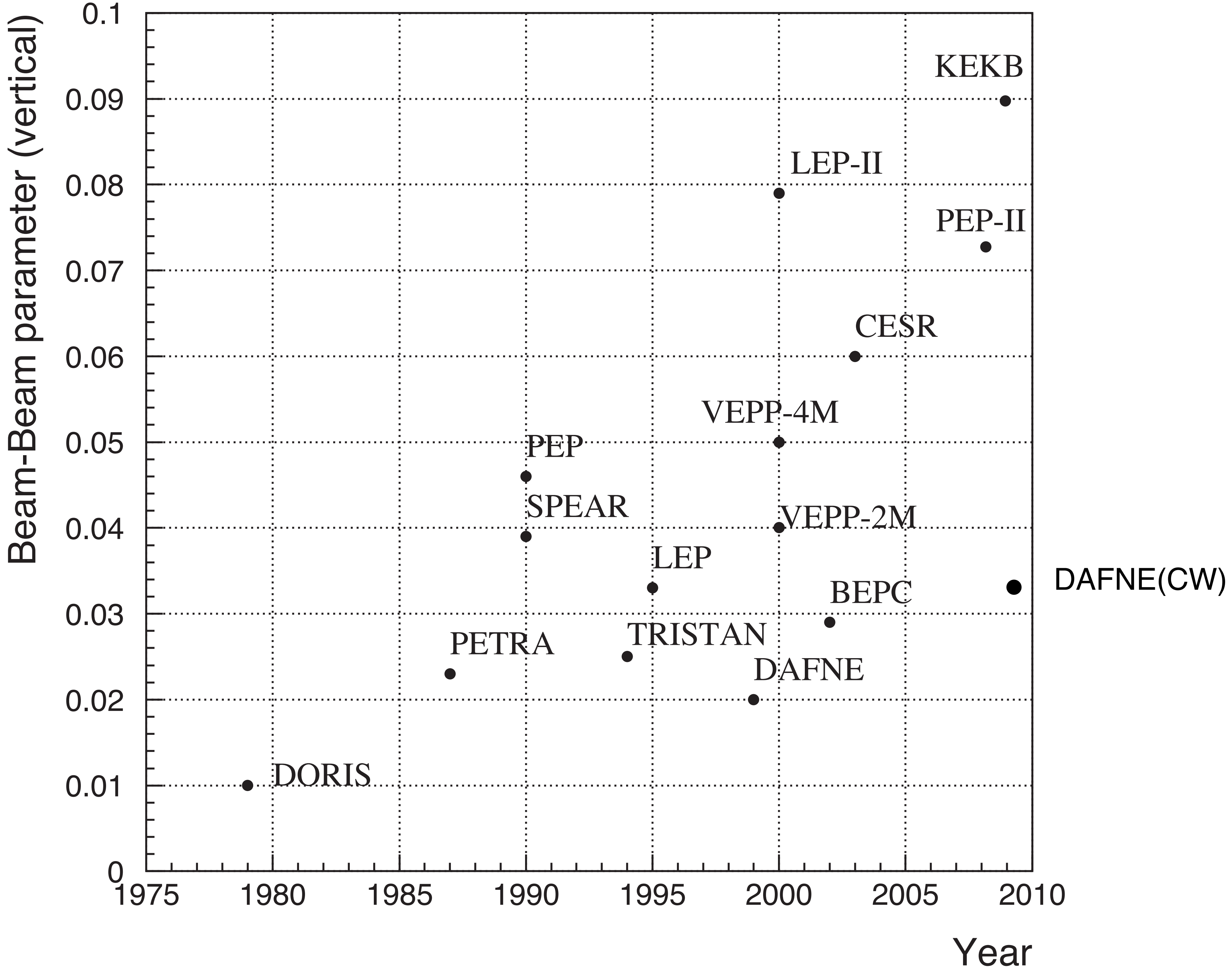
Machine Parameters

2013/July/29	LER	HER	unit	
E	4.000	7.007	GeV	
I	3.6	2.6	A	
Number of bunches	2,500			
Bunch Current	1.44	1.04	mA	
Circumference	3,016.315		m	
$\varepsilon_x/\varepsilon_y$	3.2(1.9)/8.64(2.8)	4.6(4.4)/12.9(1.5)	nm/pm	():zero current
Coupling	0.27	0.28	%	includes beam-beam
β_x^*/β_y^*	32/0.27	25/0.30	mm	
Crossing angle	83		mrad	
α_p	$3.18\text{x}10^{-4}$	$4.53\text{x}10^{-4}$		
σ_δ	$8.10(7.73)\text{x}10^{-4}$	$6.37(6.30)\text{x}10^{-4}$		():zero current
V_c	9.4	15.0	MV	
σ_z	6.0(5.0)	5(4.9)	mm	():zero current
ν_s	−0.0244	−0.0280		
ν_x/ν_y	44.53/46.57	45.53/43.57		
U_0	1.86	2.43	MeV	
$\tau_{x,y}/\tau_s$	43.2/21.6	58.0/29.0	msec	
ξ_x/ξ_y	0.0028/0.0881	0.0012/0.0807		
Luminosity	$8\text{x}10^{35}$		$\mathrm{cm}^{-2}\mathrm{s}^{-1}$	

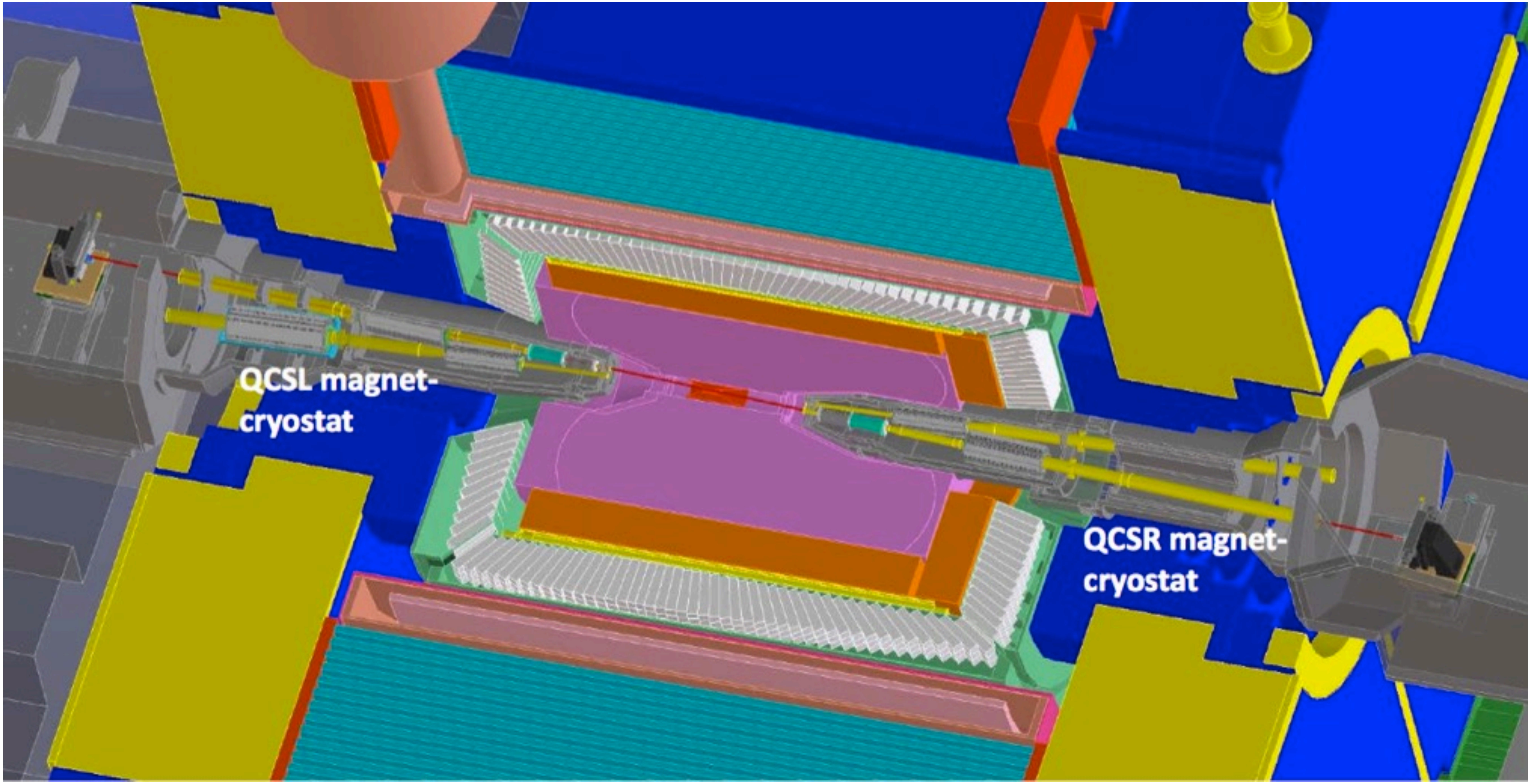
Why Beam-Beam Parameter < 0.09 ?

The assumption is based on our experiences.

Beam-Beam parameter is improving year by year.

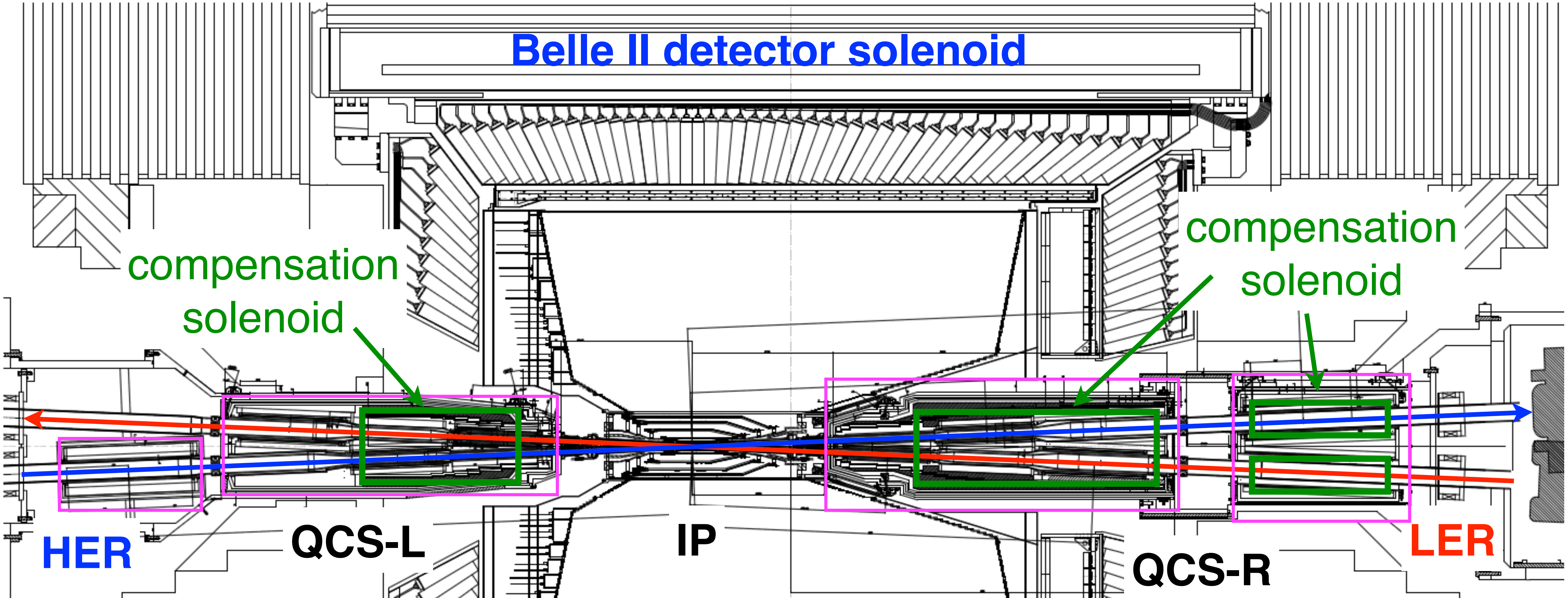


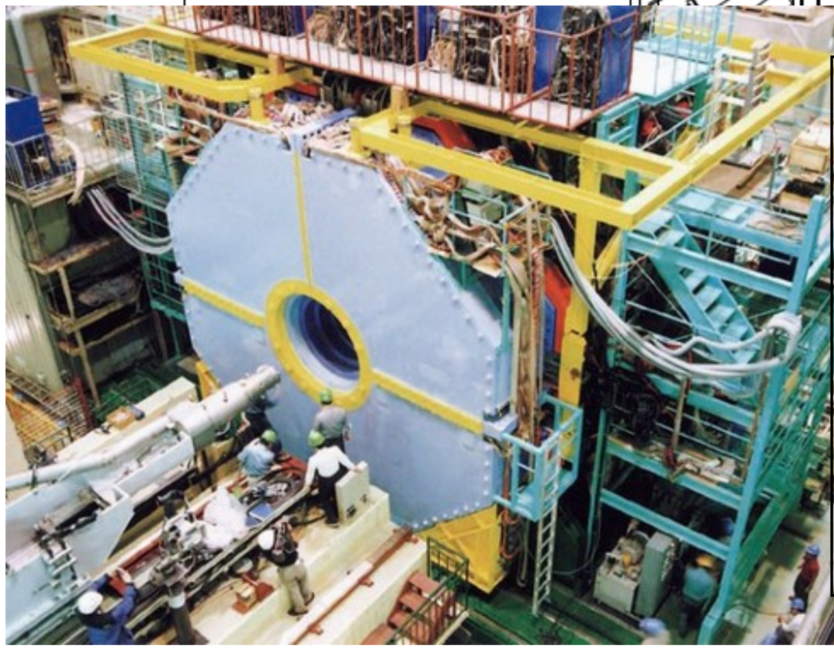
Interaction Region

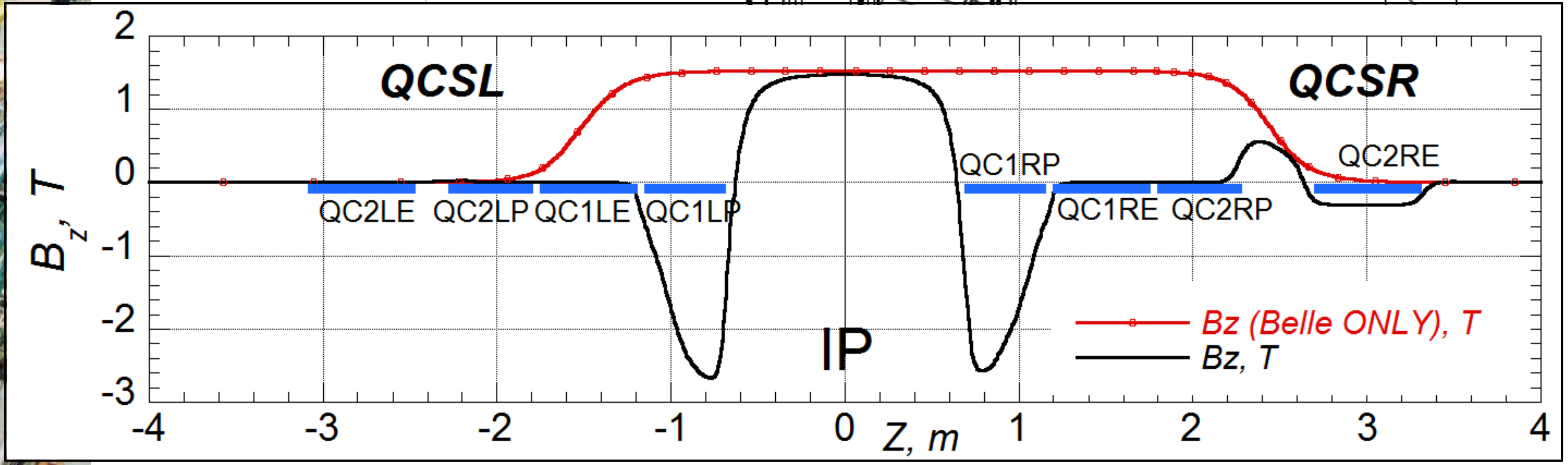


Interaction region: Superconducting Magnets

1.5 Tesla detector solenoid



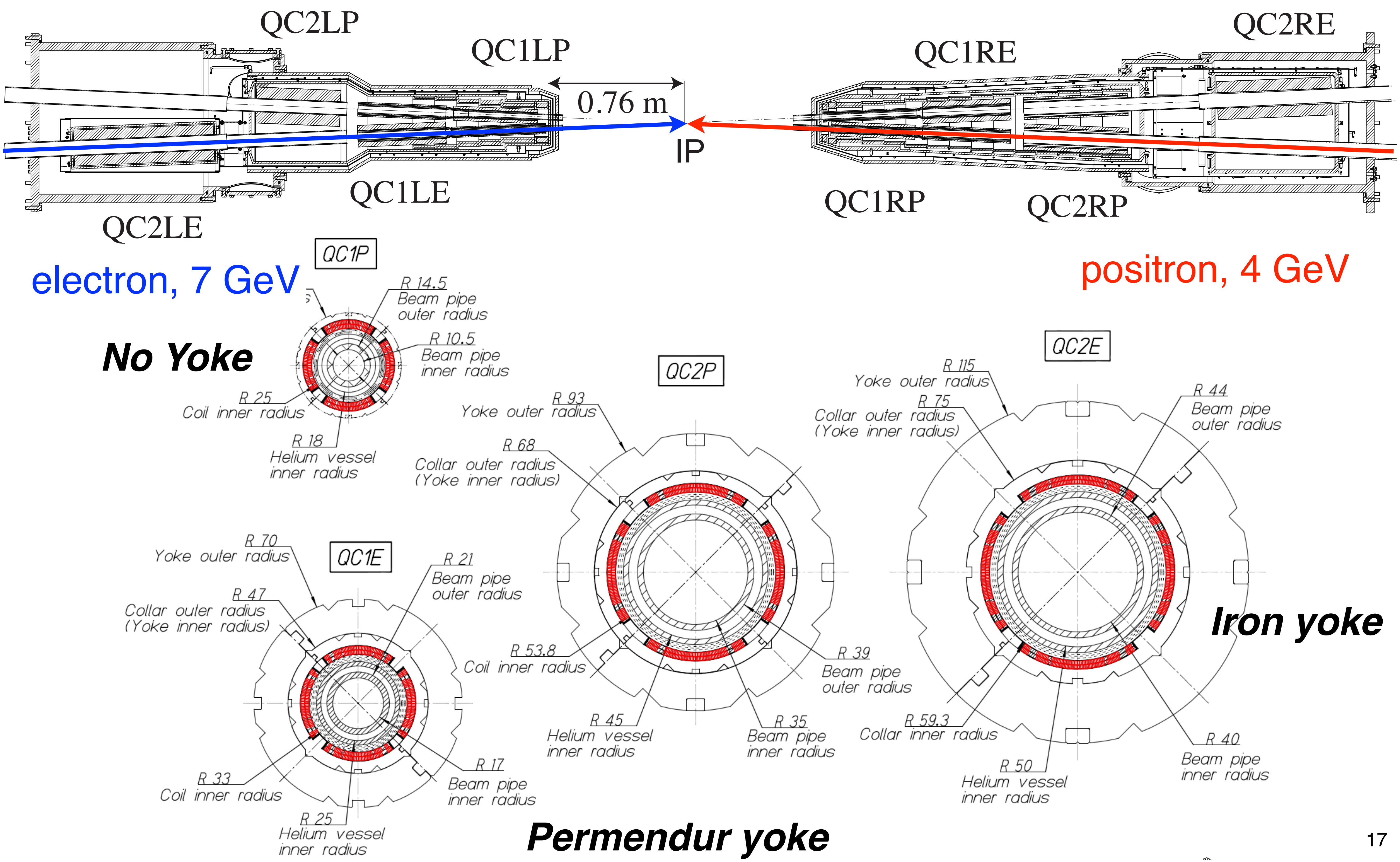




How to squeeze Beta Functions at IP ?

doublet

Top-view



electron, 7 GeV

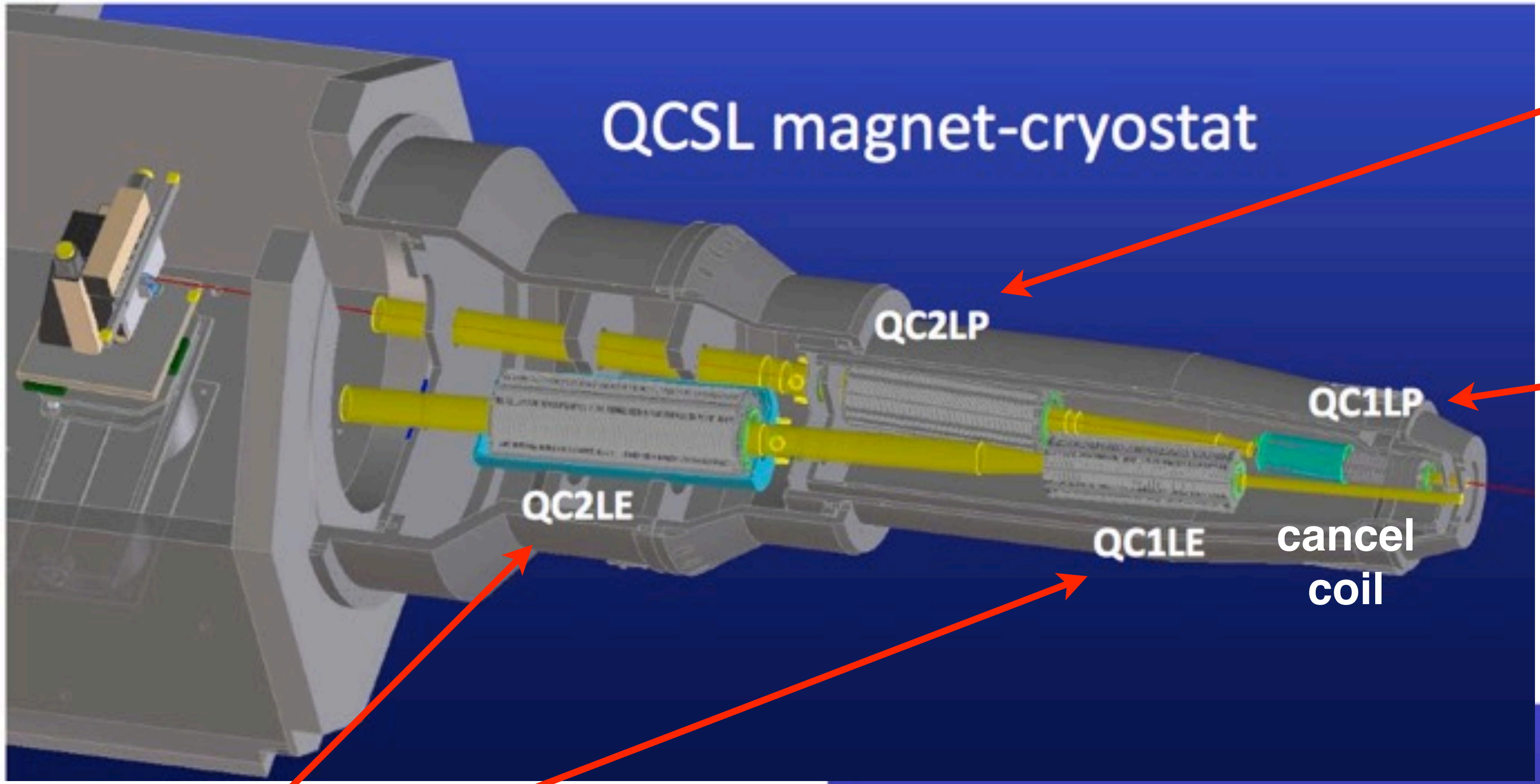
positron, 4 GeV

No Yoke

Iron yoke

Permendur yoke

Final Focus Magnets

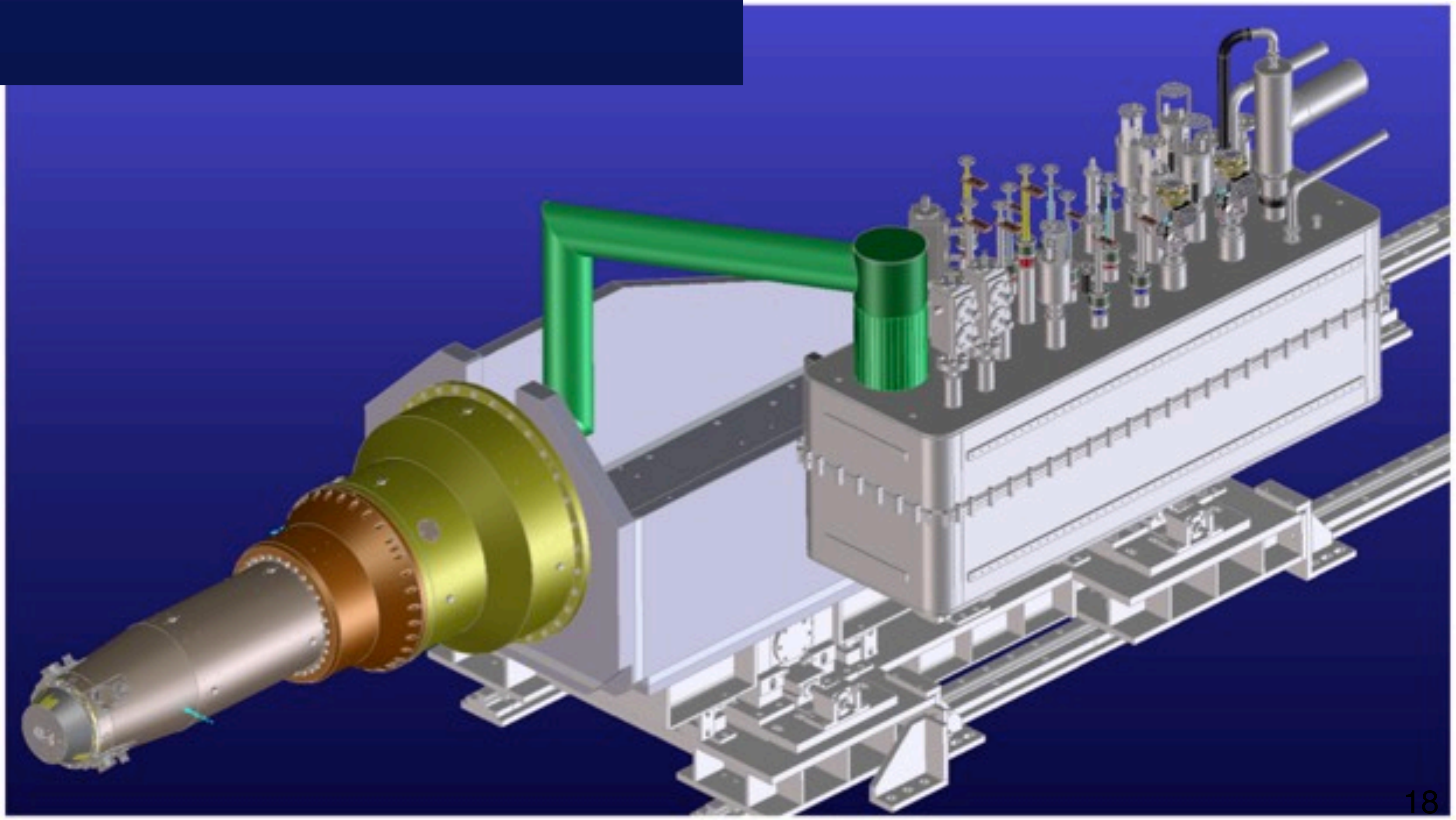


QC2P: $B_2L/r_0 = 11.4$ [T]
r_0=30 [mm], 877.4 [A]

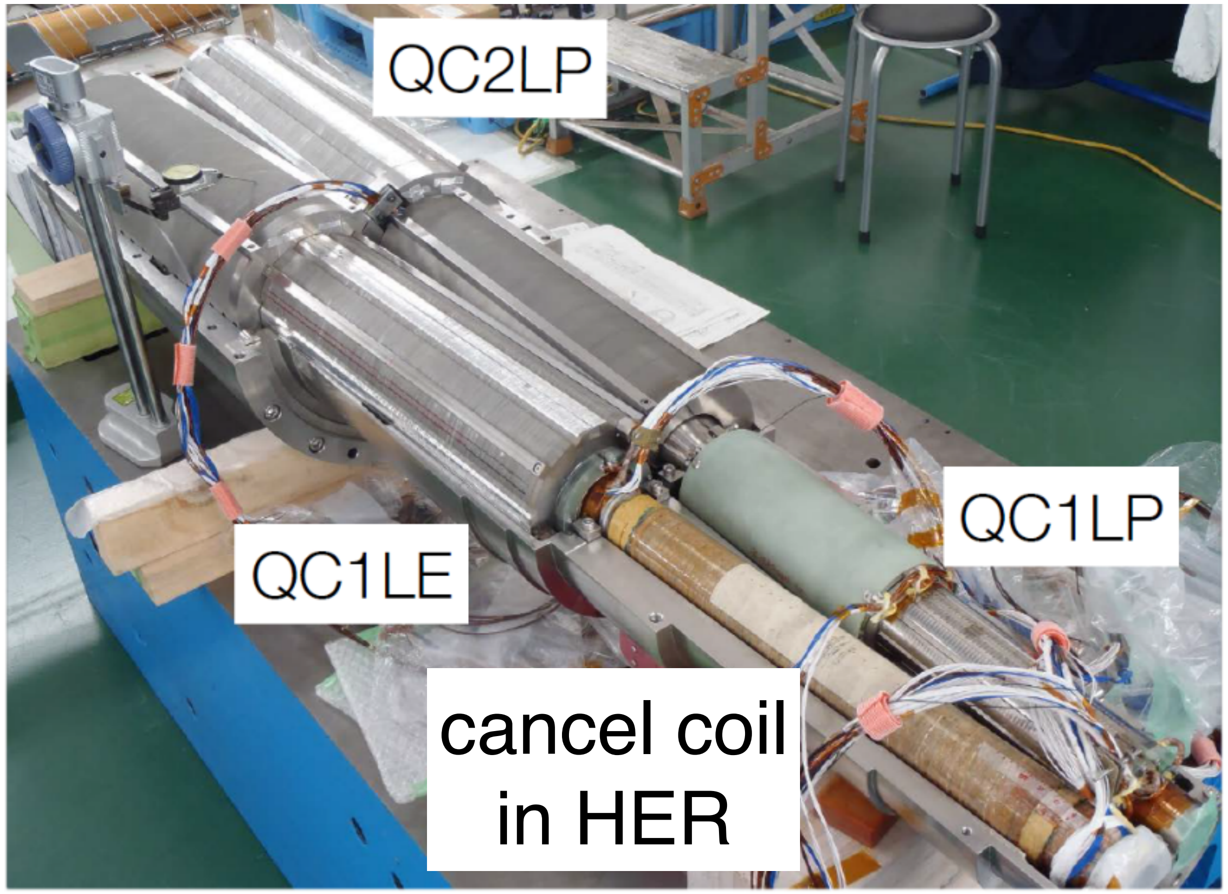
QC1P: $B_2L/r_0 = 22.9$ [T]
r_0=10 [mm], 1624.9 [A]

QC1E: $B_2L/r_0 = 26.9$ [T]
r_0=15 [mm], 1577.1 [A]

QC2E: $B_2L/r_0 = 15.2$ [T]
r_0=35 [mm], 976.95 [A]

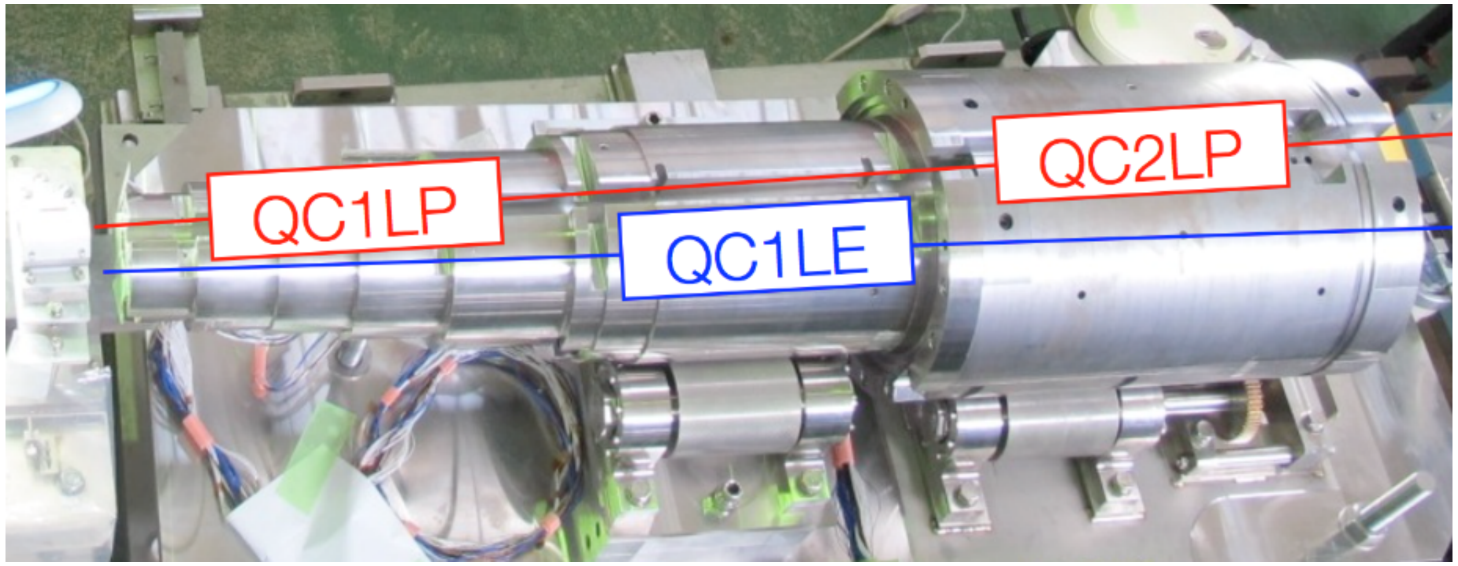


Construction of Final Focus Magnets



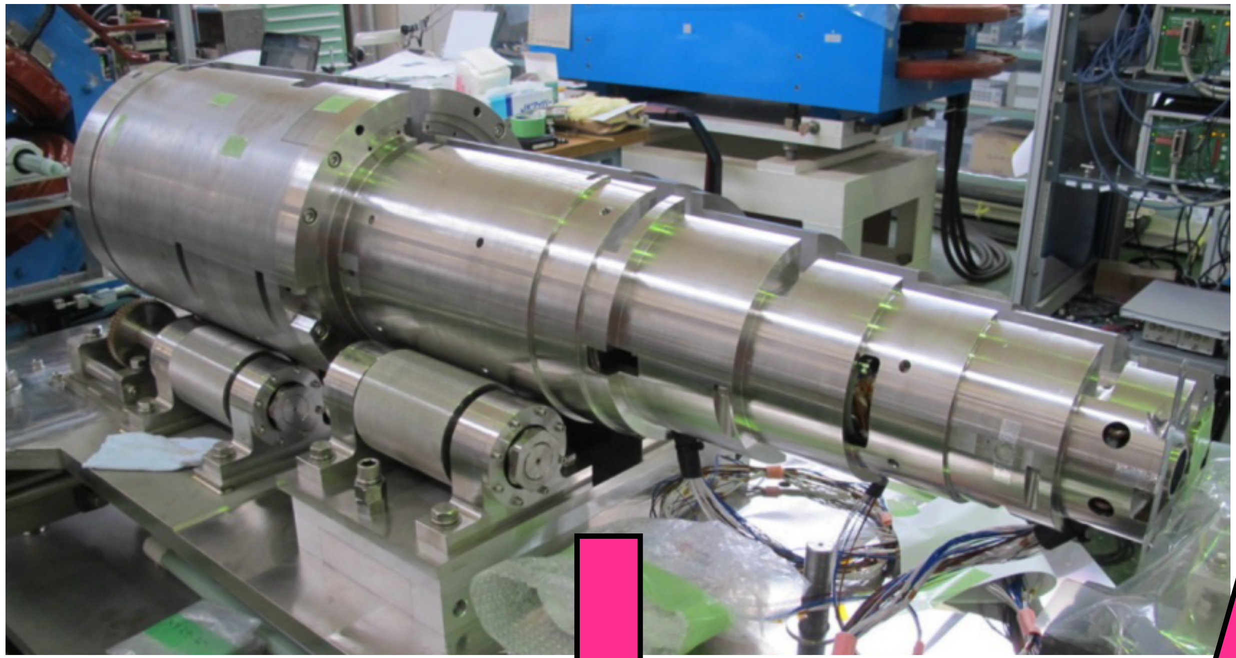
cancel coil correct leakage fields of sext, oct, deca, dodecapole.

Dipole and quadrupole are used in the lattice design.



Assemble of left-side final focus magnets has been finished.

Construction of Final Focus System



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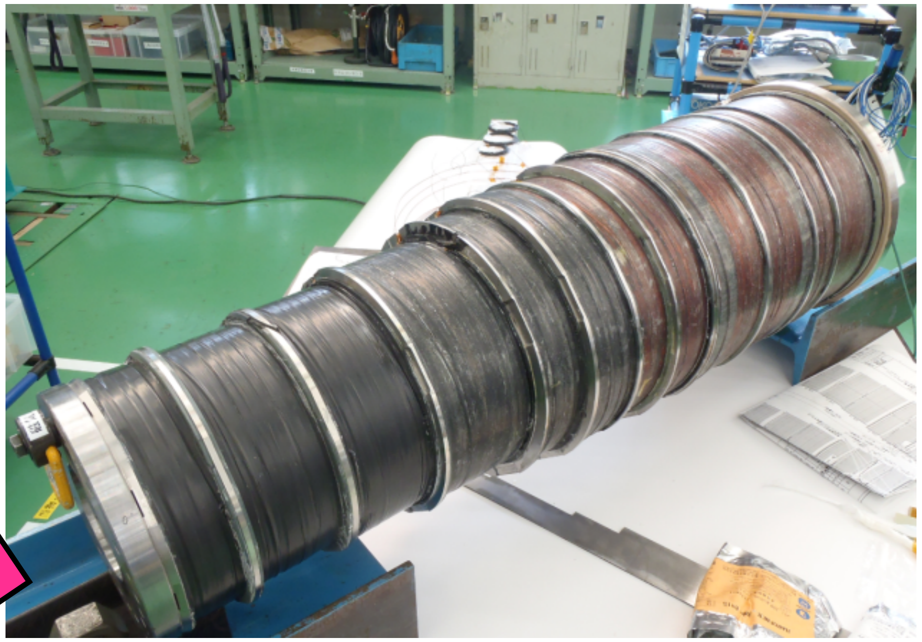
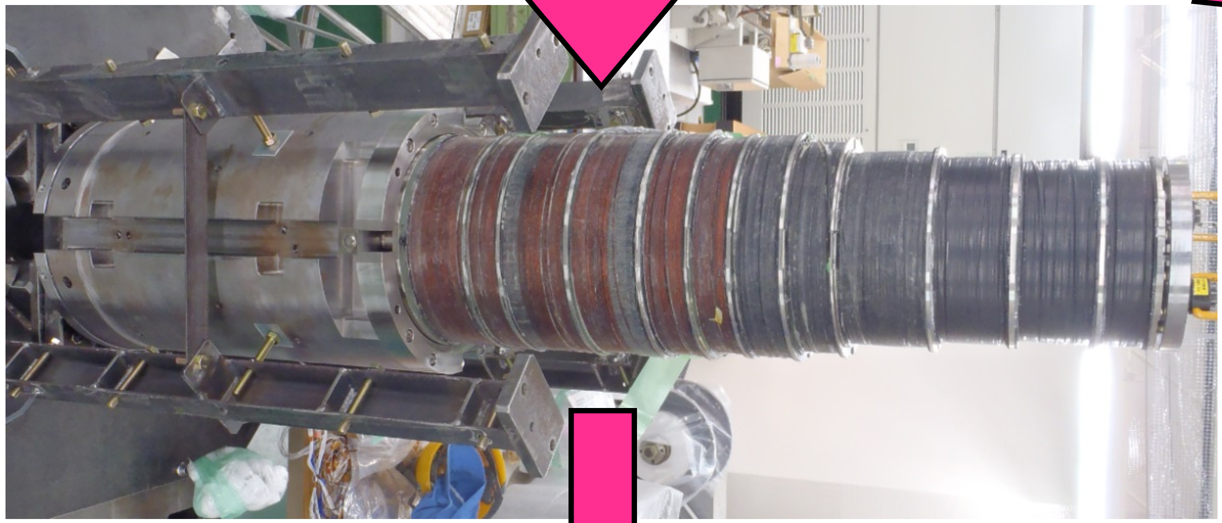
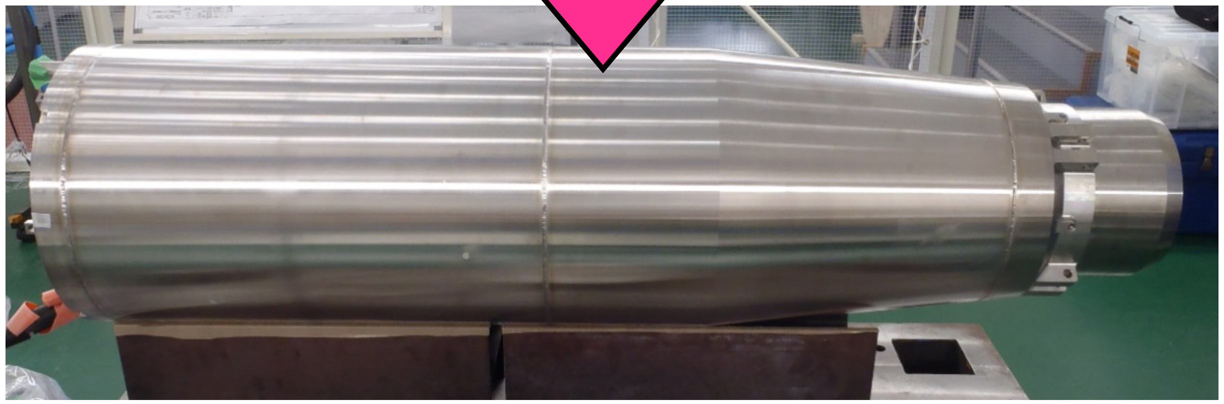


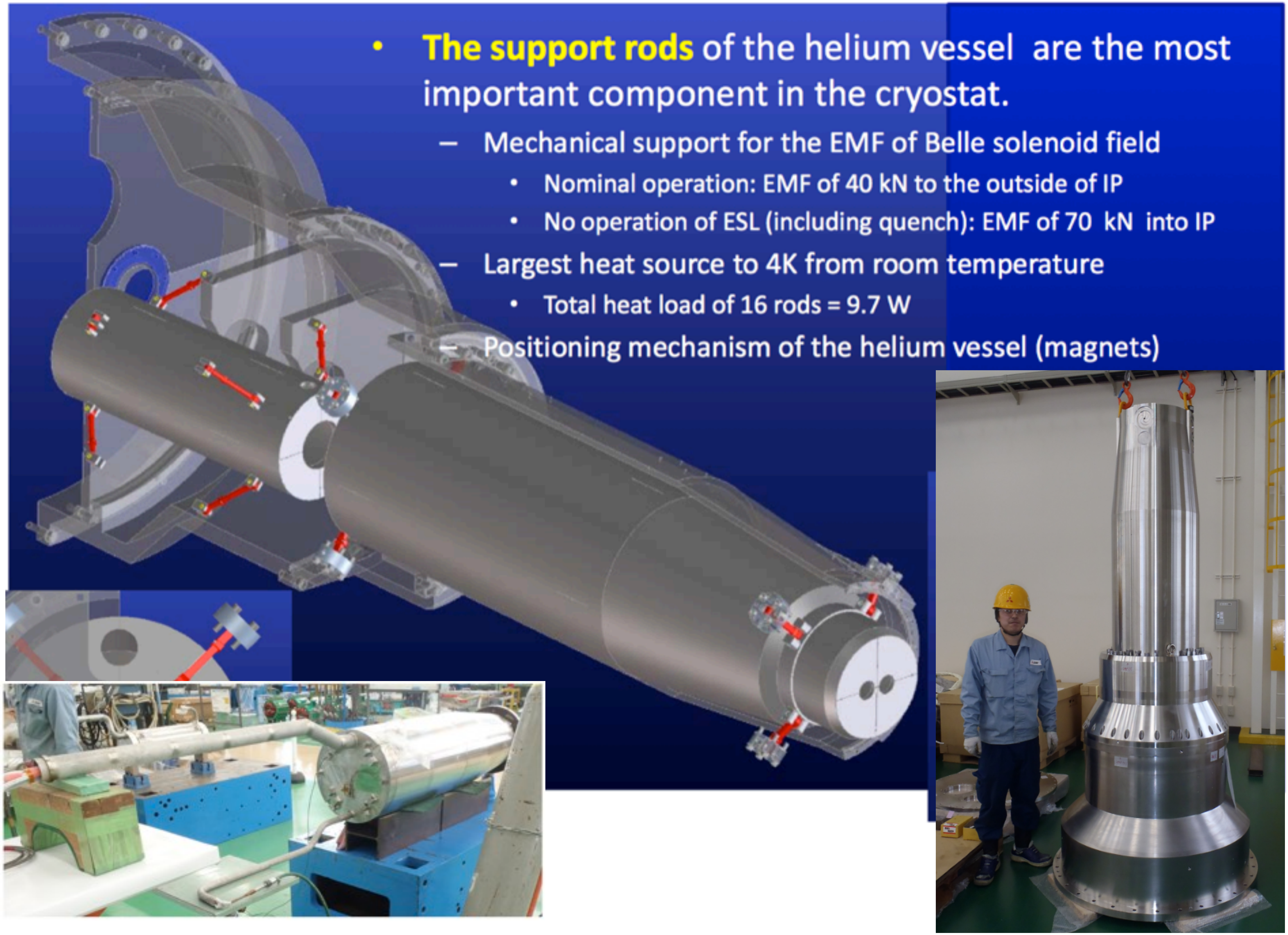
Compensation Solenoid





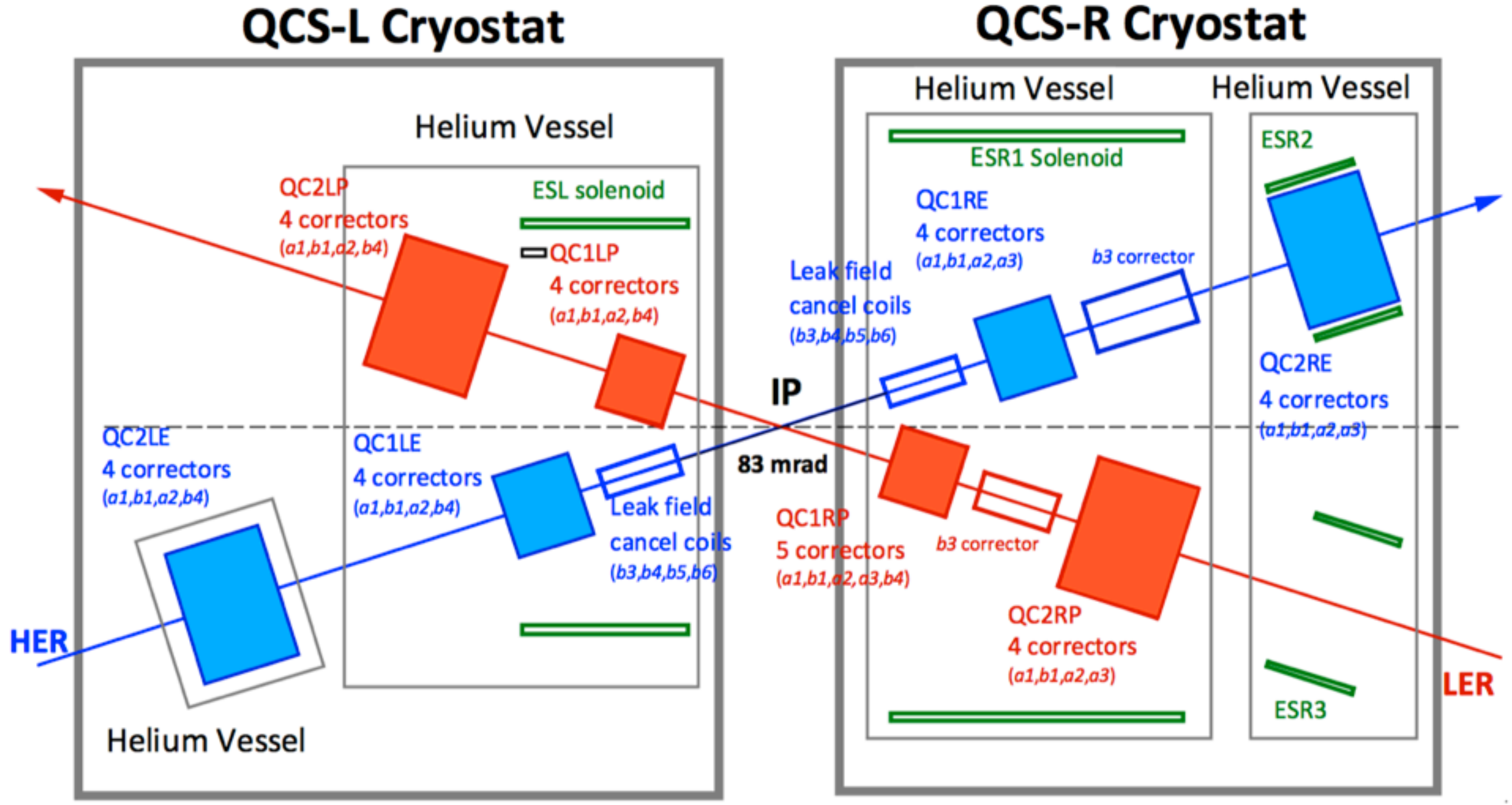
Liquid Helium Vessel

Cryostat



- **The support rods** of the helium vessel are the most important component in the cryostat.
  - Mechanical support for the EMF of Belle solenoid field
    - Nominal operation: EMF of 40 kN to the outside of IP
    - No operation of ESL (including quench): EMF of 70 kN into IP
  - Largest heat source to 4K from room temperature
    - Total heat load of 16 rods = 9.7 W
  - Positioning mechanism of the helium vessel (magnets)

Corrector Coils in Final Focus System



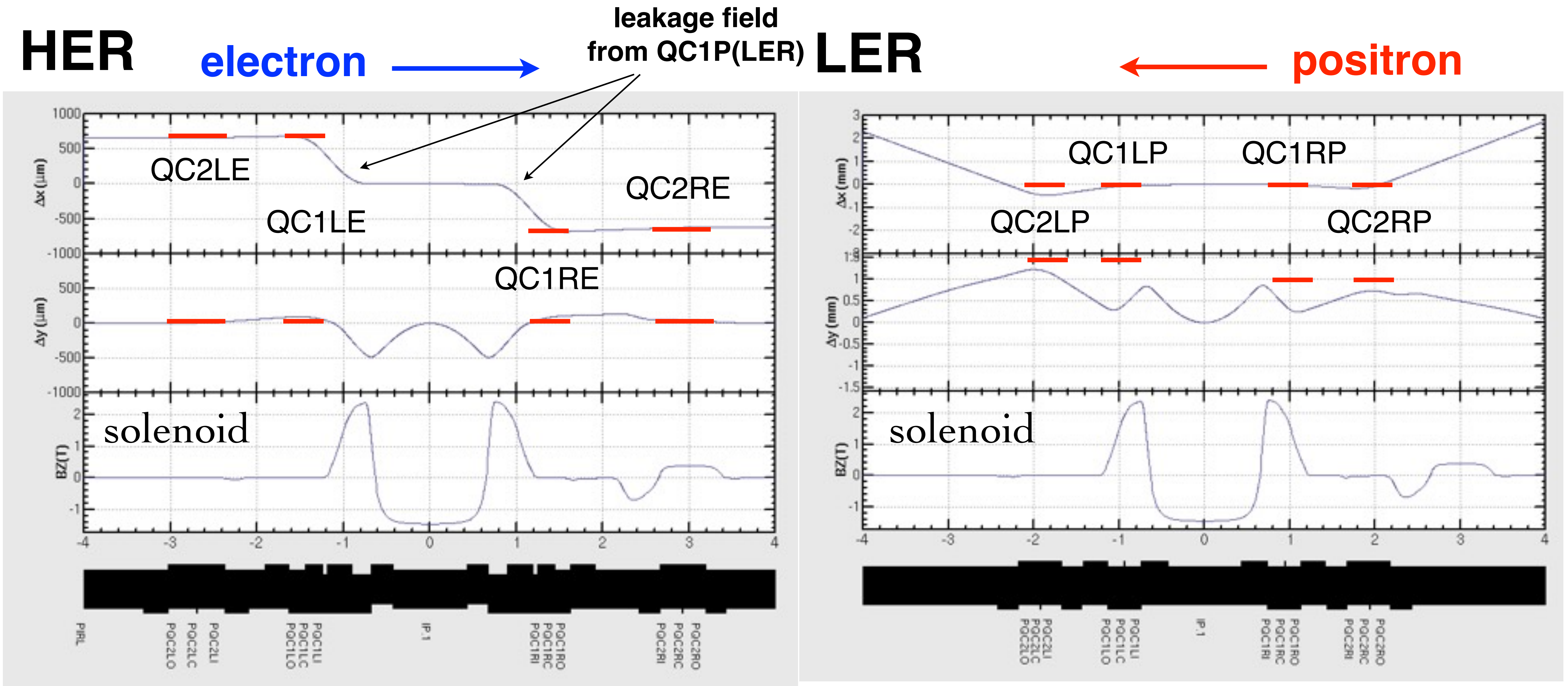
a1, b1, a2, b4

to optimize dynamic aperture

a1, b1, a2, a3

to correct a3 error field

Orbit in the vicinity of IP



offset/rot.	QC2LE	QC1LE	QC1RE	QC2RE
Δx (mm)	+0.7	+0.7	-0.7	-0.7
Δθ (mrad)	0	0	0	0

offset/rot.	QC2LP	QC1LP	QC1RP	QC2RP
Δy (mm)	+1.5	+1.5	+1.0	+1.0
Δθ (mrad)	-3.725	-13.65	+7.204	-2.114

QC1/QC2 offset is adopted to control the orbit with weaker corrector field.

Slice model of 1 cm thickness is used for the optics calculation for IR.

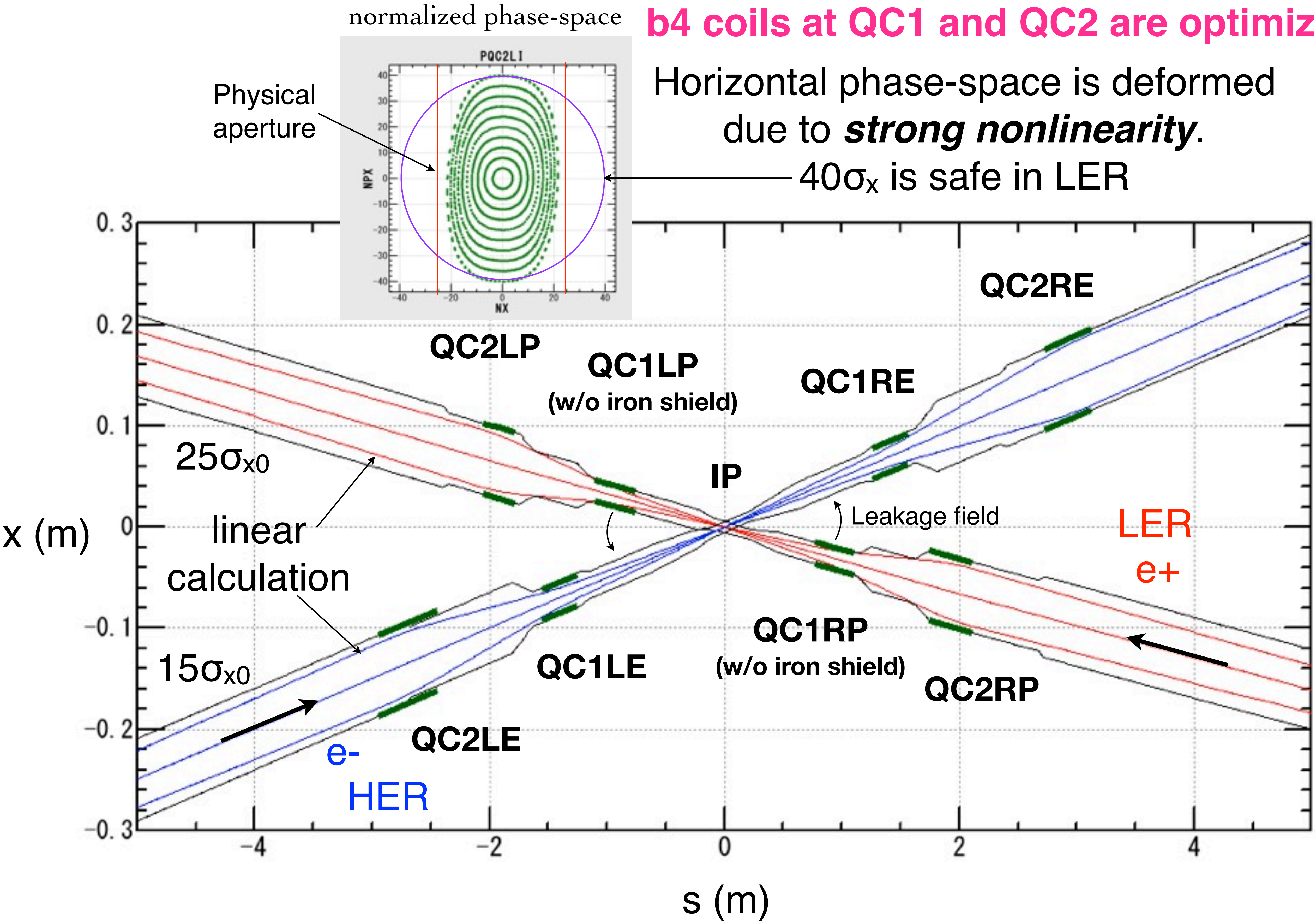
Each slice has Maxwellian fringe and up to b_{22} and a_{22}.

Beam envelope for design parameters

b4 coils at QC1 and QC2 are optimized.

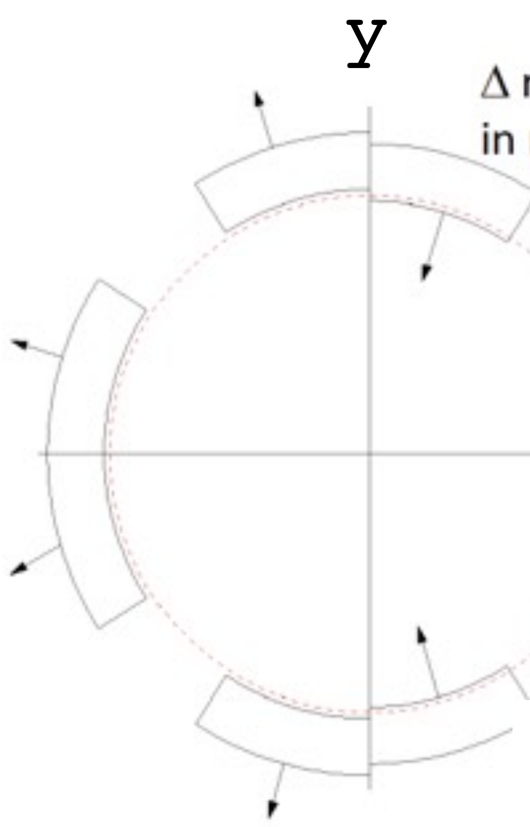
Horizontal phase-space is deformed due to ***strong nonlinearity***.

$40\sigma_x$ is safe in LER



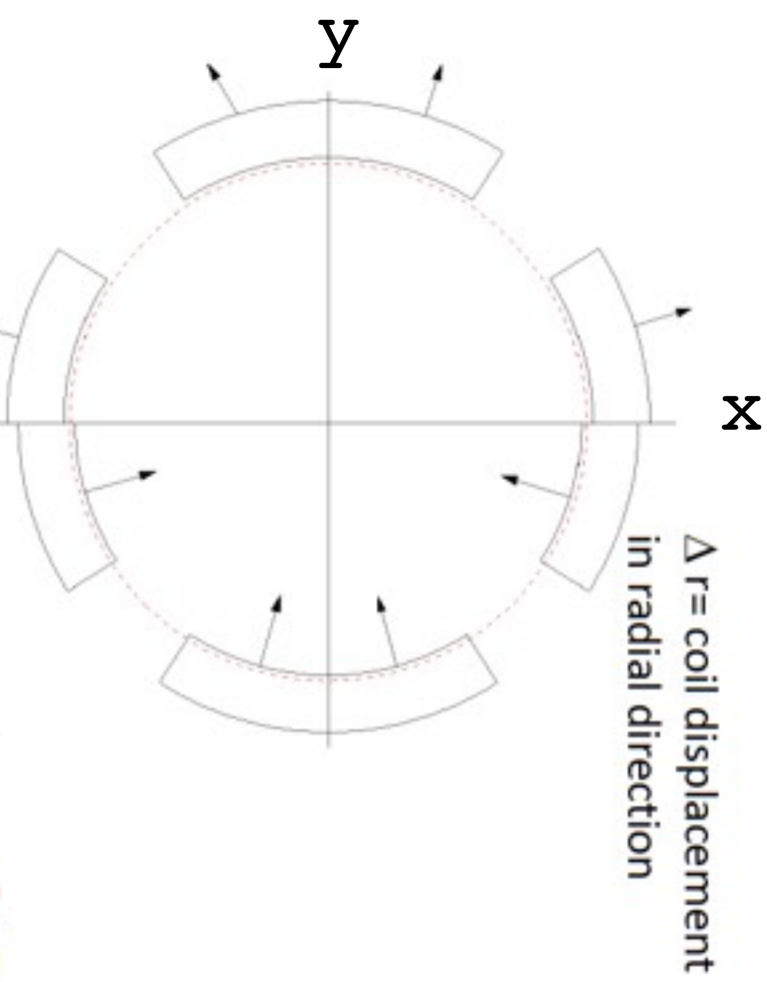
Misalignment of quadrupole coils in QC1 and QC2

Sextupole field



Δ r= coil displacement in radial direction

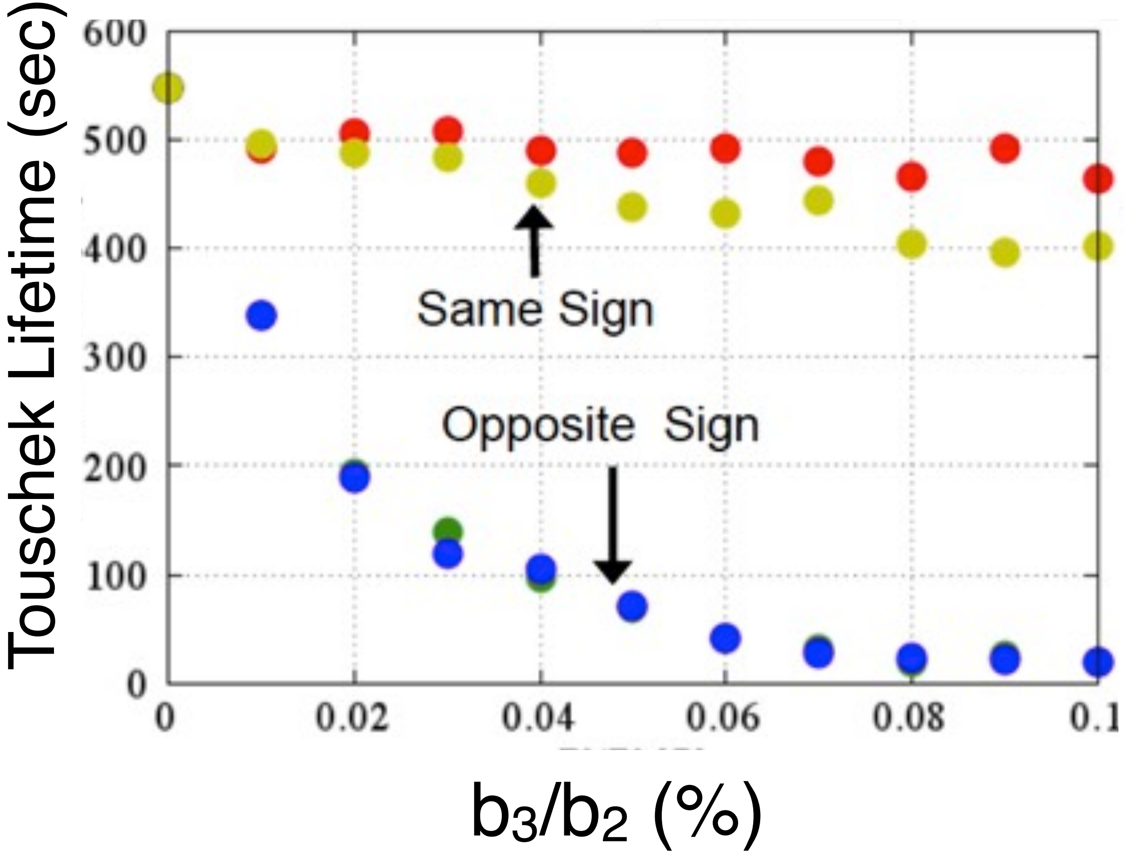
Skew sextupole field

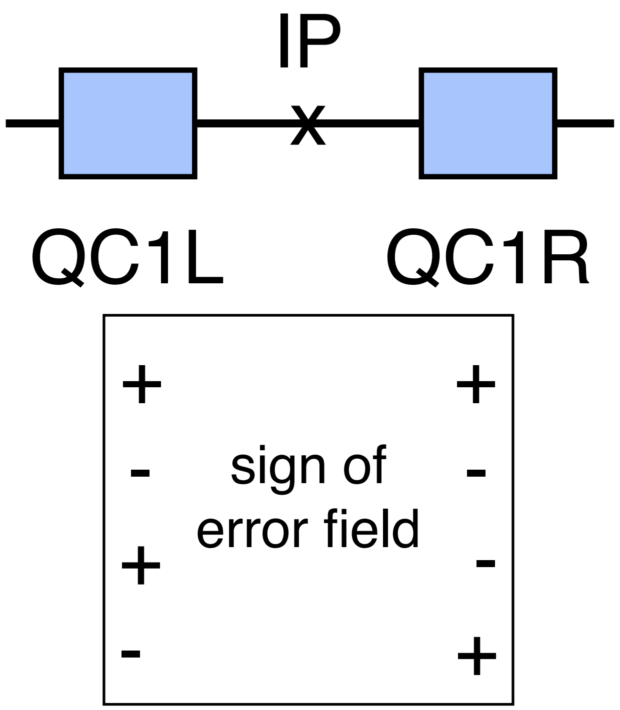


Δr=35 μm induces 0.1 % of b_3/b_2.

b_3 ~7 Gauss

without any corrections



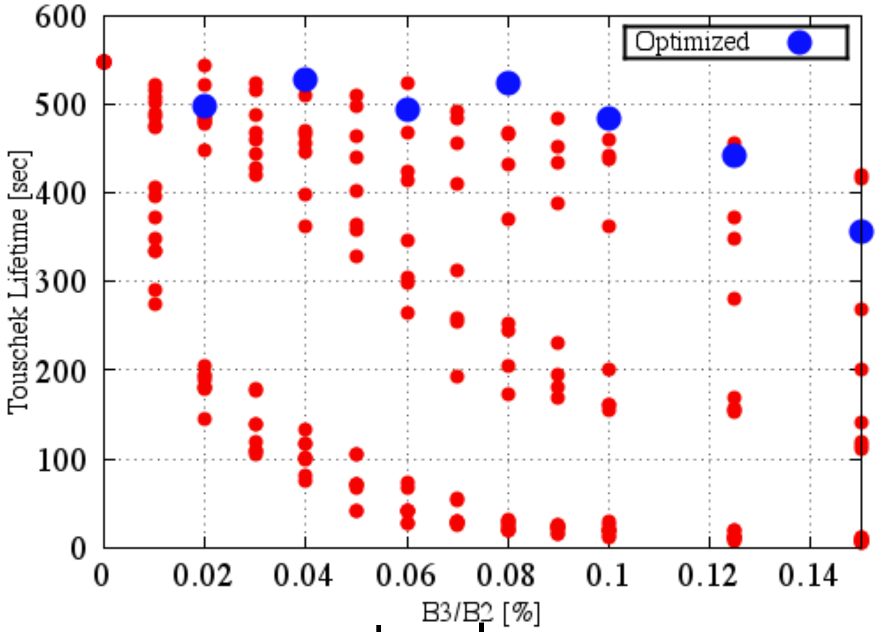


Sextupole Error Field: Normal and Skew

Touschek lifetime for 16 combinations of field error in 4 QCs

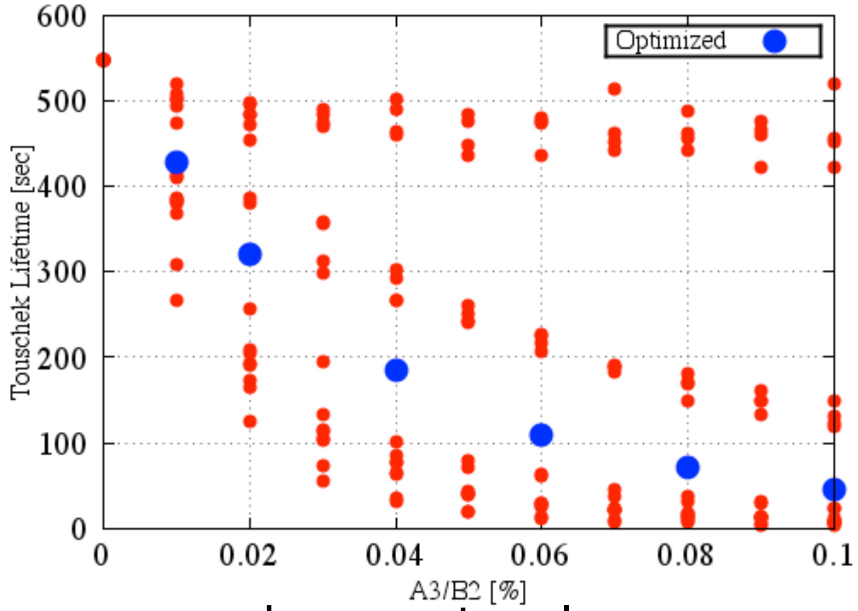
Dynamic aperture is optimized by using normal sextupoles(108) and skew sextupoles(24) in the arc.

LER



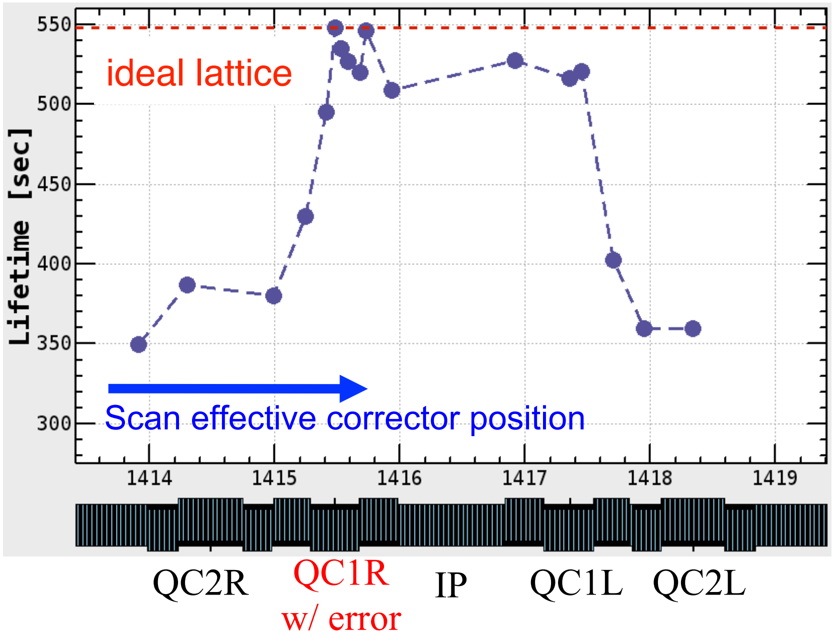
sextupole error

LER



skew sextupole error

Sextupole error can be recovered by using normal sextupoles(in the arc), however, skew sextupoles error can not be corrected for enough level.



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Position dependence of the skew corrector coil is stronger than that of normal.

Skew sextupole corrector must be installed in the vicinity of the error source.

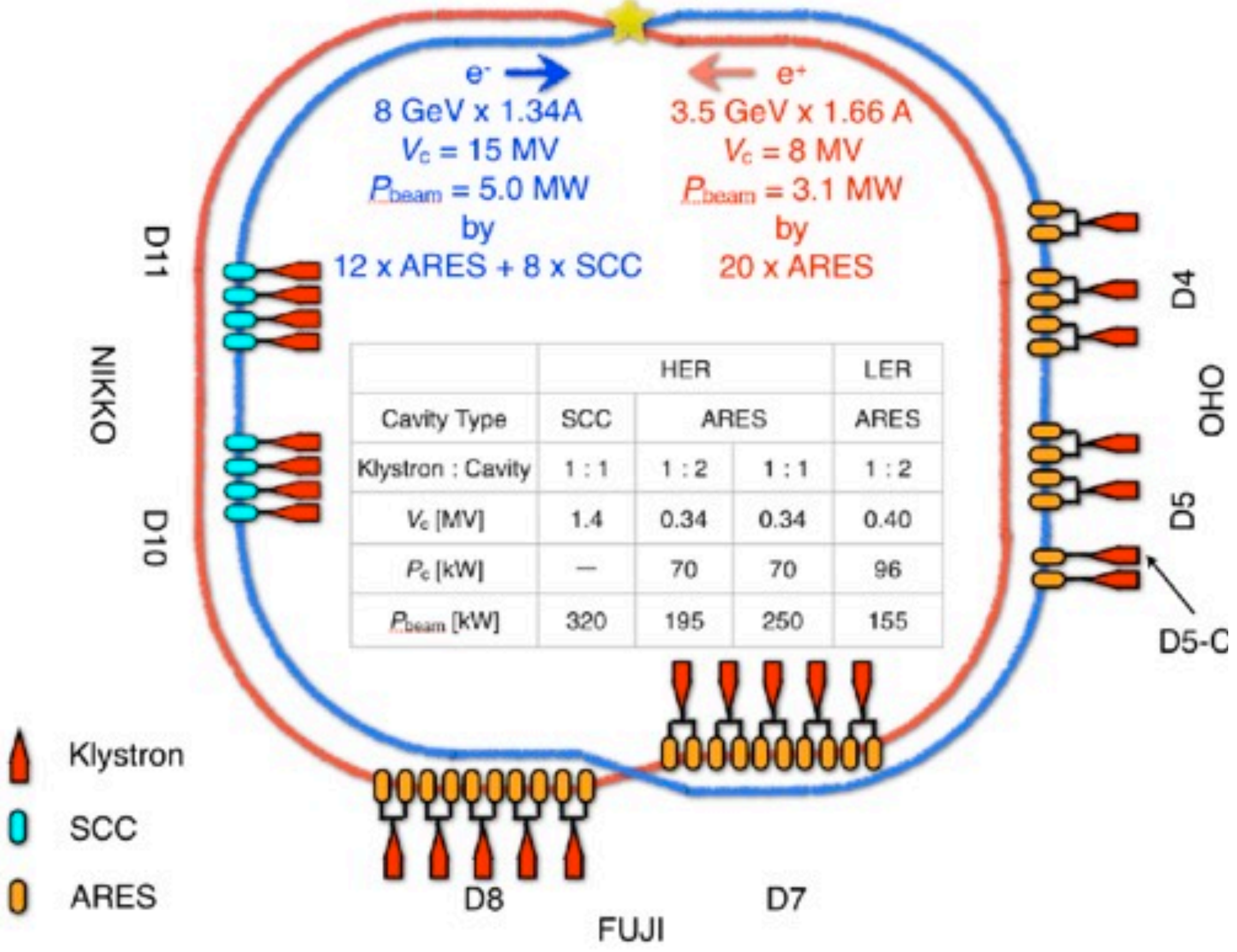
a3 coils at QC1 and QC2 correct error.

How to increase Beam Current ?

Add klystrons, power supplies and HPRF system
Add RF cavities
Relocation of normal conducting cavities (ARES)
Upgrade input coupler to provide more beam power to cavity

KEKB → SuperKEKB

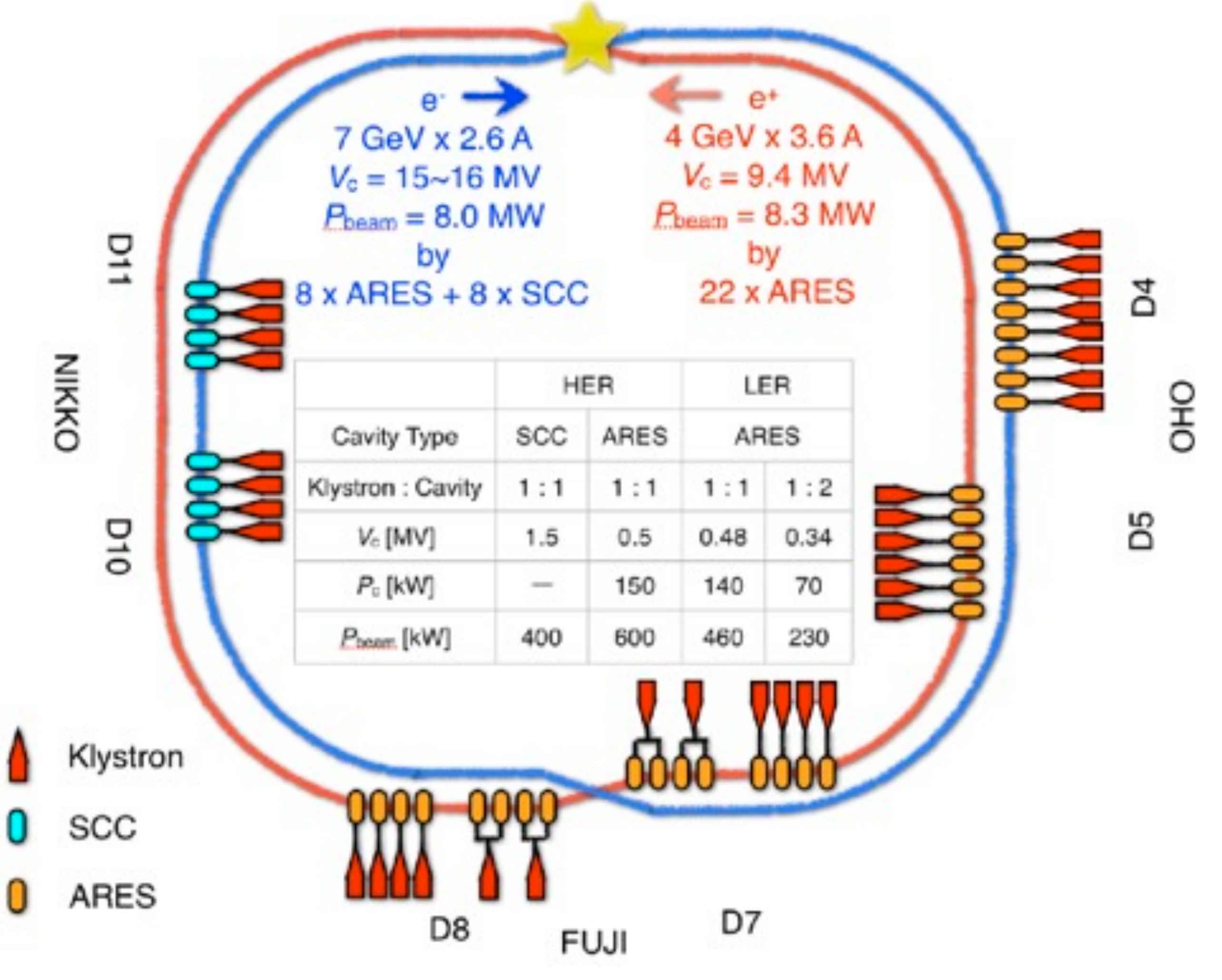
$L = 1.71 \times 10^{34}$ cm^{-2}s^{-1} (Nov. 15, 2006)



	HER			LER
Cavity Type	SCC	ARES		ARES
Klystron : Cavity	1 : 1	1 : 2	1 : 1	1 : 2
V_c [MV]	1.4	0.34	0.34	0.40
P_c [kW]	—	70	70	96
P_{beam} [kW]	320	195	250	155

1 klystron drives 2 cavities

$L = 8 \times 10^{35}$ cm^{-2}s^{-1}



	HER		LER	
Cavity Type	SCC	ARES	ARES	
Klystron : Cavity	1 : 1	1 : 1	1 : 1	1 : 2
V_c [MV]	1.5	0.5	0.48	0.34
P_c [kW]	—	150	140	70
P_{beam} [kW]	400	600	460	230

1 klystron drives 1 cavity

Two Types of Accelerating Cavities

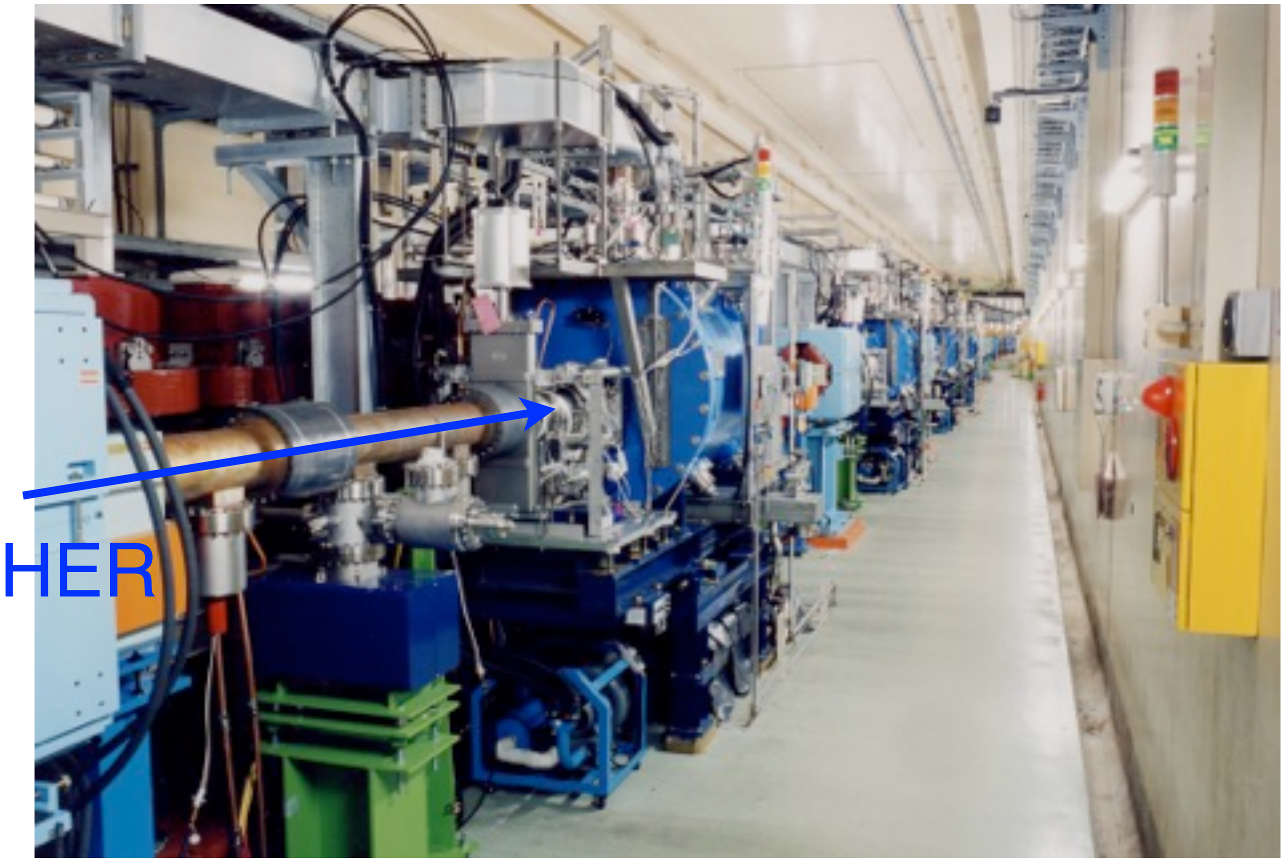
30 Normal Conducting
ARES Cavities:
22 in LER, 8 in HER

π/2 mode
HOM-damped cavity

e+, LER

e-, HER

8 Superconducting
Cavities in HER



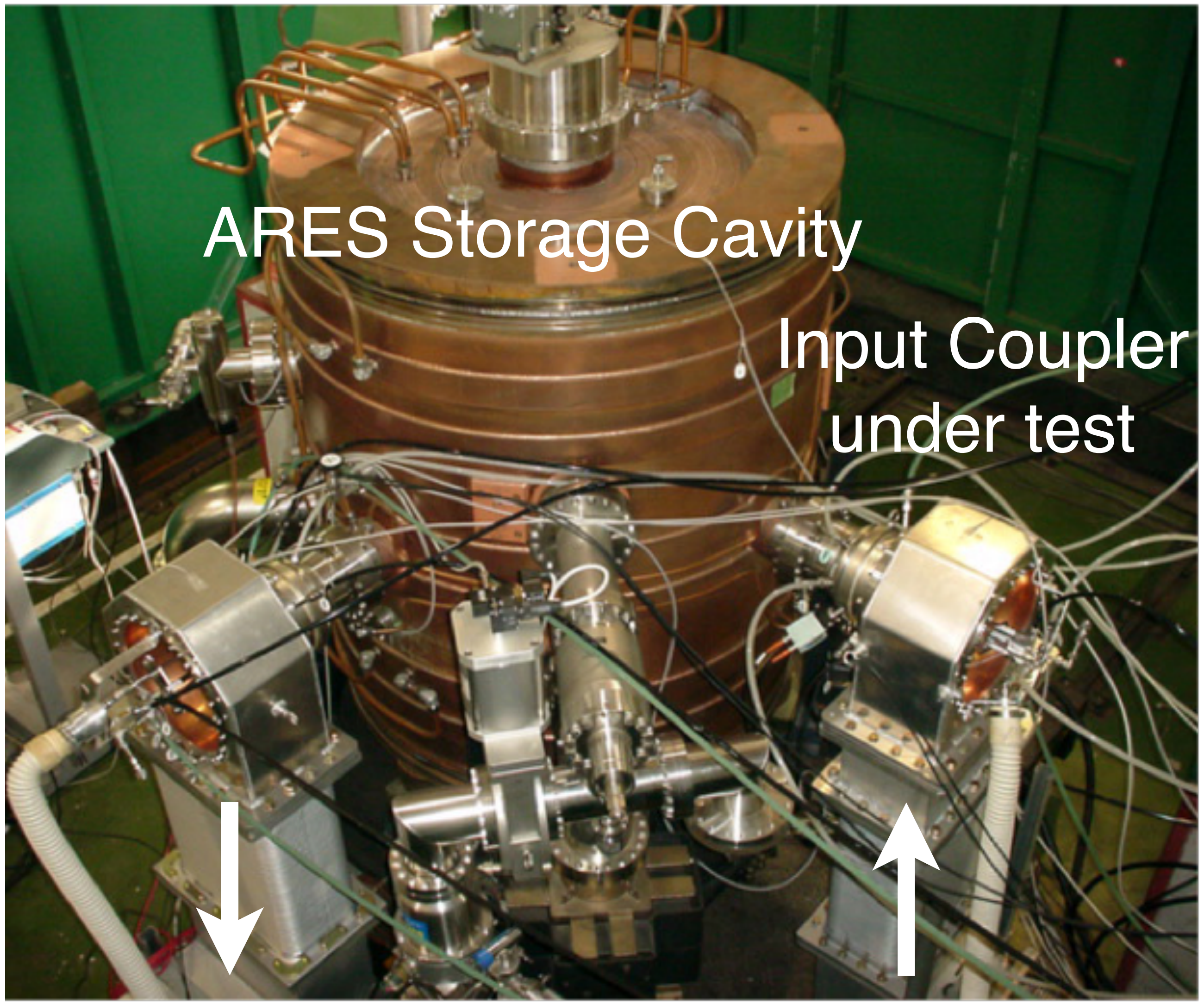
e-, HER

single-cell

Improvement of ARES Input Coupler

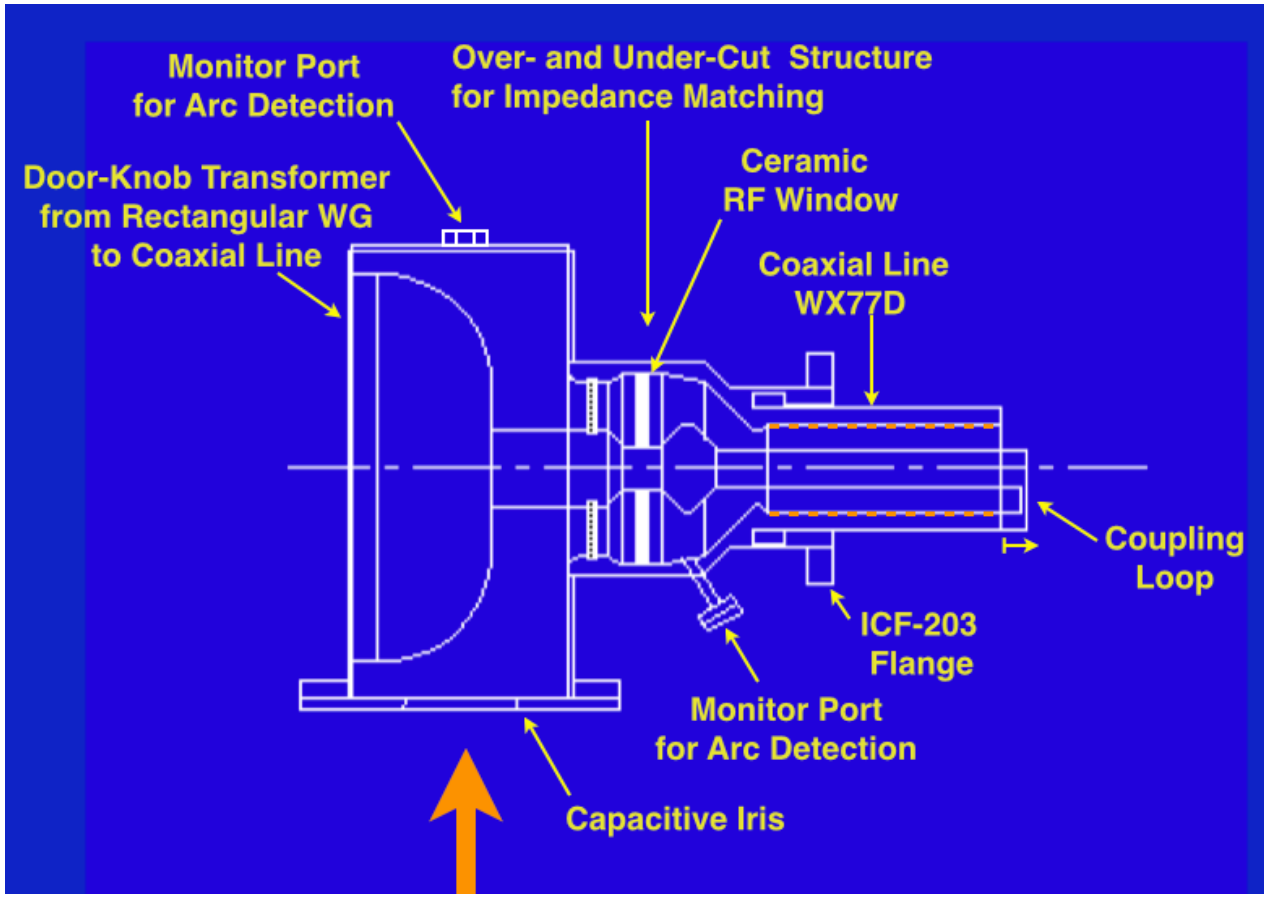
The performance of input coupler should be improved to handle higher input power: 14 input couplers have been processed up to 750-800 kW so far.

High Power Test Stand



1 MW
water load

1 MW CW
Klystron



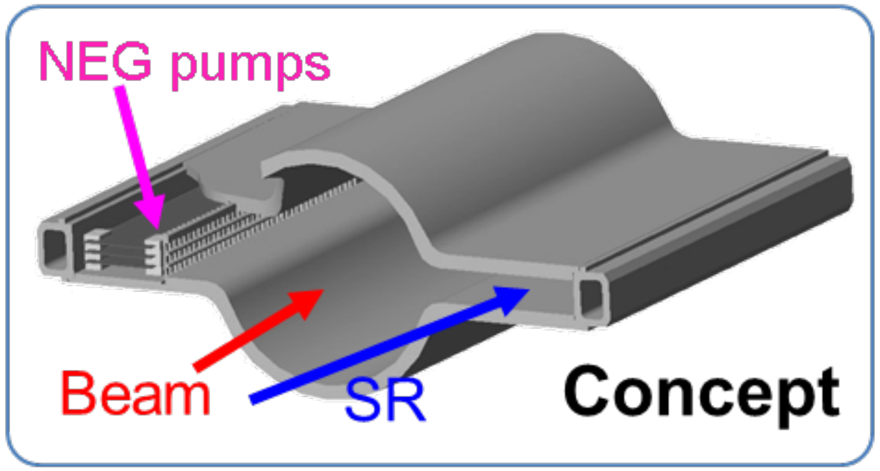
	P_{input} [kW]	Pc [kW]	P_{beam} [kW]
SuperKEKB	750	150	600
KEKB	350	150	200

Vacuum System

We replaced old chamber with ante-chamber in LER (positron ring).

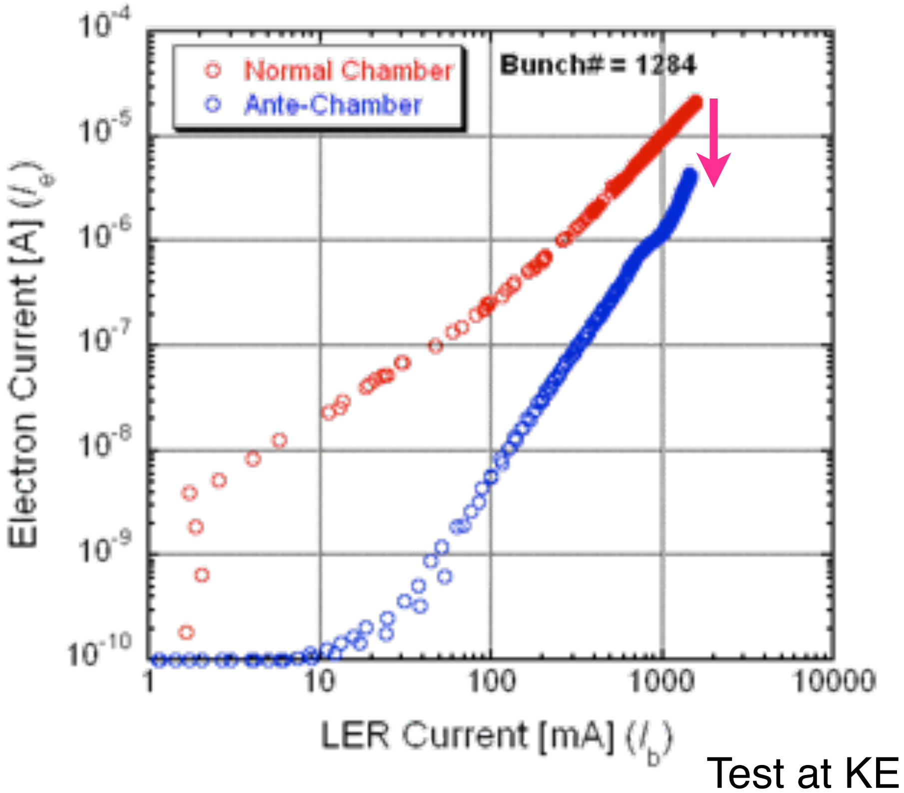

Beam pipes for bending magnets


Beam pipes for wigglers



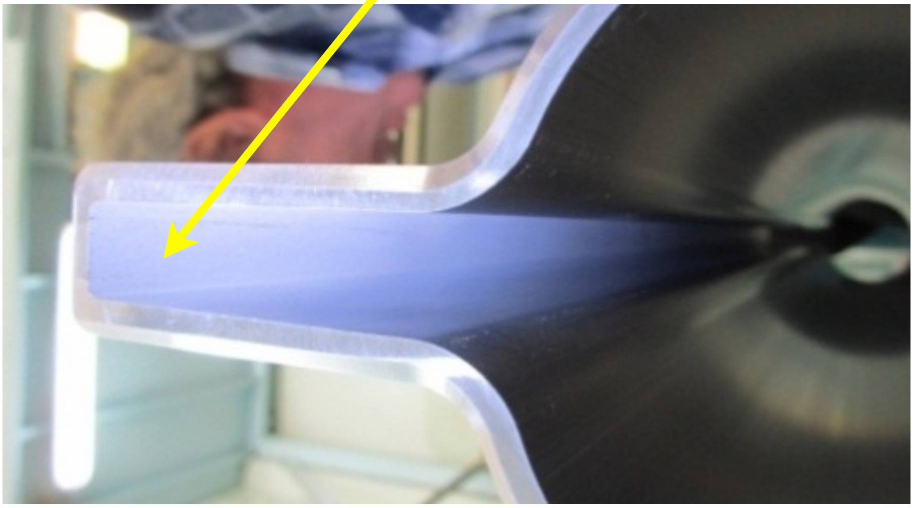
made of Aluminum alloy (A6063)

OFC



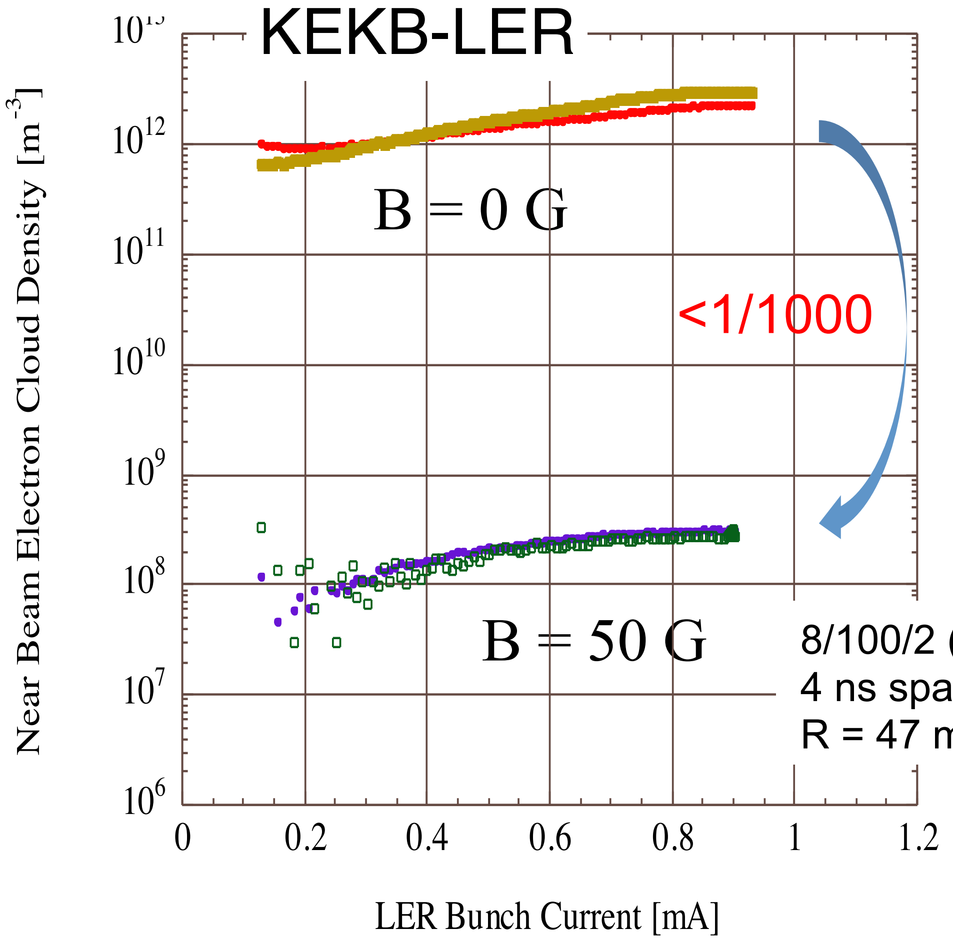
mitigation of Electron Cloud ~1/5

Rough surface at the side wall reduces photon reflection.



Test at KEKB-LER

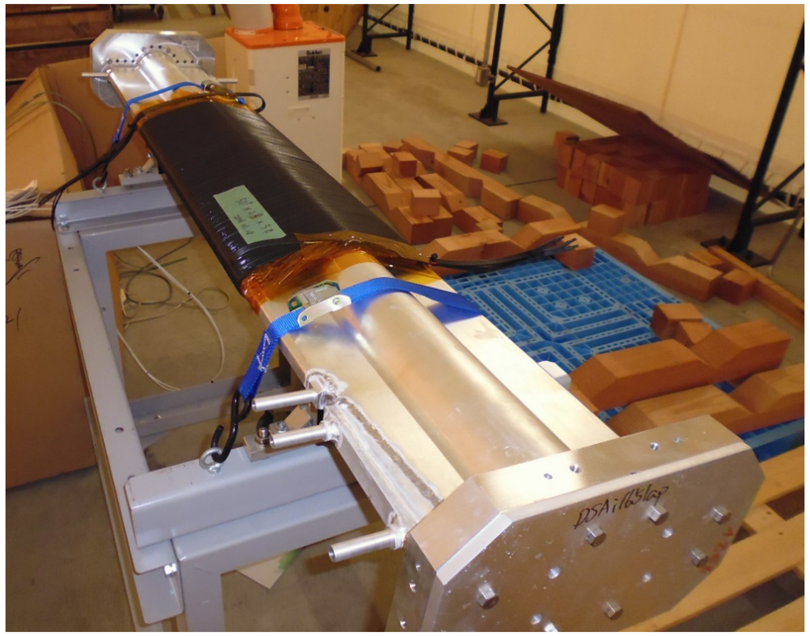
Mitigation of Electron Cloud

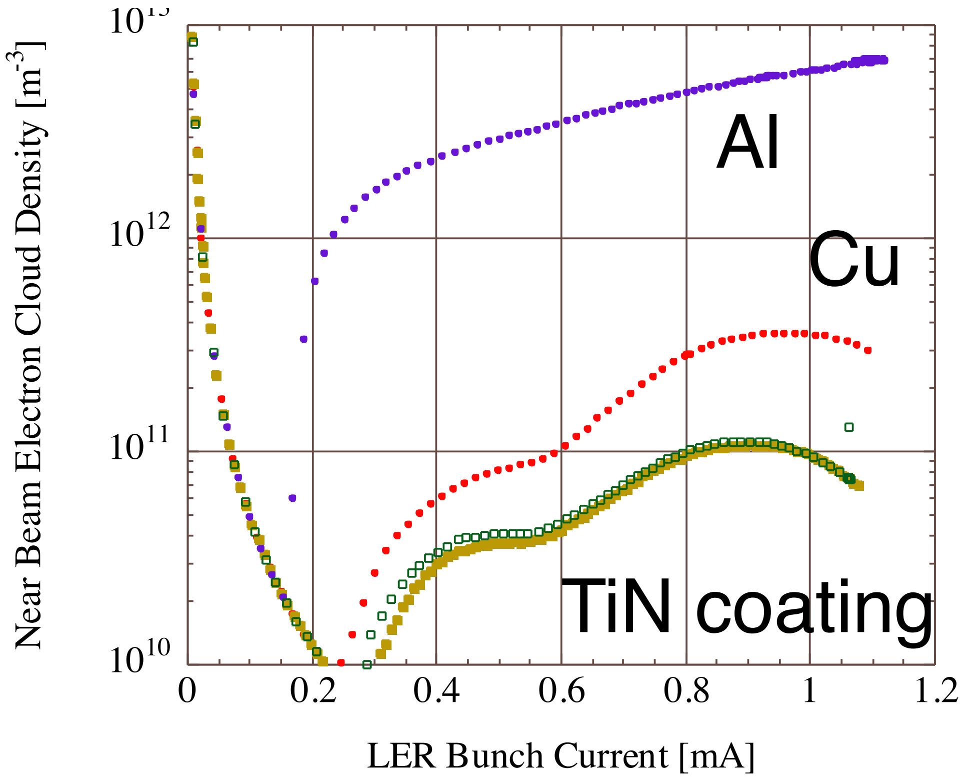


8/100/2 (800)
4 ns spacing
R = 47 mm (Circular)

mitigation
~1/50

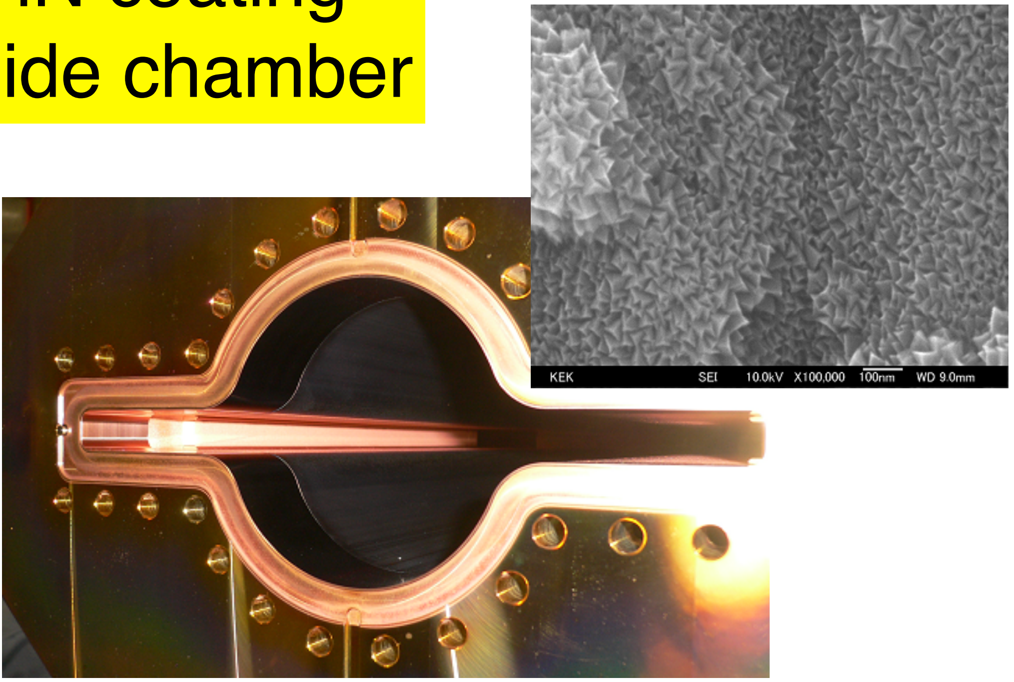
Solenoid coil in drift space





mitigation
~3/5

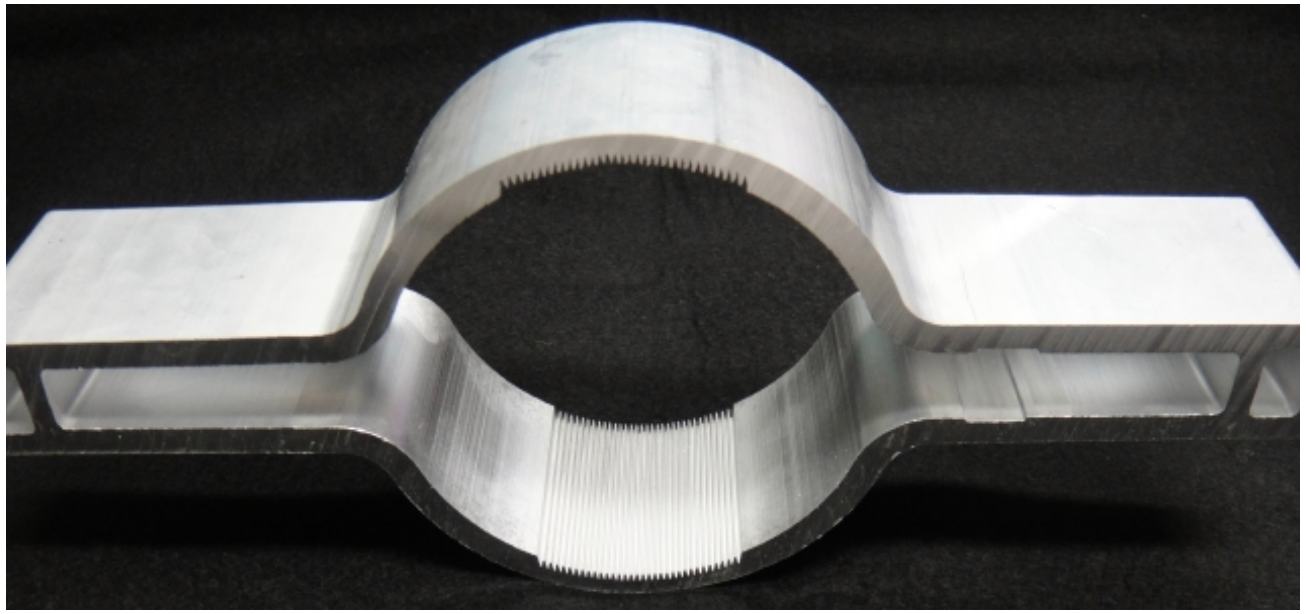
TiN coating inside chamber

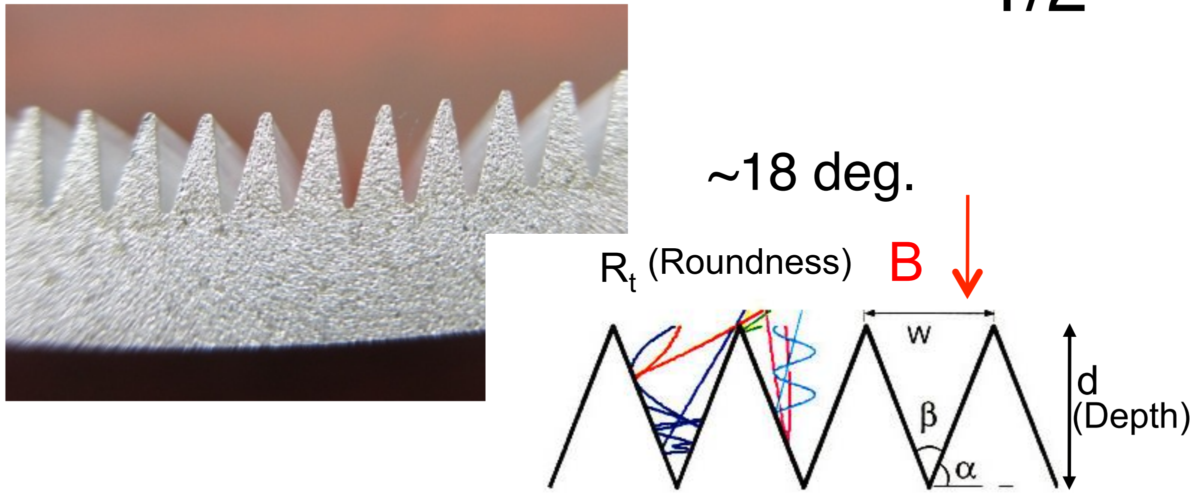


Mitigation of Electron Cloud

Grooved surface reduces SEY in a dipole magnet.

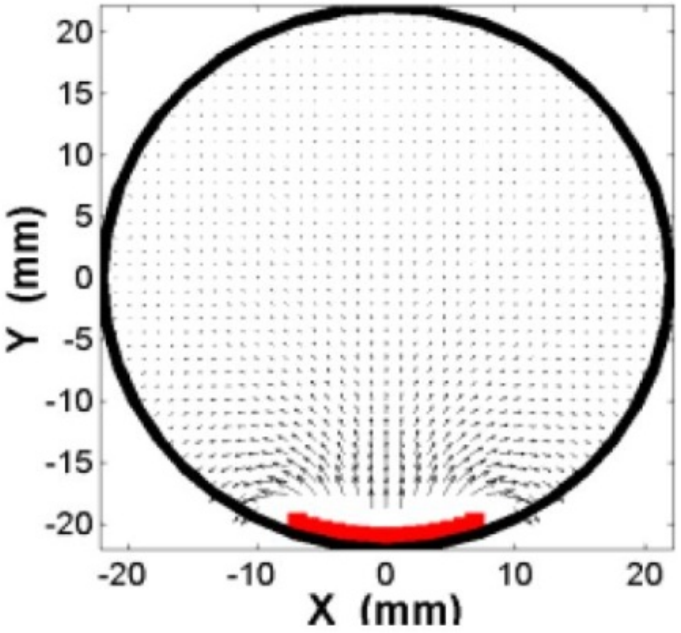
mitigation
~1/2





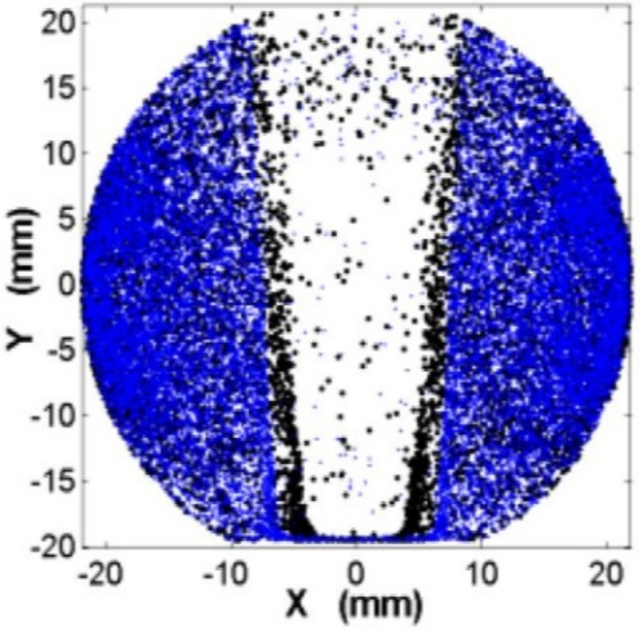
by L. Wang et al.

Clearing Electrode

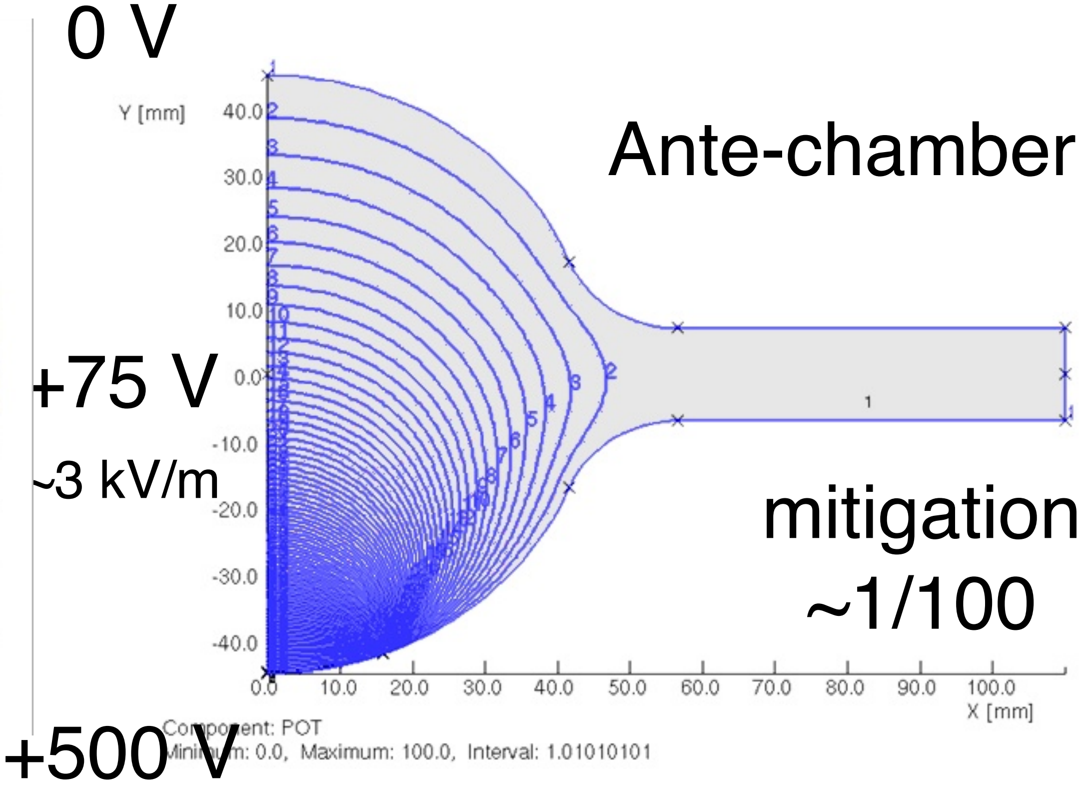


Electrode

Electron Density



L. Wang et al.



Ante-chamber

mitigation
~1/100

Summary of Electron Cloud Mitigation

	Drift	Dipole magnet	Wiggler magnet	Quadrupole magnet
Coverage	64%	17%	5%	9%
Material	Al	Al	Cu (OFC)	Al
Ante chamber	✓ 1/5	✓	✓	✓
TiN	✓ 3/5	✓		✓
Solenoid	✓ 1/50			
Grooved		✓ 1/4		
Clearing electrode			✓ 1/100	

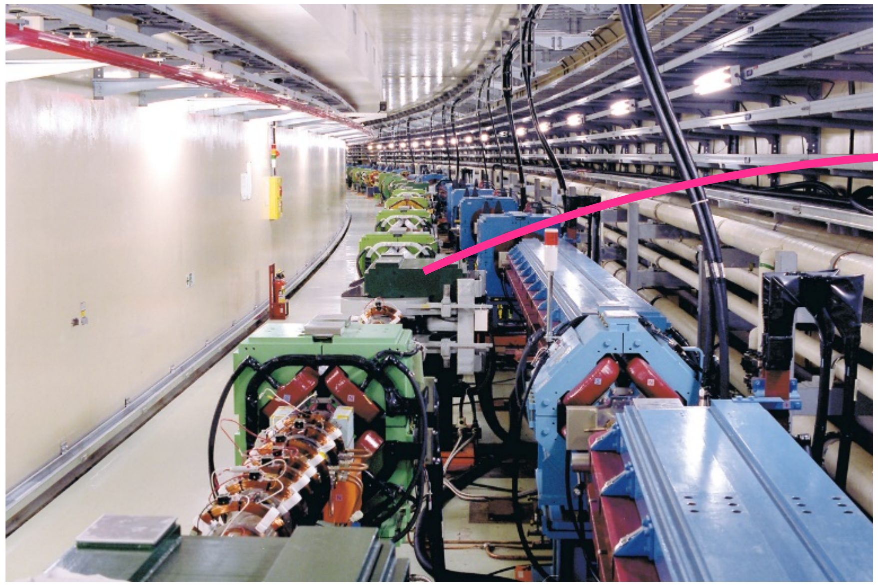
Low Emittance Lattice

In the case of no mode coupling, the emittance cab be written by:

$$\varepsilon_x = \frac{C_\gamma \gamma^2}{J_x} \frac{1}{2\pi\rho^2} \oint_b H(s)ds$$

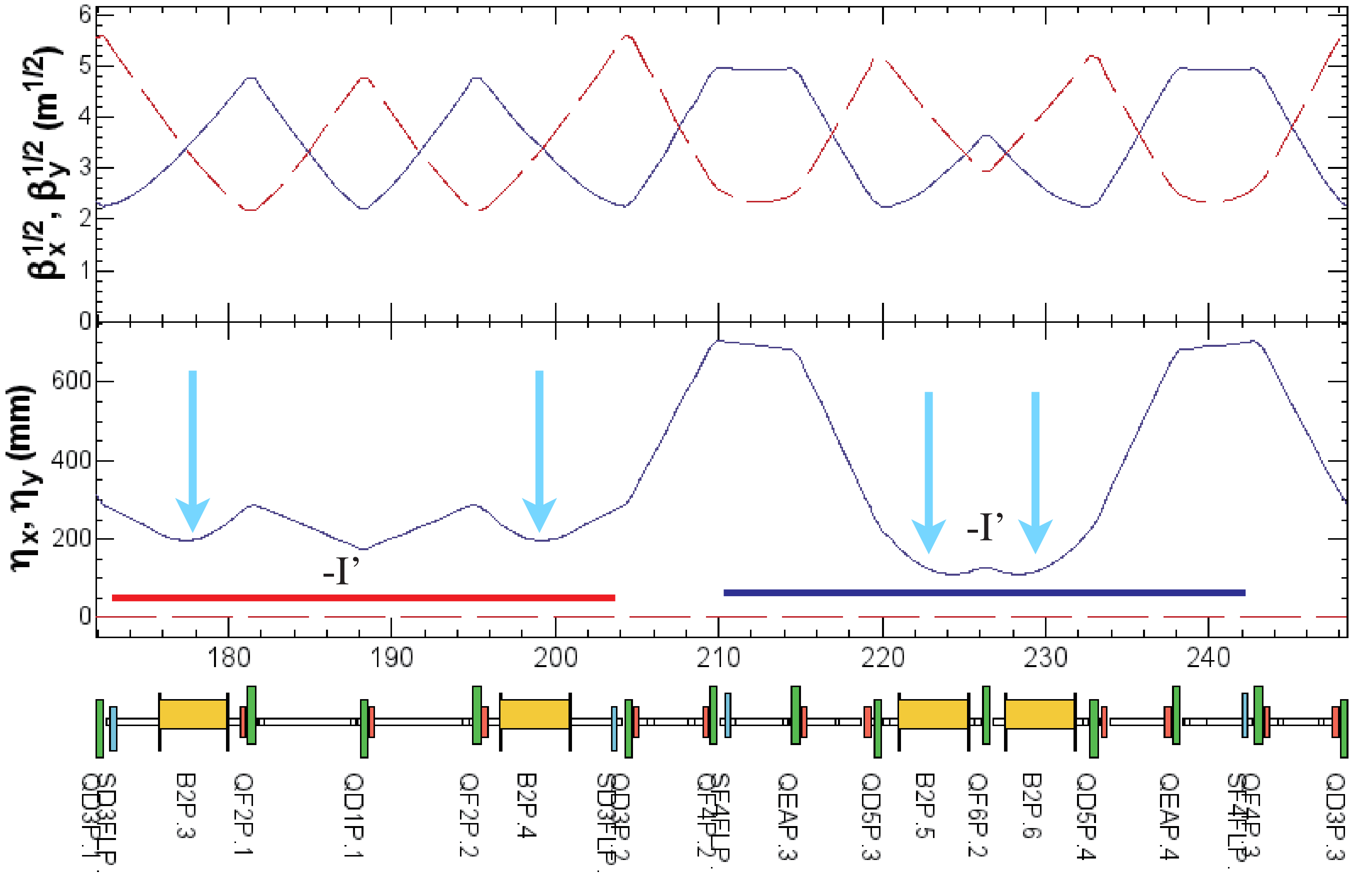
$$H(s) = \gamma_x \eta_x^2 + 2\alpha_x \eta_x \eta_{px} + \beta_x \eta_{px}^2$$

KEKB-LER dipole: ρ = 16 m



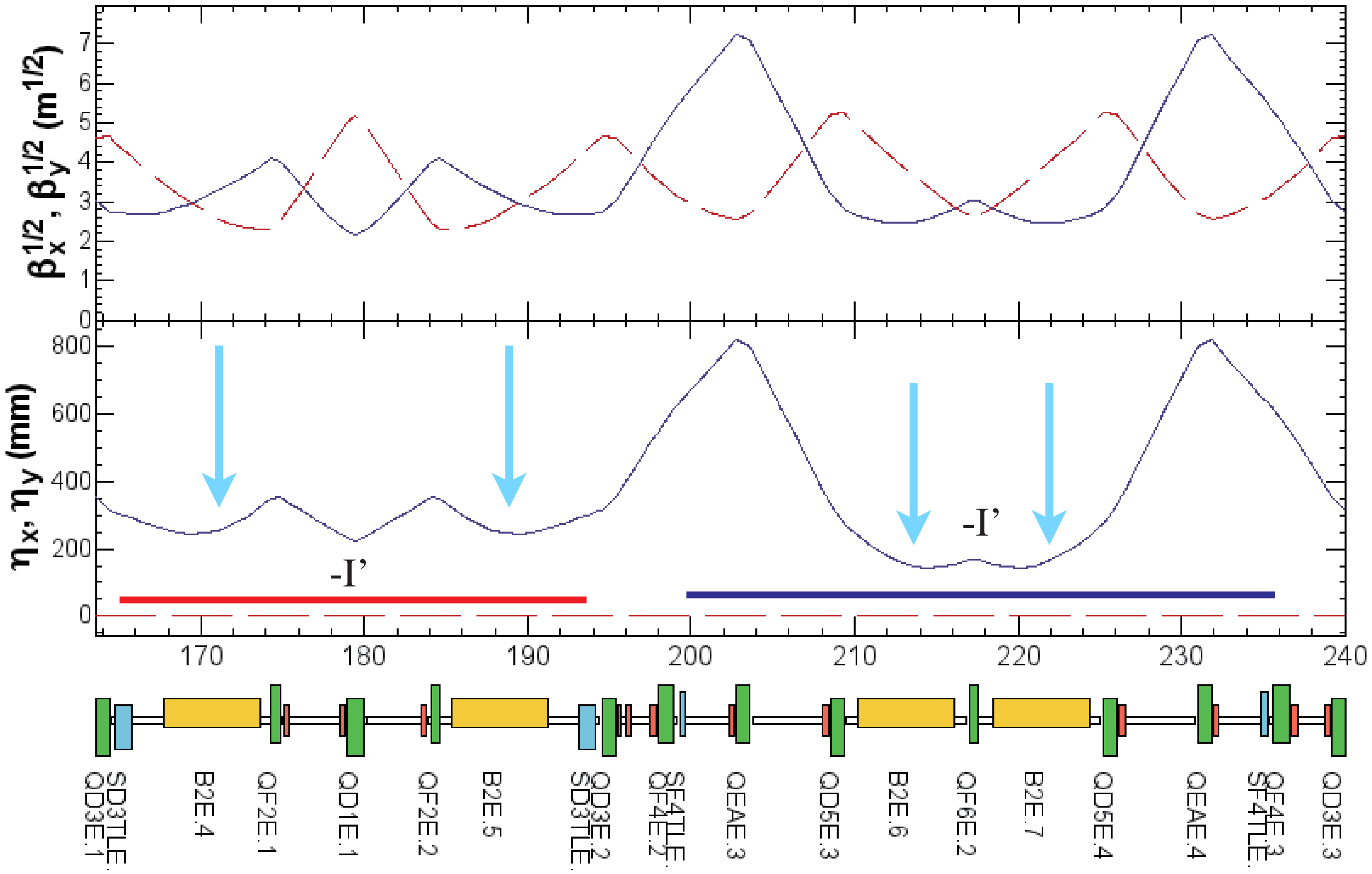
SuperKEKB-LER dipole: ρ = 74 m

Low Emittance Lattice: Arc Cell



LER

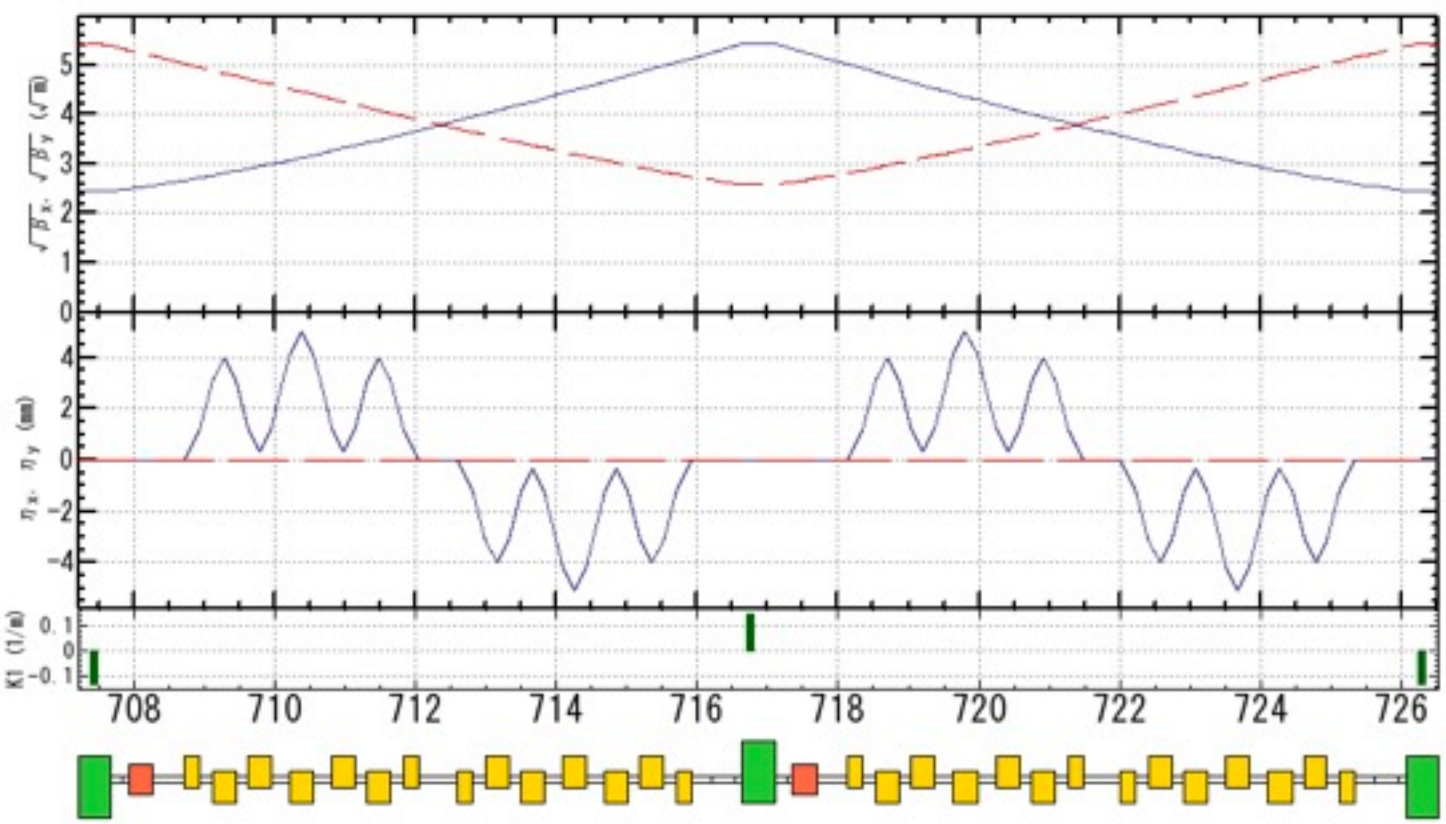
$\varepsilon_x = 4$ nm



HER

$\varepsilon_x = 5$ nm

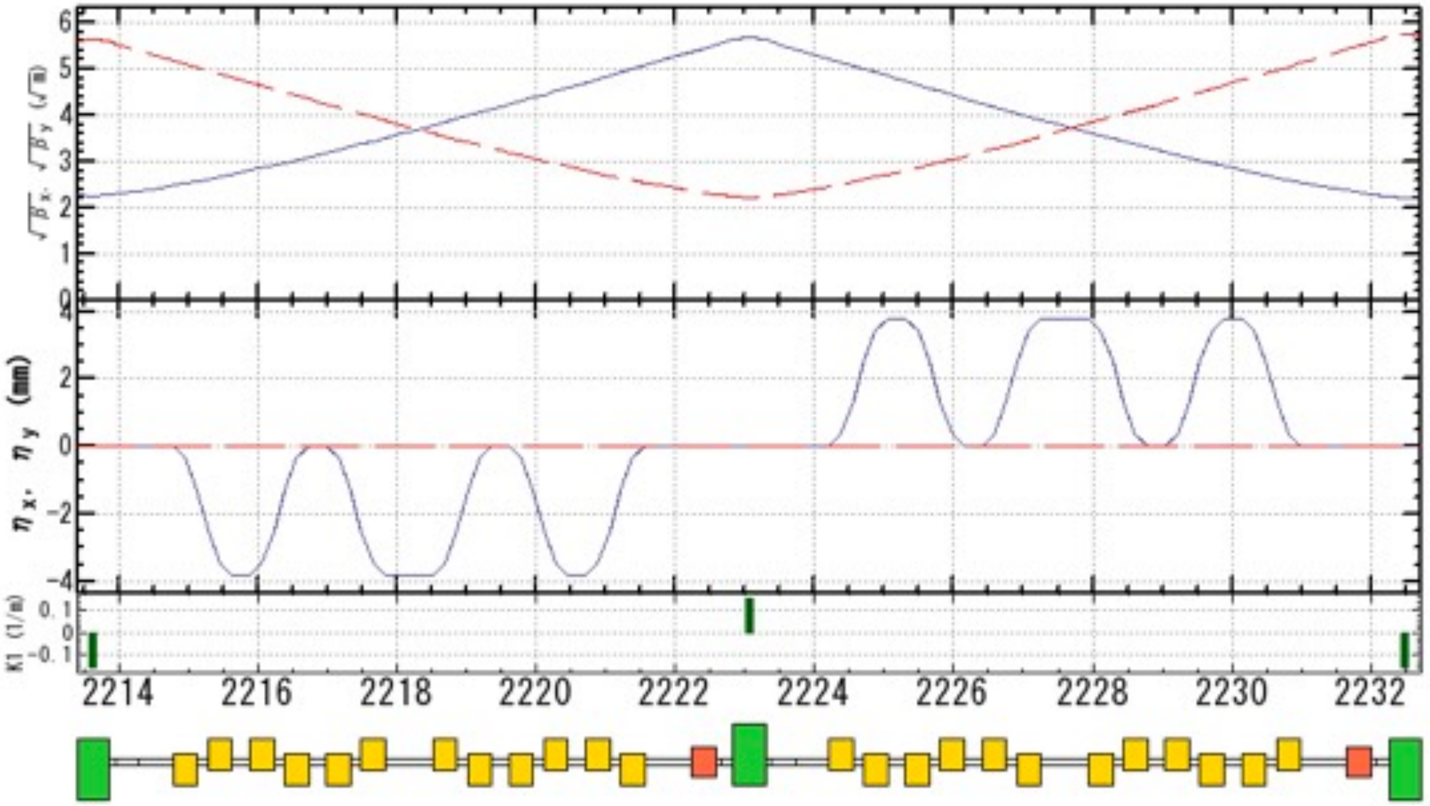
Low Emittance Lattice: Wigglers



LER

ε_x = 1.9 nm (arc+wiggler)

B = 0.87 [T]



HER

ε_x = 4.4 nm (arc+wiggler)

B = 0.51 [T]

Interaction Region Design Features

- Natural chromaticity:

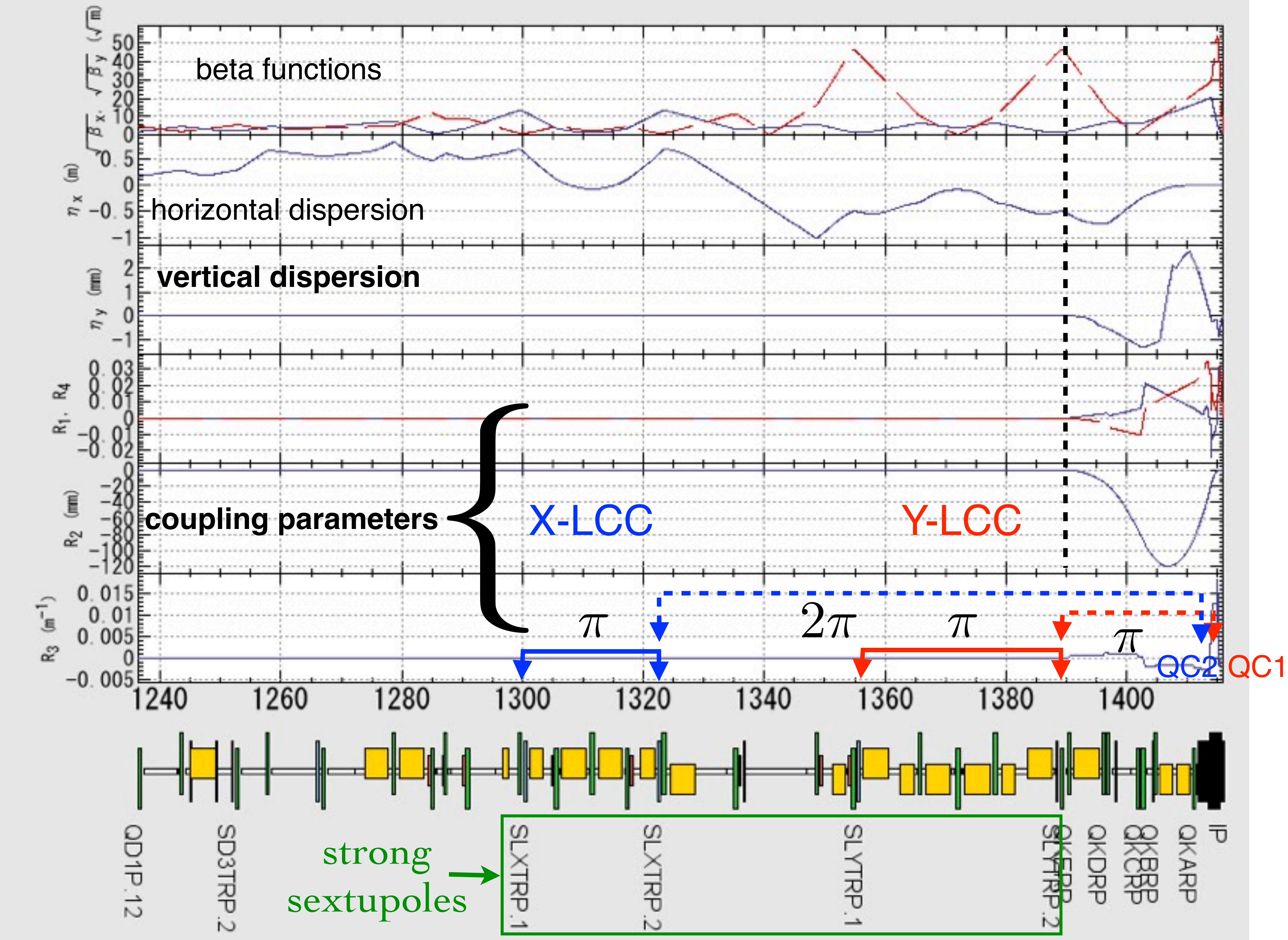
	SuperKEKB		KEKB (1999~2010)	
	LER	HER	LER	HER
ξ_{x0}	**-105**	**-171**	-72	-70
ξ_{y0}	**-776**	**-1081**	-123	-124

- 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. Skew coils and/or rotation of QC1 and QC2 are used to correct the X-Y coupling and vertical dispersion between IP and the local chromaticity correction.

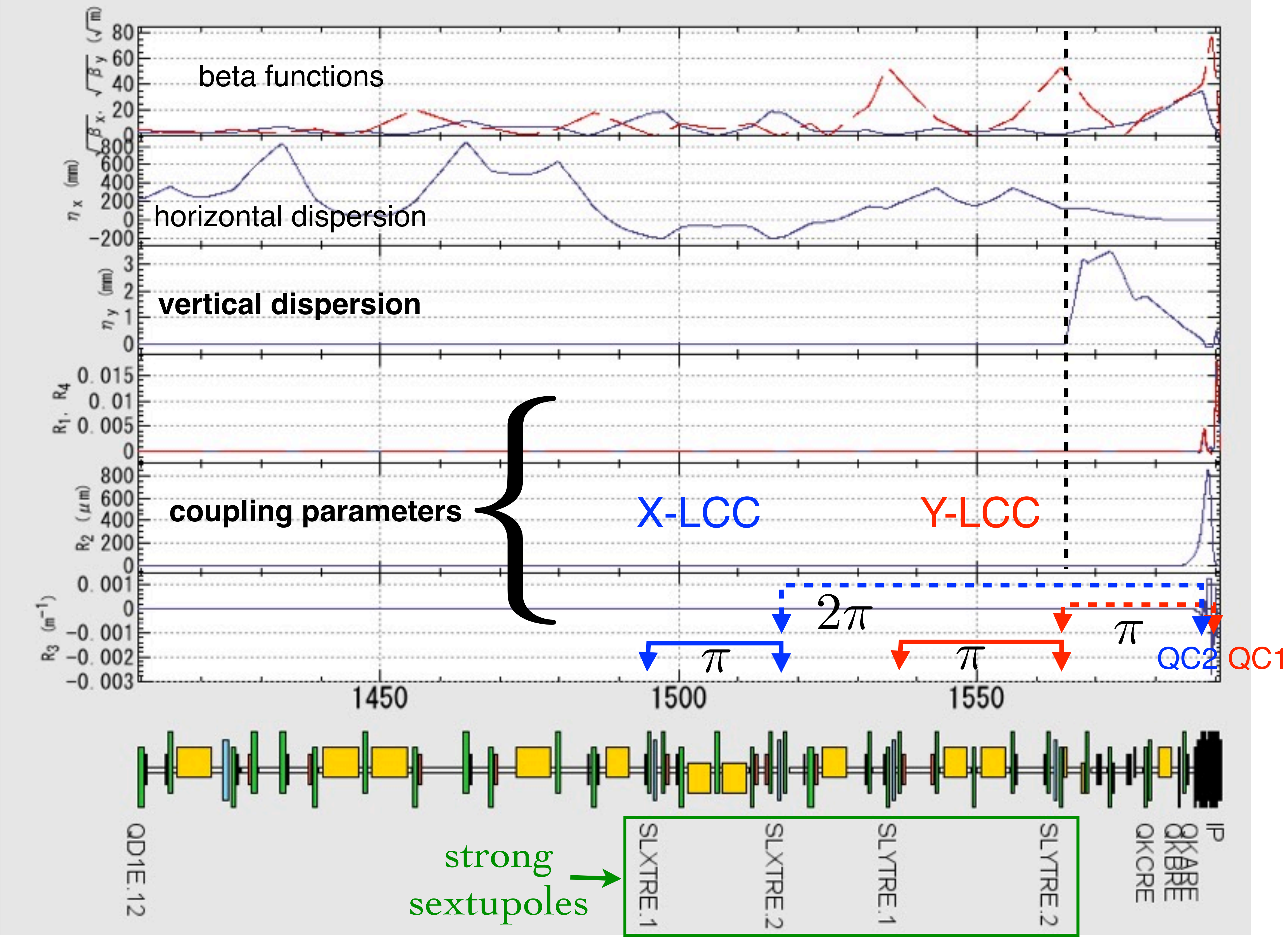
IR optics in LER

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



IR optics in HER

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



beta functions

horizontal dispersion

vertical dispersion

coupling parameters

X-LCC

Y-LCC

2π

π

π

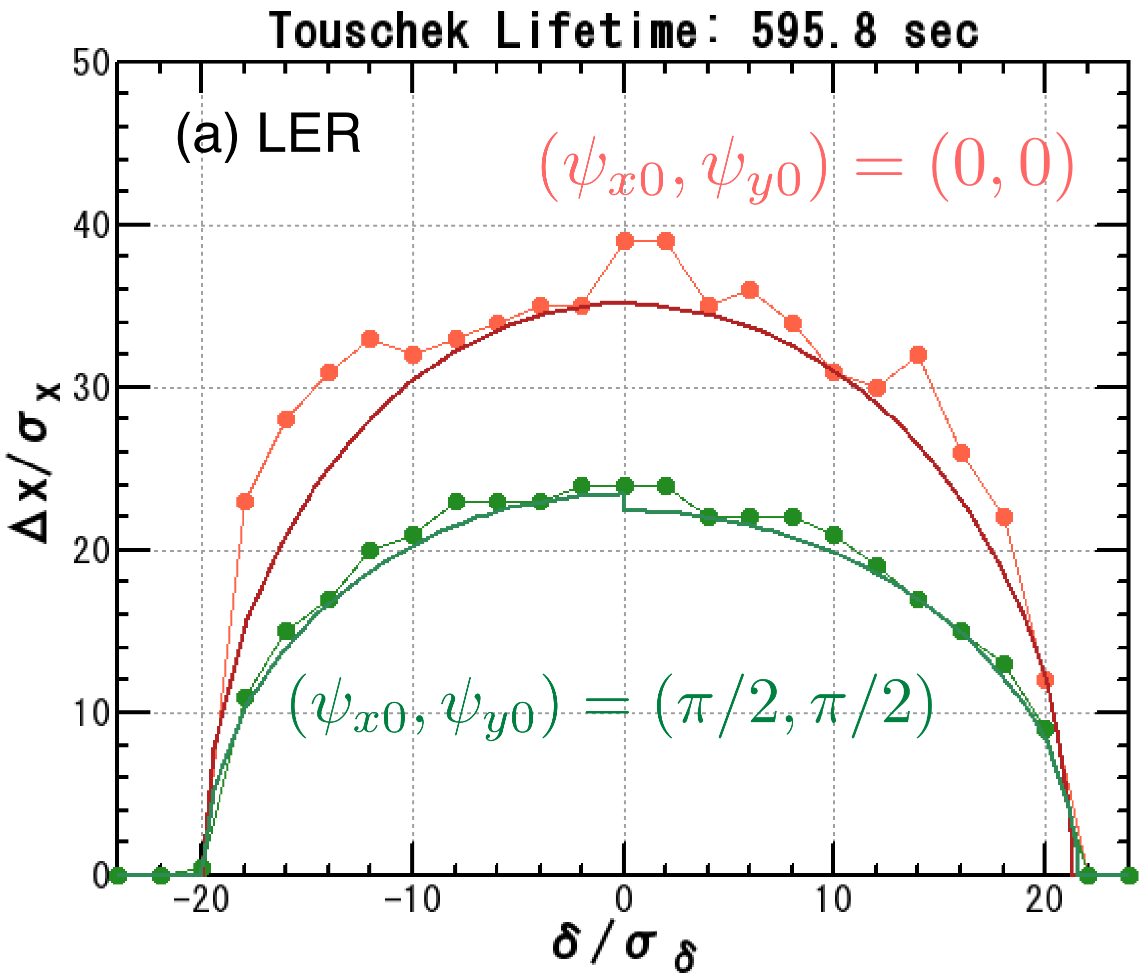
π

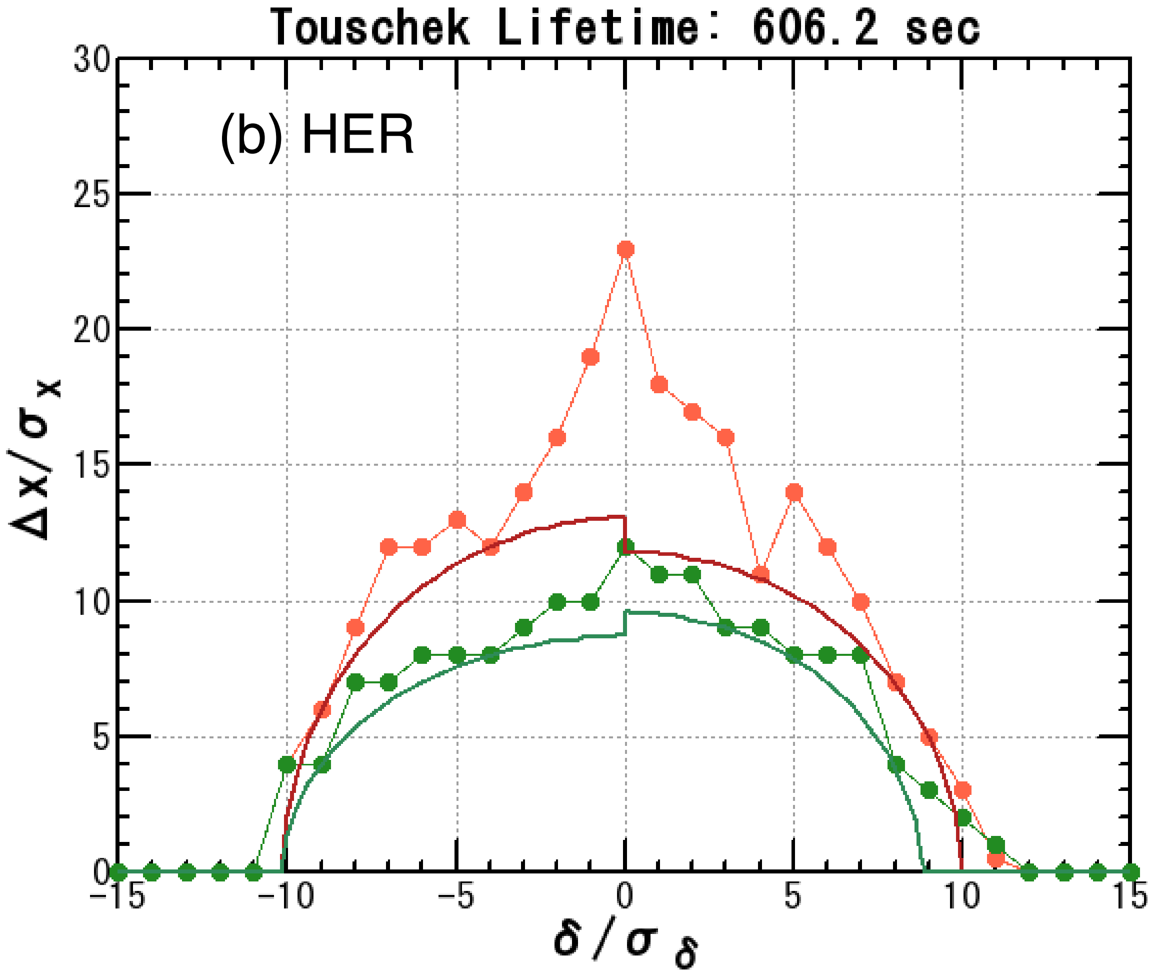
QC2 QC1

strong sextupoles

Dynamic Aperture

Target Touschek lifetime is 600 sec.





Top-up injection is necessary to keep Luminosity.

Sextupoles, skew sextupoles, octupoles are optimized to make DA large as much as possible.

Injector Linac

Photo-cathode RF gun system

< e- beam>

Low emittance ($\gamma\varepsilon \leq 20$ µm)

high bunch charge (≥ 5nC)

Positron Damping Ring (DR)

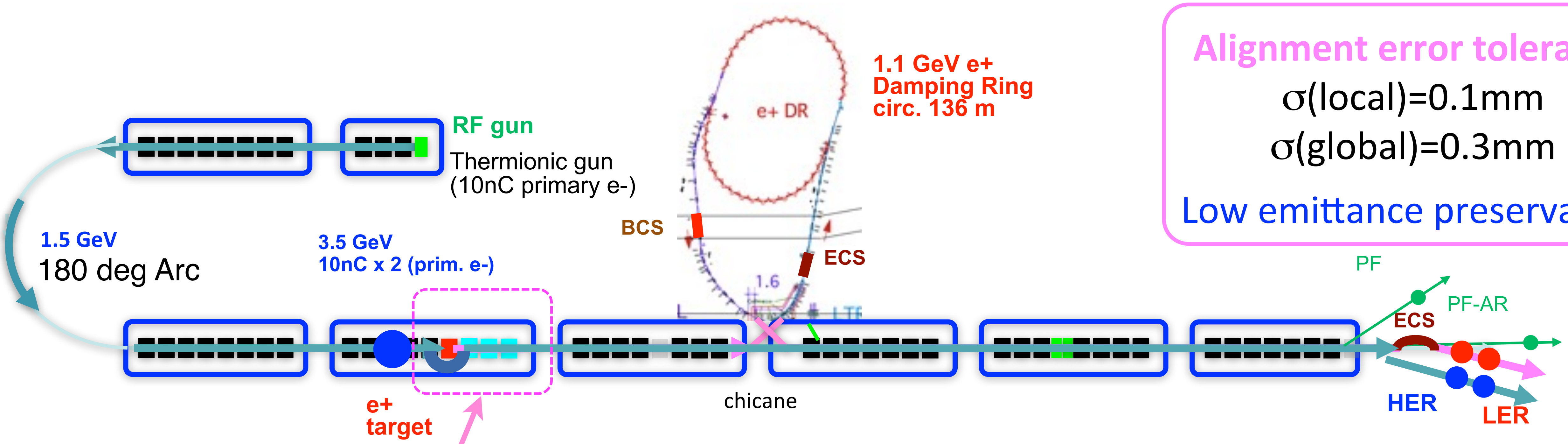
Low emittance e+ beam

Alignment error tolerance

σ(local)=0.1mm

σ(global)=0.3mm

Low emittance preservation



Positron Capture Section

- Flux concentrator (FC)
- Large aperture S-band accelerator Structures (LAS)

4 times higher e+ yield

- **RF phases are switched for each beam energy**
- **Pulsed Quads & Pulsed Steering Magnets are installed for switching the optics for each mode**

Event Timing System and Pulsed Modules

- **Synchronization for 5-rings including DR.**

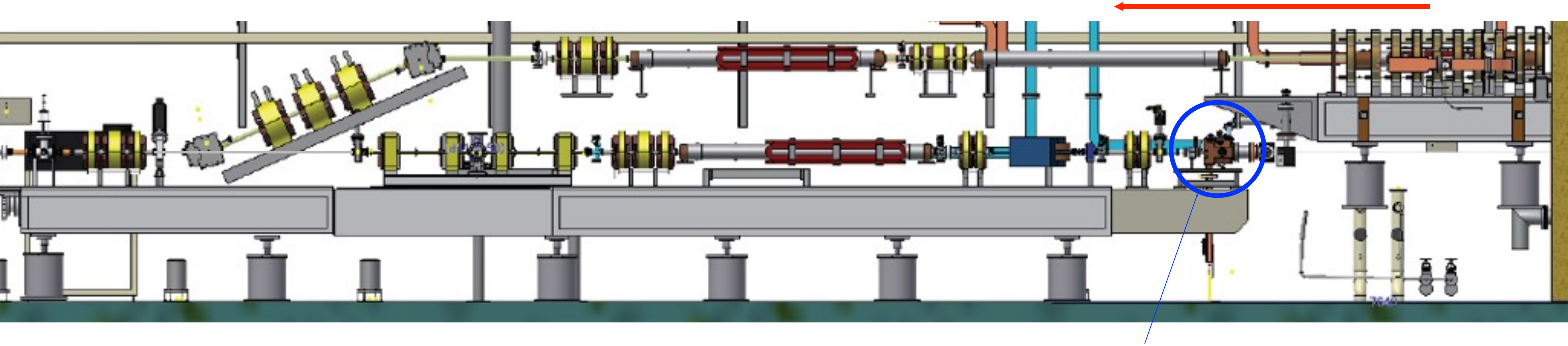
Requirement for Injector Linac

	for KEKB		for SuperKEKB	
	e+	e-	e+	e-
Energy	3.5 GeV	8.0 GeV	4.0 GeV	7.0 GeV
Bunch charge	Primary e-10nC →1 nC	1 nC	Primary e-10nC → 4 nC	5 nC
Num. of Bunch / Pulse	2	2	2	2
Normalized Emittance (γβε)	2100 (μm)	100 (μm)	100/20 (Hor./Ver.) (μm)	50/20 (Hor./Ver.) (μm)
Energy spread	0.125%	0.125%	0.1%	0.1%
Repetition rate	50 Hz		50 Hz	

Layout of Electron Guns

- Thermionic electron gun are located upstairs to produce ~10 nC primary electrons for positron production.

- Photocathode RF gun for low emittance e- production is located on the straight line.



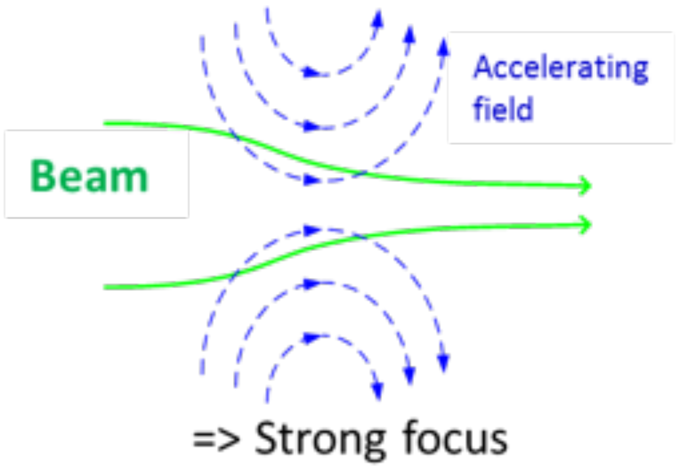
Junction

Thermionic gun
(primary e- 10nC)

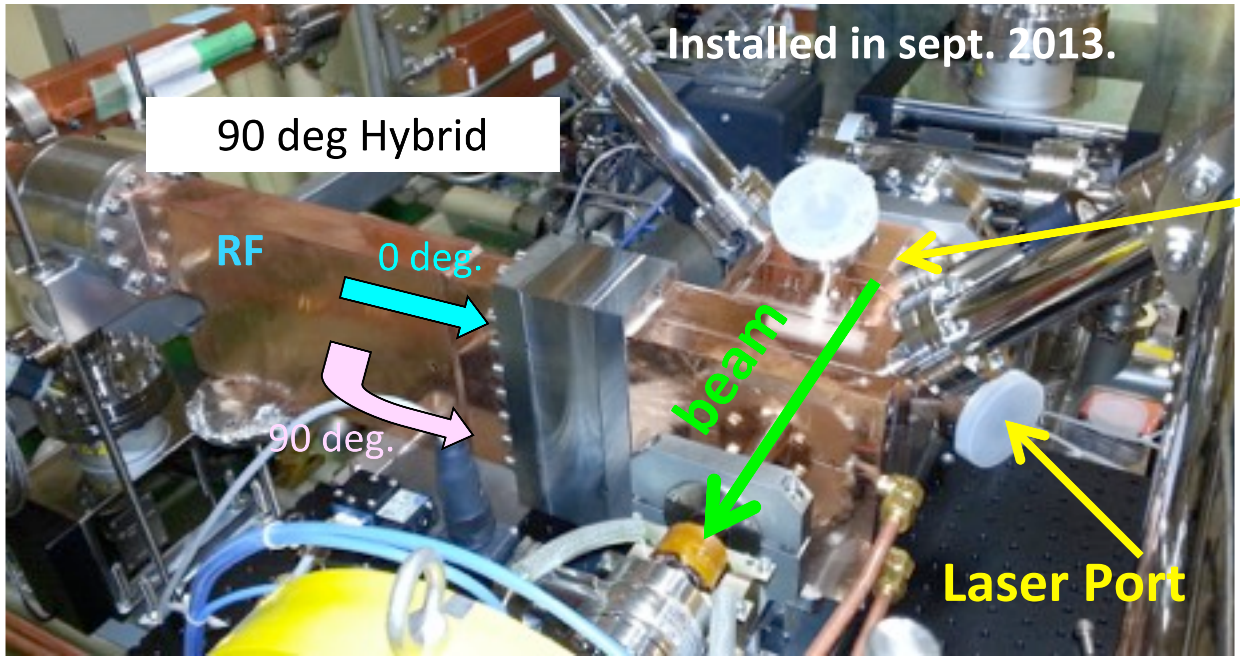
Photocathode RF gun
(low emittance)

Quasi Traveling Wave Side Couple RF GUN

Strong focusing force using accelerating field

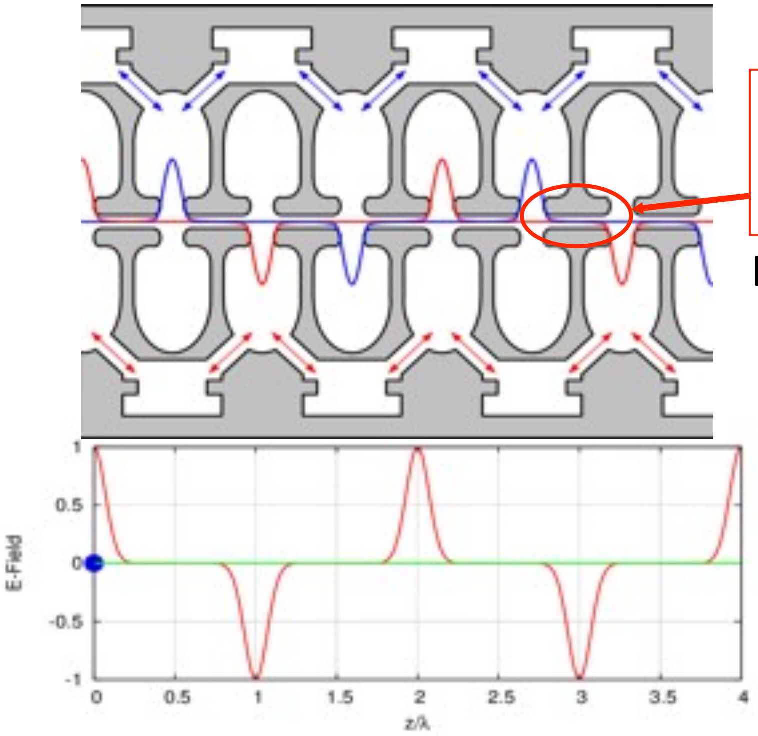


Quasi traveling wave (QTW) side couple RF gun



QE=1×10^{-4} @266nm
Long lifetime

Incident angle: 60deg to the cathode surface.

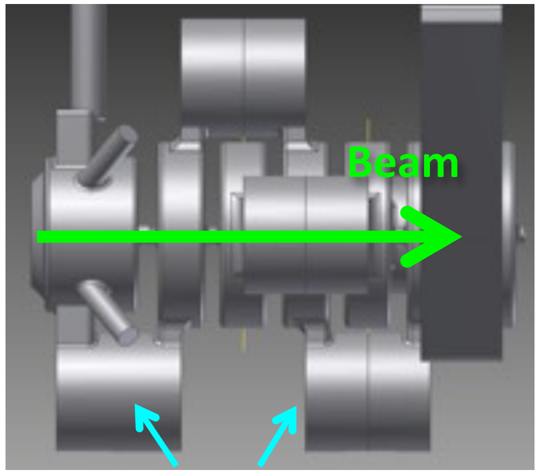


QTW type is adopted to make drift space short.

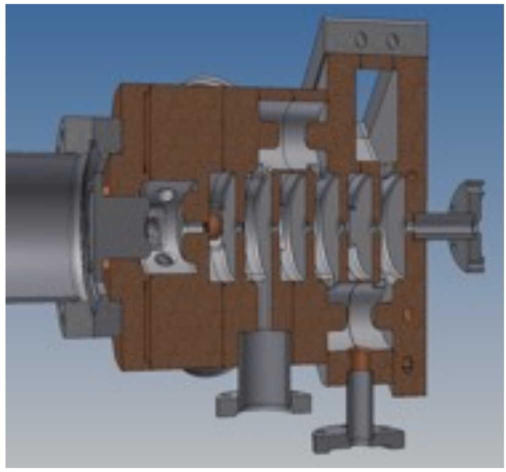
Drift space = no focus field

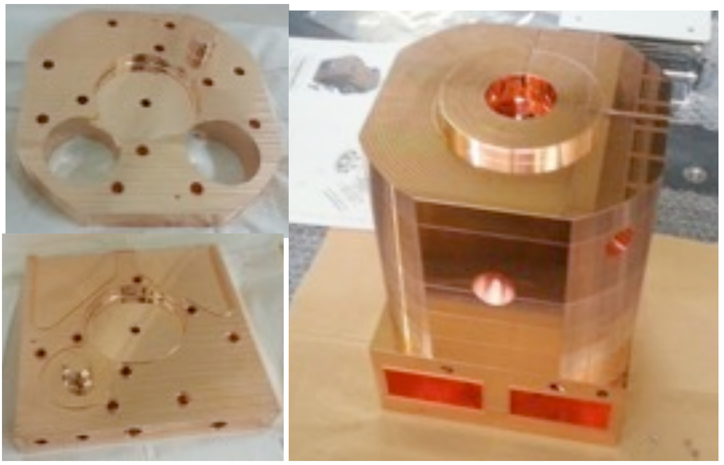
7 cell, 13.5 MeV@design
Norm. ε: 5.5 mm-mrad @5 nC (by simulation)
This RF gun can generate e- up to 10 nC

QTW is made by two standing waves with 90deg phase difference.



coupling cavities

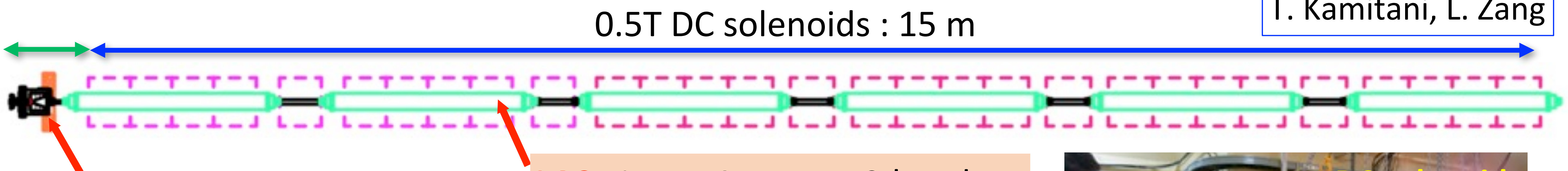




T.Natsui, M.Yoshida

Positron Capture Section

T. Kamitani, L. Zang



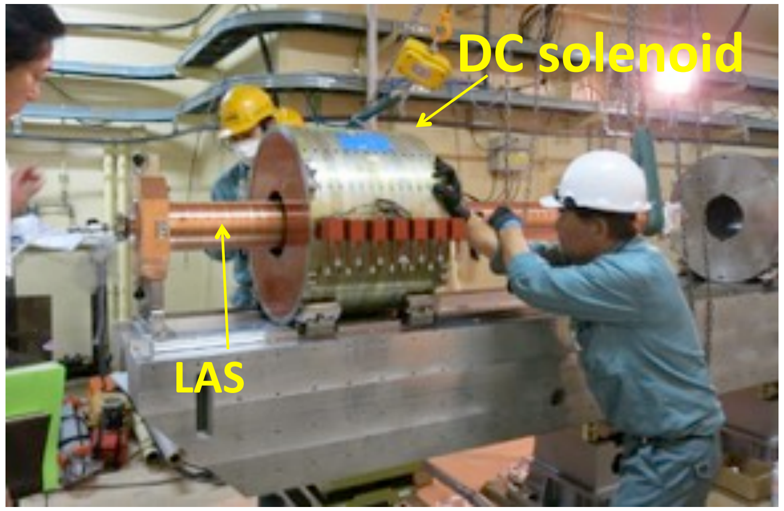
FC : Flux concentrator

Large energy acceptance

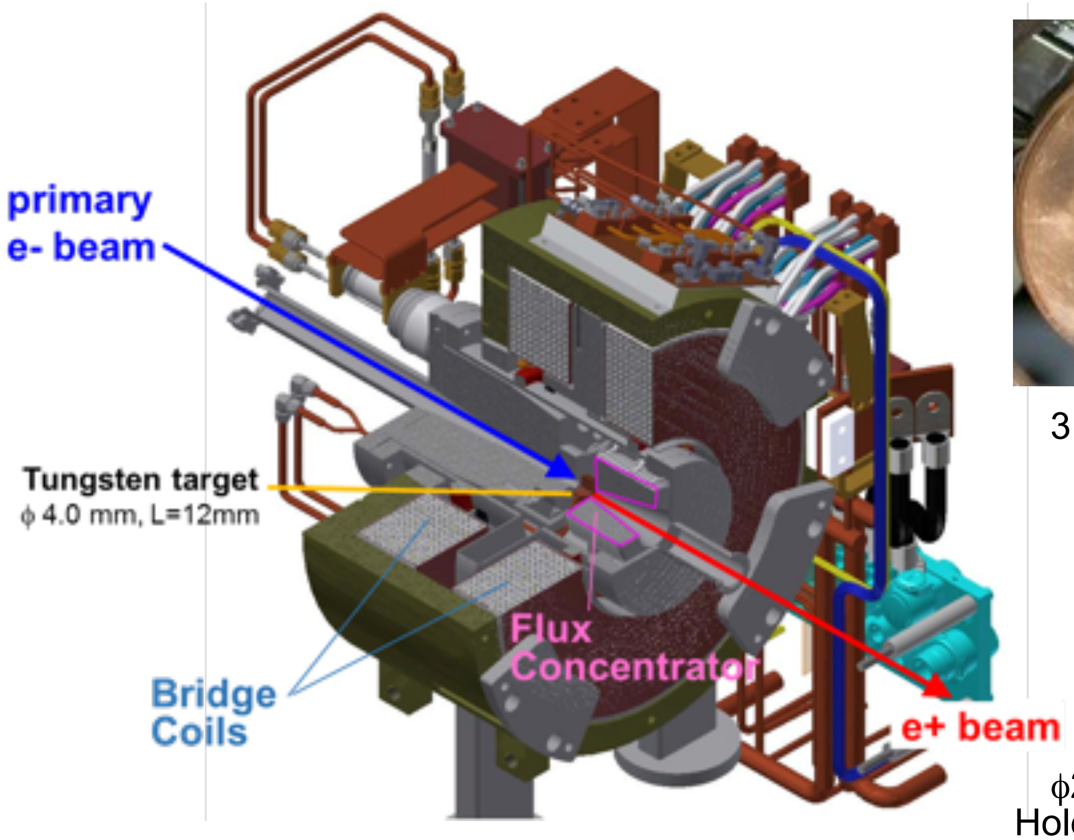
LAS : Large Aperture S-band accelerator Structures

Aperture ϕ20mm → ϕ 30mm

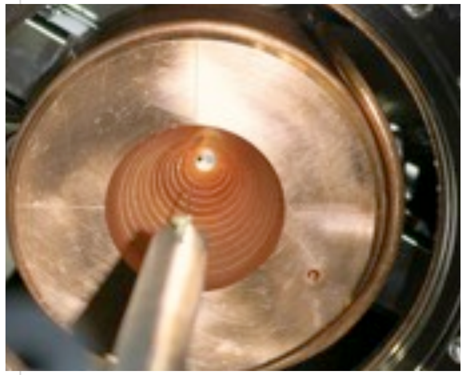
Large transverse acceptance



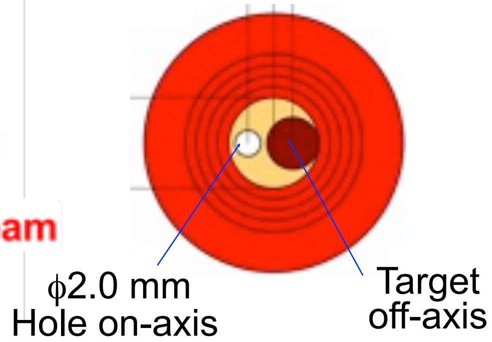
Solenoid field at e+ production target = 3.5T(FC)+1T(Bridge coil) = 4.5 T

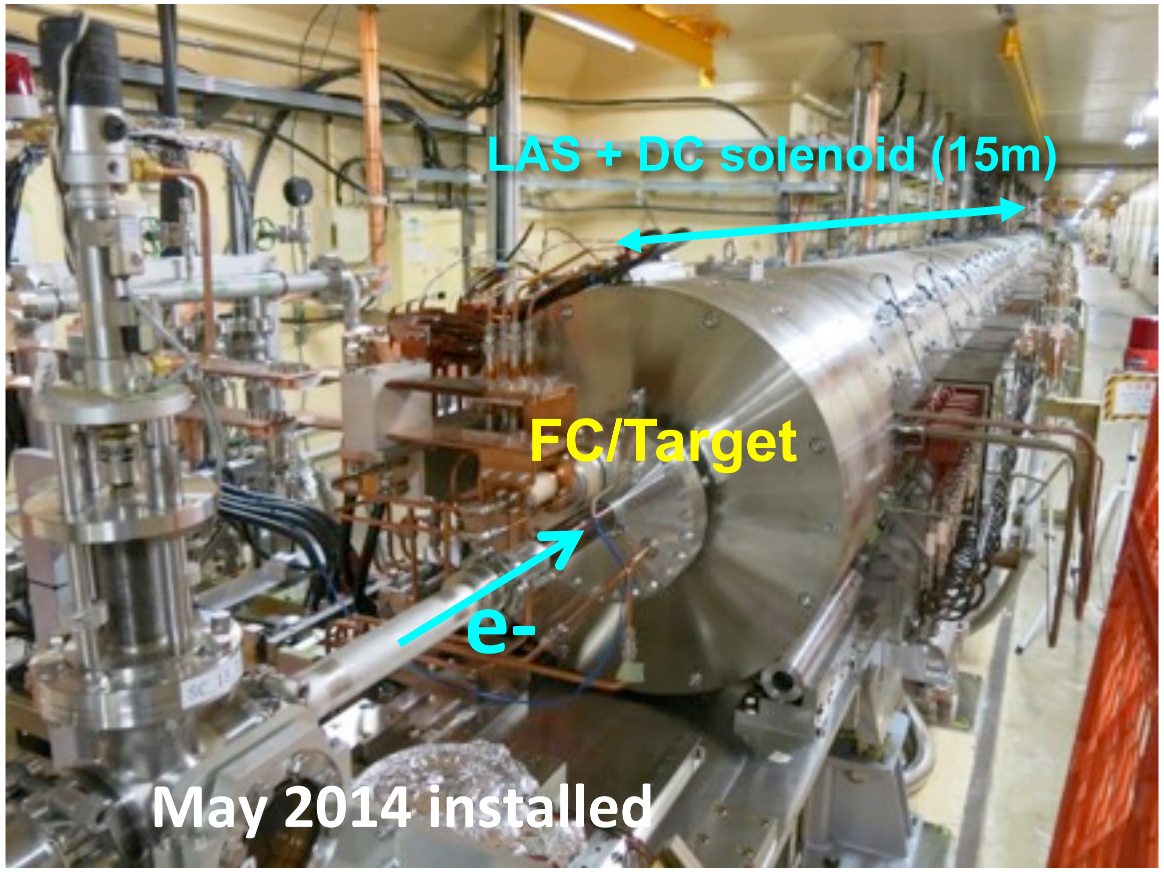


FC viewed from downstream



3.5T@12kA, 6μs (half sine)





Beam Dynamics Issues

Beam Dynamic Issues

- **Dynamic aperture optimization**
  - Local chromaticity correction
  - Sextupoles, skew sextupoles, octupoles,... 74 variables !
- **Dynamic aperture under influence of Beam-Beam**
  - Interference between Beam-Beam and lattice nonlinearity
  - Crab-Waist and nonlinear lattice
- **Luminosity degradation**
  - Interference among Beam-Beam, space charge, and lattice nonlinearity

Dynamic Aperture and Lattice Nonlinear

Dynamic aperture is restricted by fringe field of final focus magnet and kinematic term of drift space. Hamiltonian of nonlinear terms is:

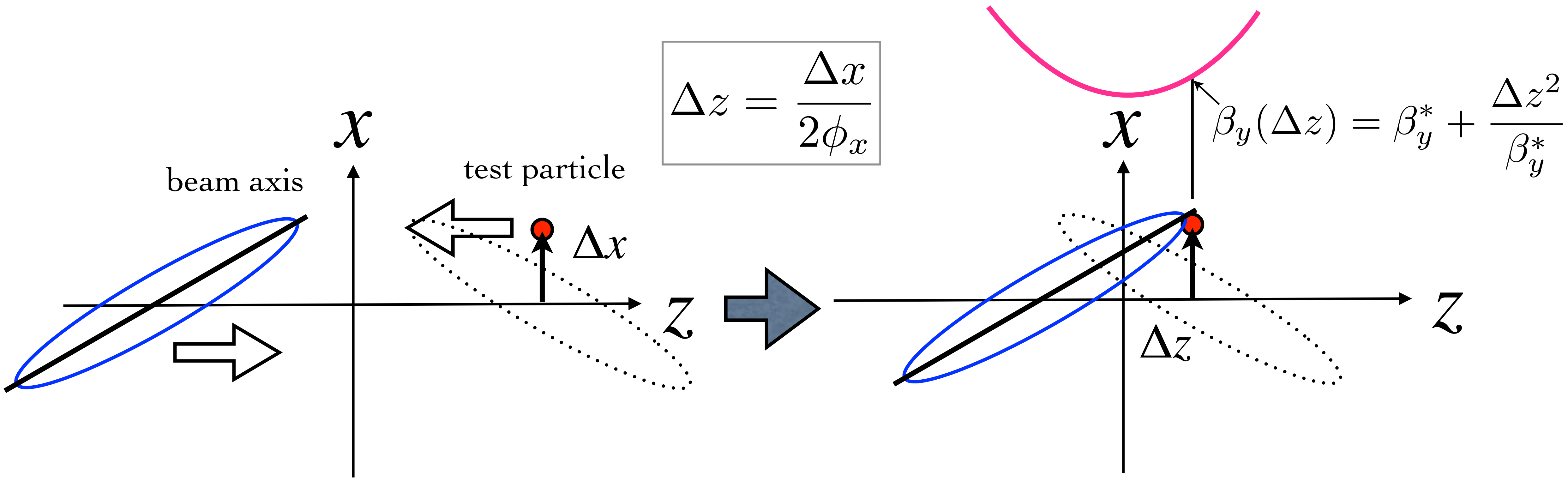
$$H_{nl} = \boxed{\left(1-\frac{2}{3}k_1 L^{*2}\right)\frac{L^*}{\beta_y^{*2}}} J_y^2 \cos\psi_y \qquad k_1 = \frac{1}{B\rho}\frac{\partial B_y}{\partial x}$$

Strength of nonlinearity is 200 times larger than KEKB !

	β_y^* [mm]	k1 [m^{-2}]	L* [m]	coefficient [$\mu\mathrm{m}^{-1}$]
SuperKEKB-HER	**0.30**	**-3.05**	**1.22**	**55.56**
SuperKEKB-LER	**0.27**	**-5.1**	**0.76**	**31.25**
FCC-ee	**1.0**	**-0.336**	**2.0**	**3.79**
CEPC	**1.2**	**-0.176**	**1.5**	**1.32**
KEKB	**5.9**	**-1.78**	**1.76**	**0.237**
DAFNE	**8.66**	**-9.23**	**0.20**	**0.0033**

Beam-Beam Effect for Large Horizontal Orbit

- The horizontal orbit(deviation from beam axis) is translated into the longitudinal displacement in the nano-beam scheme.



$$\Delta z = \frac{\Delta x}{2\phi_x}$$

$$\beta_y(\Delta z) = \beta_y^* + \frac{\Delta z^2}{\beta_y^*}$$

$$\Delta x = 30\sigma_{x0} \rightarrow \Delta z = 3.6\ mm$$

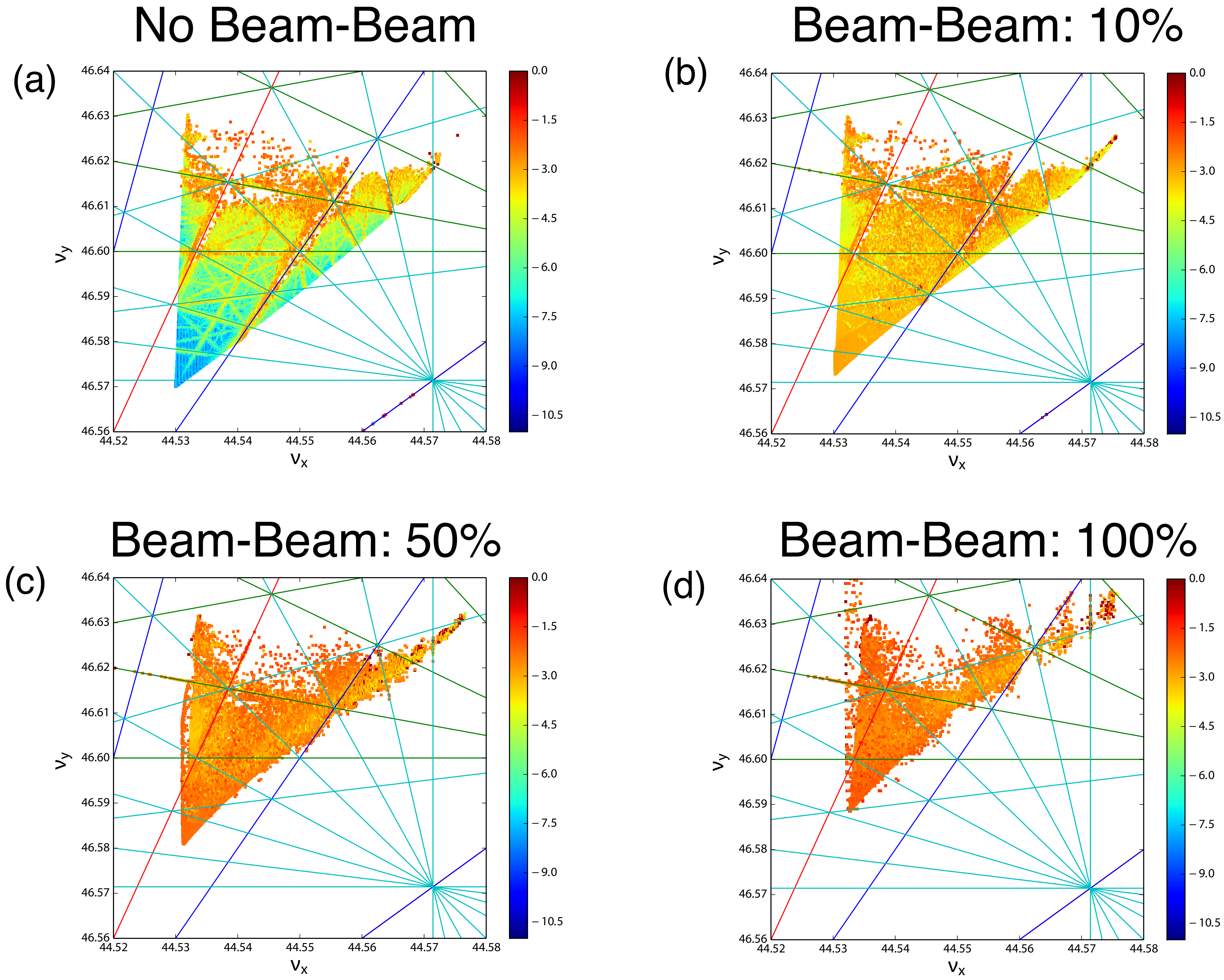
$$\text{high vertical beta} \rightarrow \beta_y(\Delta z) = 48\ mm >> \beta_y^* = 0.27\ mm$$

$$\Delta y \propto \theta_y^{bb}\sqrt{\beta_y(\Delta z)}$$

~factor of 180

- Particles with a large horizontal orbit are kicked by beam-beam at high vertical beta region if there is a vertical orbit. Consequently, the vertical betatron oscillation increases due to the vertical beam-beam kick. The transverse aperture decreased, which implies small dynamic aperture.

FMA for Beam-Beam effect in LER



No Beam-Beam

Beam-Beam: 10%

Beam-Beam: 50%

Beam-Beam: 100%

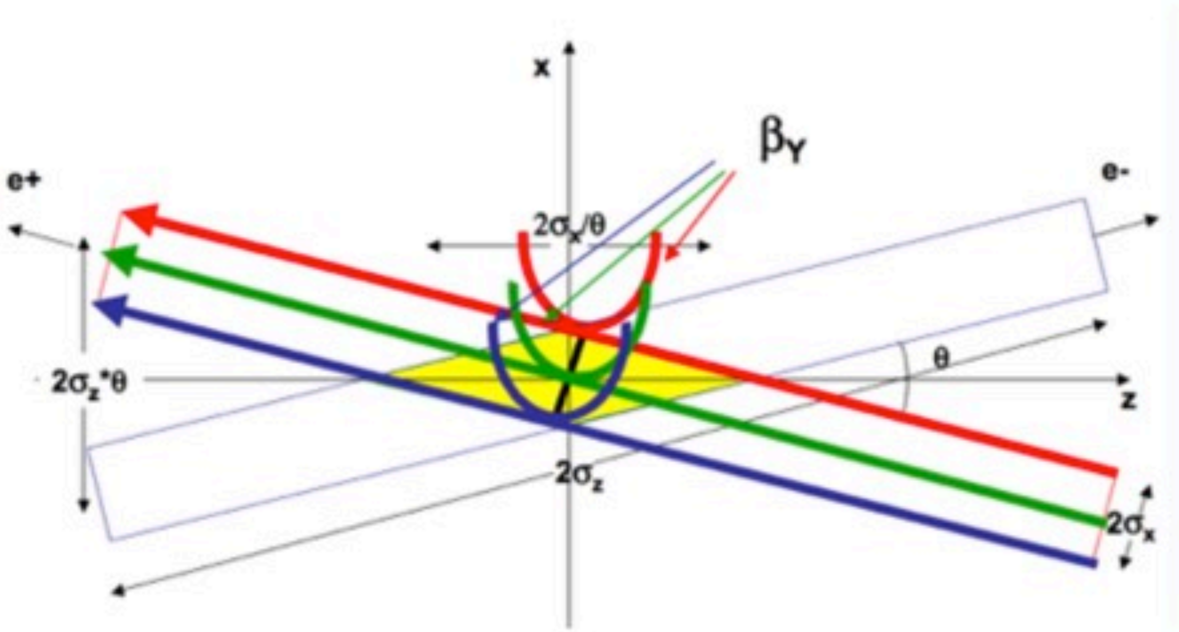
Crab-Waist Scheme

Insert Crab-Waist Hamiltonian into the IP:

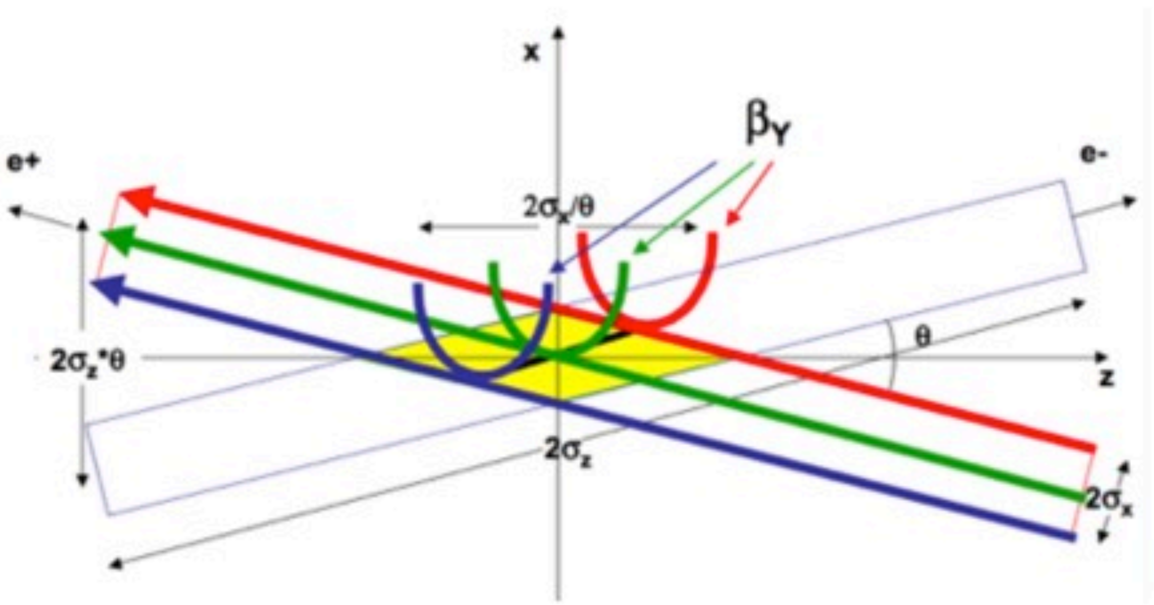
$$H_{cw} = \frac{1}{2\tan 2\phi_x} x p_y^2 \quad \Rightarrow \quad \begin{pmatrix} \tilde{y} \\ \tilde{p_y} \end{pmatrix} = \begin{pmatrix} 1 & \overset{\Delta z}{\overset{\swarrow}{\frac{x}{\tan 2\phi_x}}} \\ 0 & 1 \end{pmatrix} \begin{pmatrix} y \\ p_y \end{pmatrix}$$

Waist can move proportional to the horizontal amplitude.

w/o CW



w/ CW

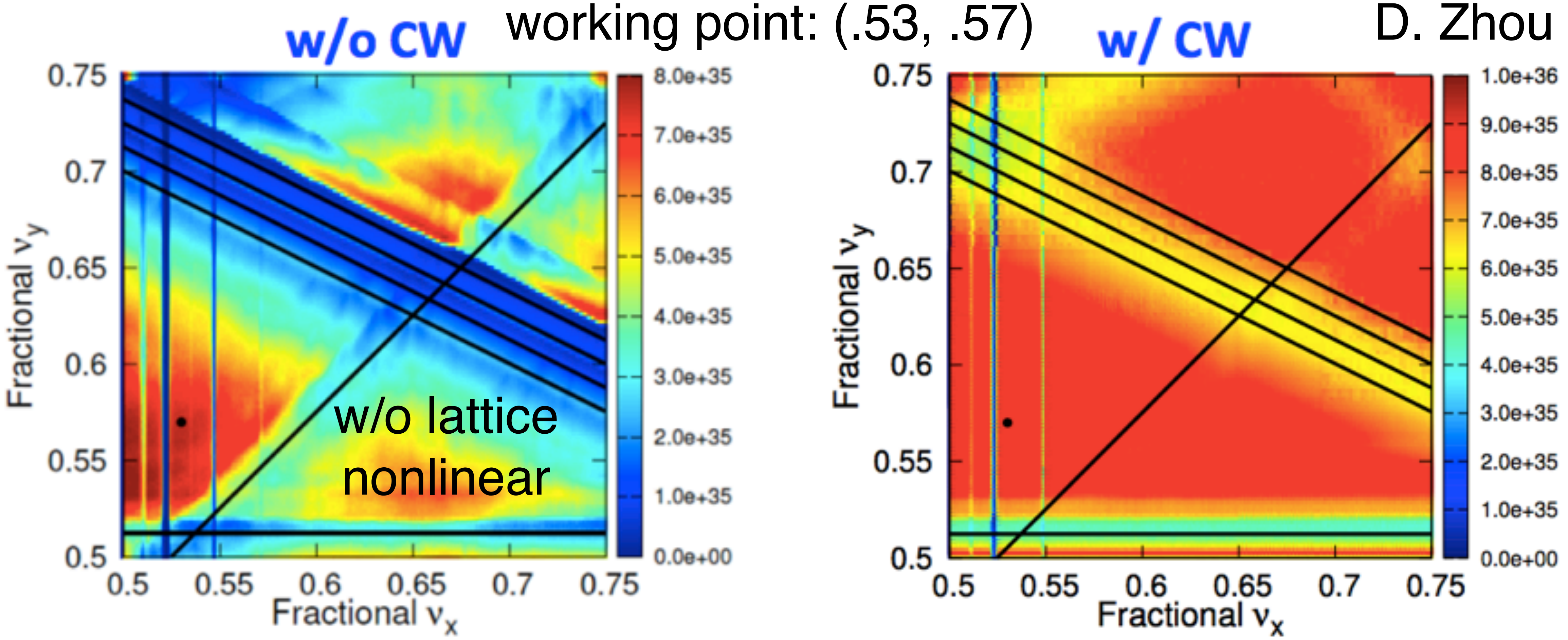


M. Zobov, Phys. Part. Nucl. 42 (2011) 782-799

Stability of Luminosity and Recover of DA

working point: (.53, .57)

D. Zhou



w/o CW

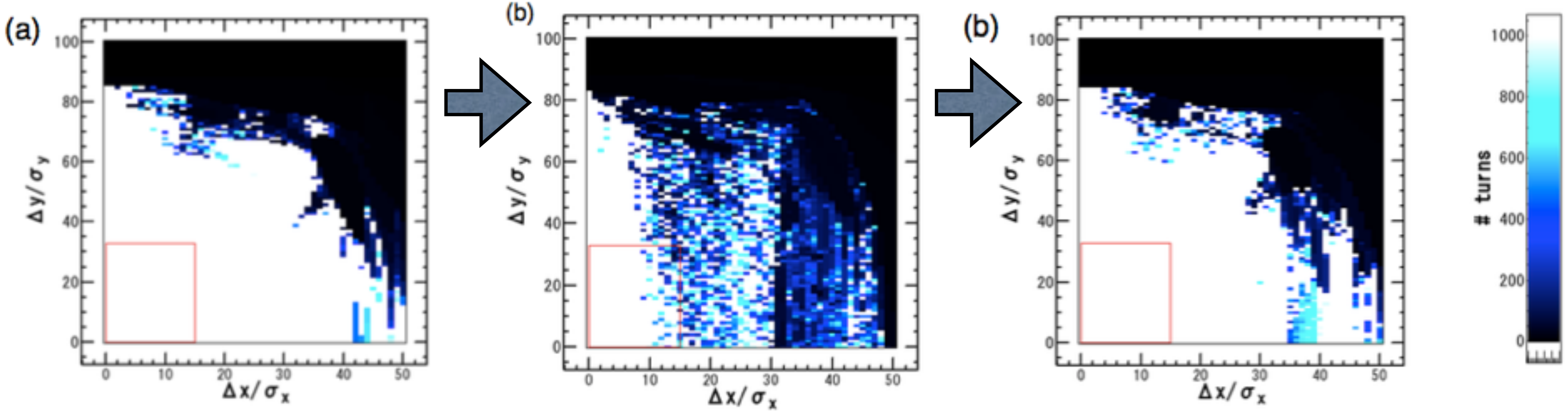
w/ CW

w/o lattice nonlinear

w/o BB

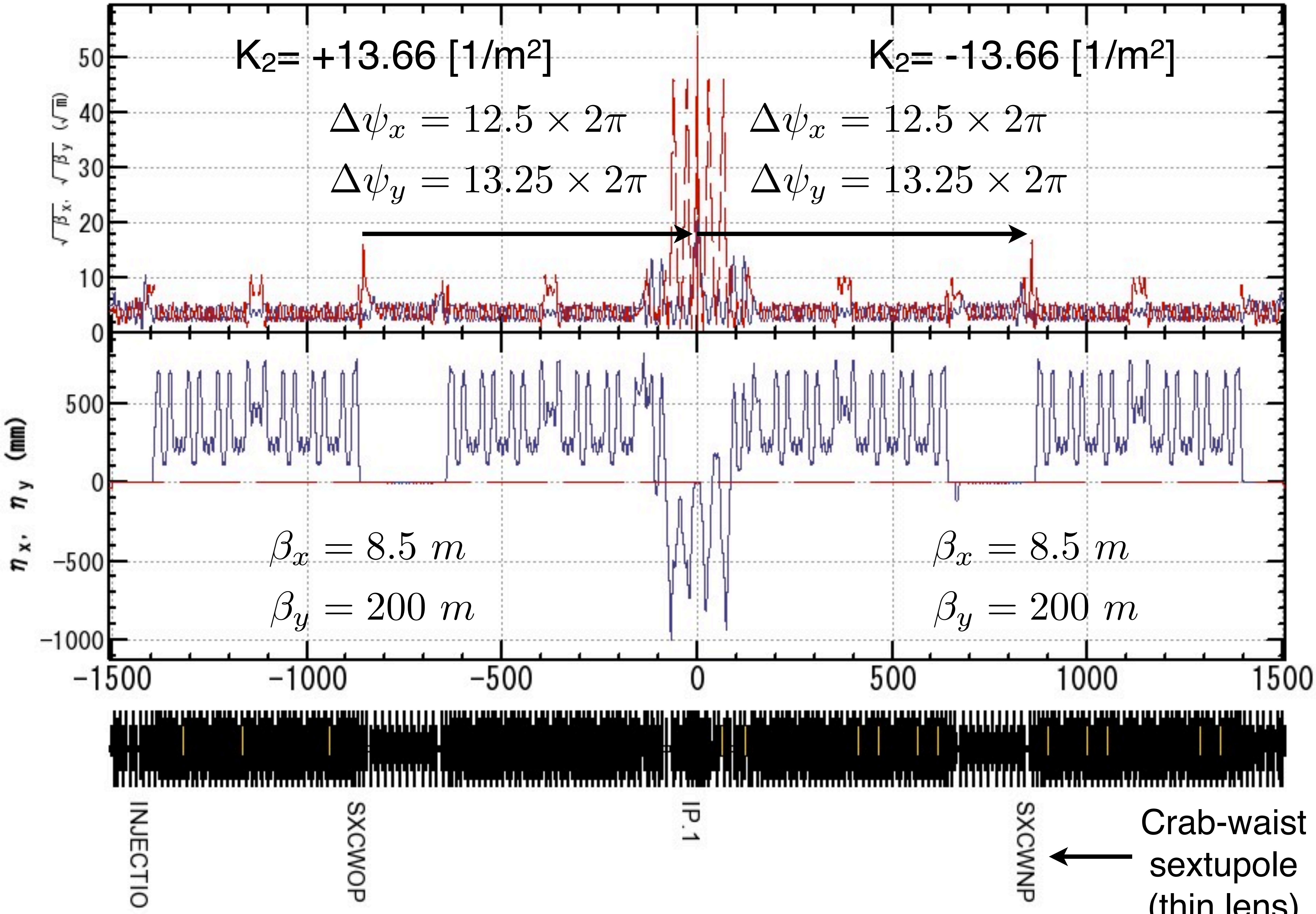
w/ BB

w/ BB+ ideal CW



Crab-Waist Optics in LER

sler_1689_cw2d.sad

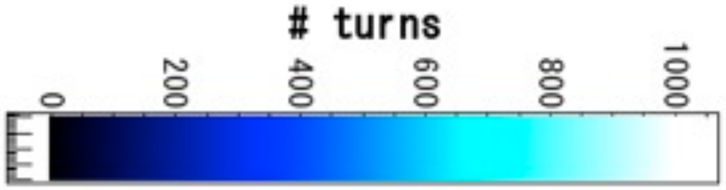


Crab-waist sextupole (thin lens)

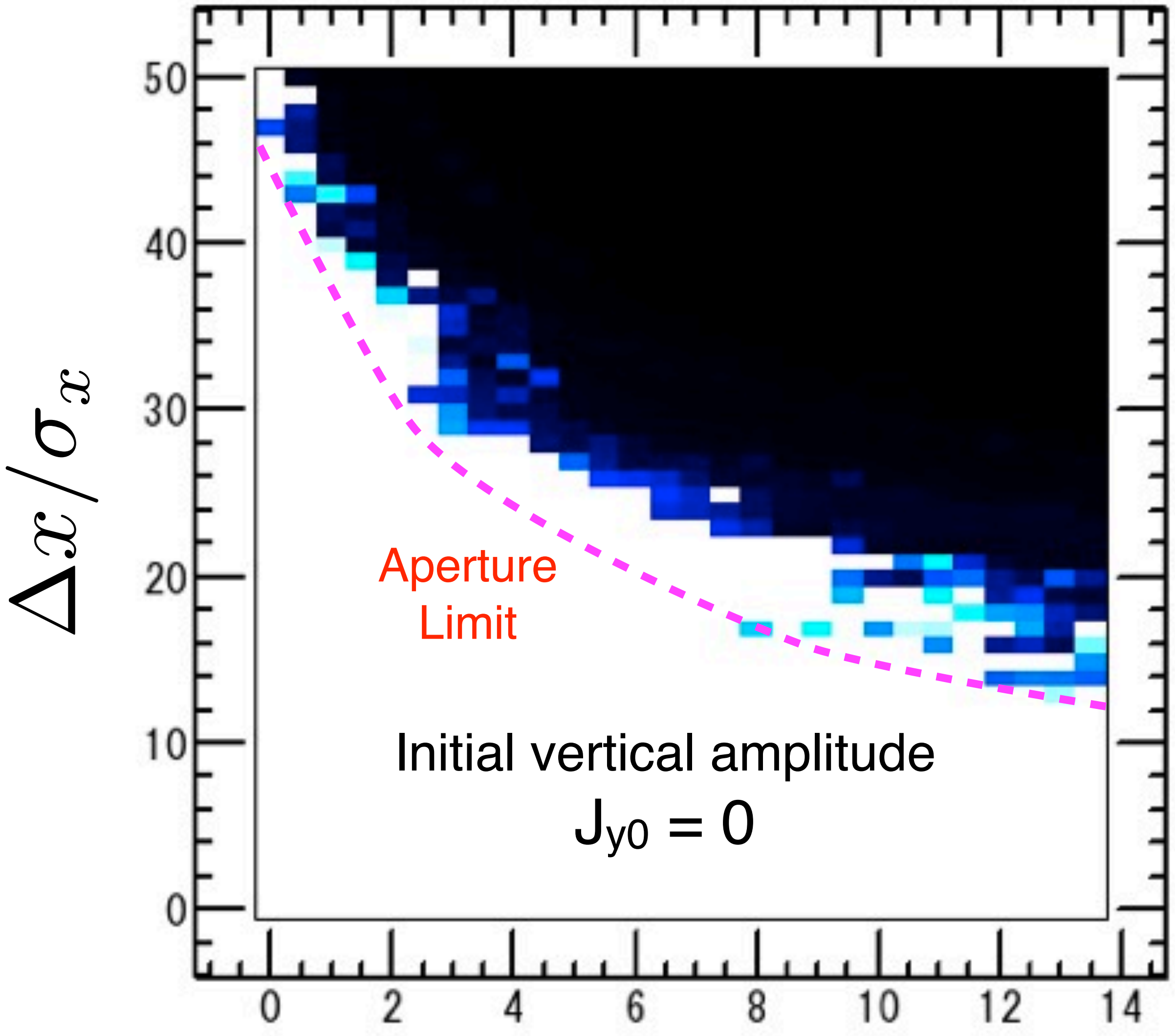
Transverse Aperture for Crab-Waist Scheme

Initial momentum deviation

$$\delta_0 = \Delta p/p_0 = 0$$



without Beam-Beam



Aperture Limit

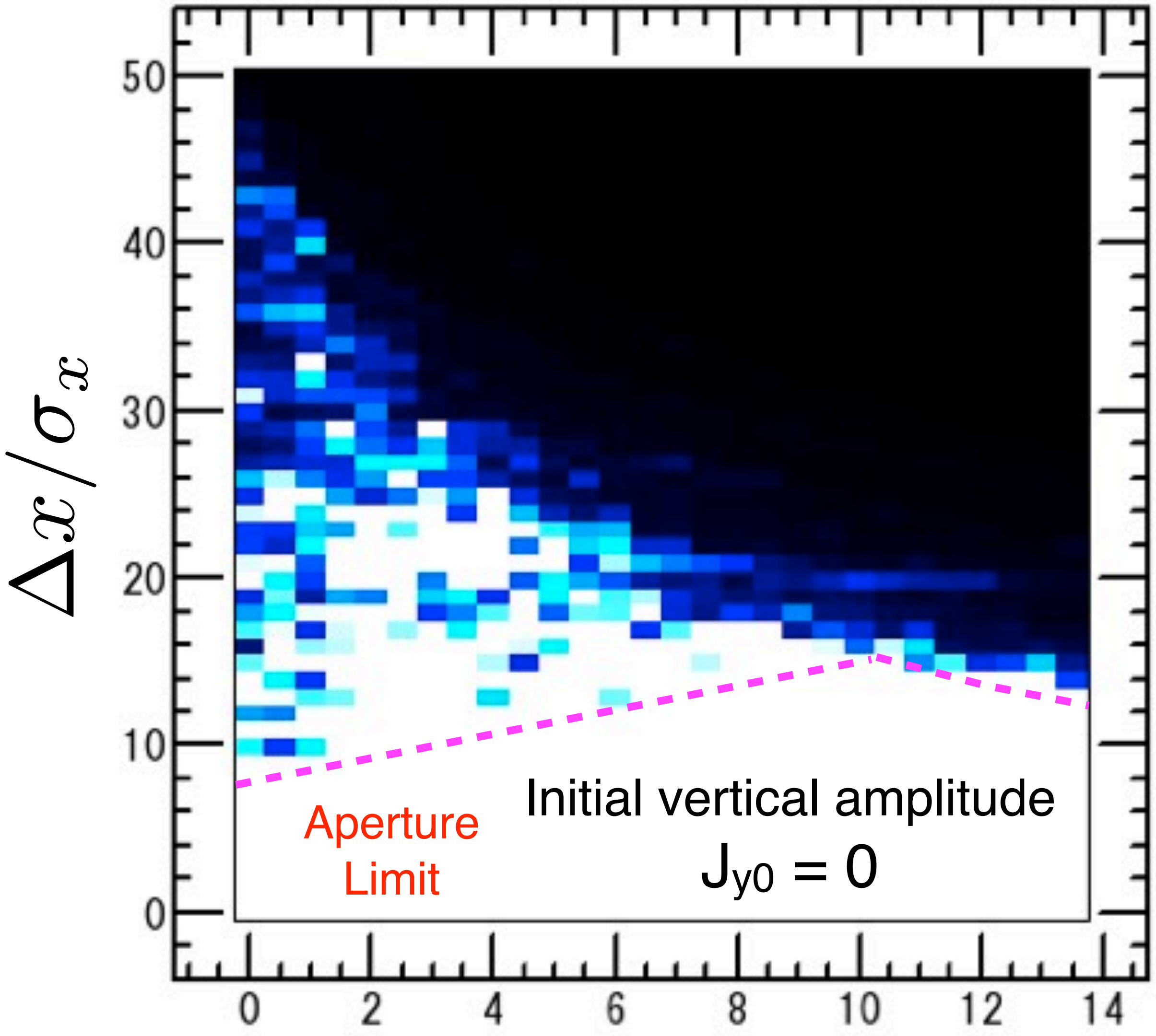
Initial vertical amplitude $J_{y0} = 0$

$|K_2|$ [1/m^2]

Crab-Waist Sextupole OFF

Aperture is constrained by sextupole strength.

with Beam-Beam



Aperture Limit

Initial vertical amplitude $J_{y0} = 0$

$|K_2|$ [1/m^2]

Crab-Waist Sextupole OFF

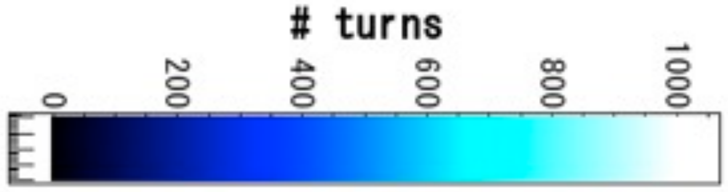
Aperture is recovered up to w/o Beam-Beam.

Transverse Aperture for Crab-Waist Scheme

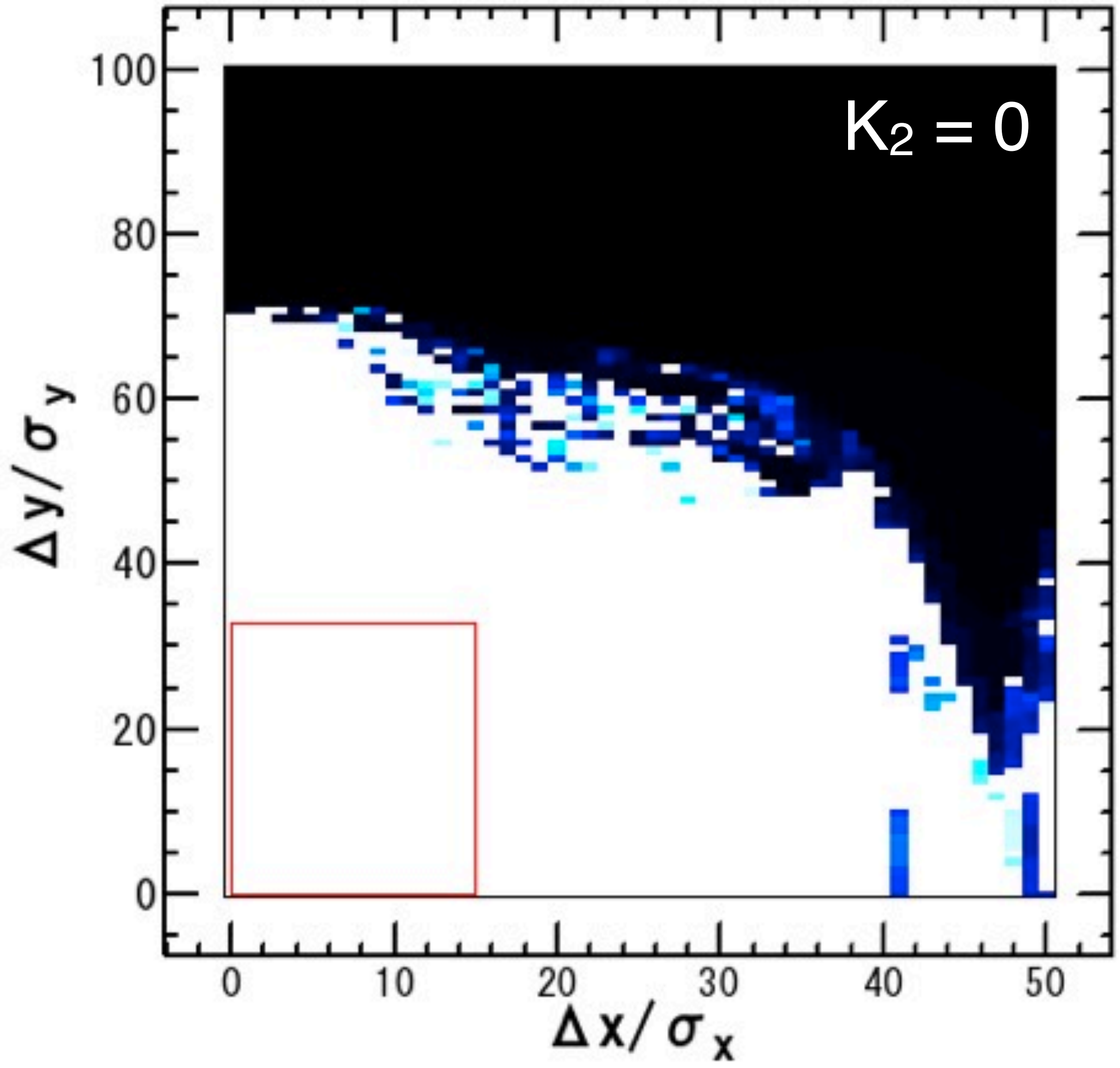
without Beam-Beam

Initial momentum deviation

$$\delta_0 = \Delta p/p_0 = 0$$

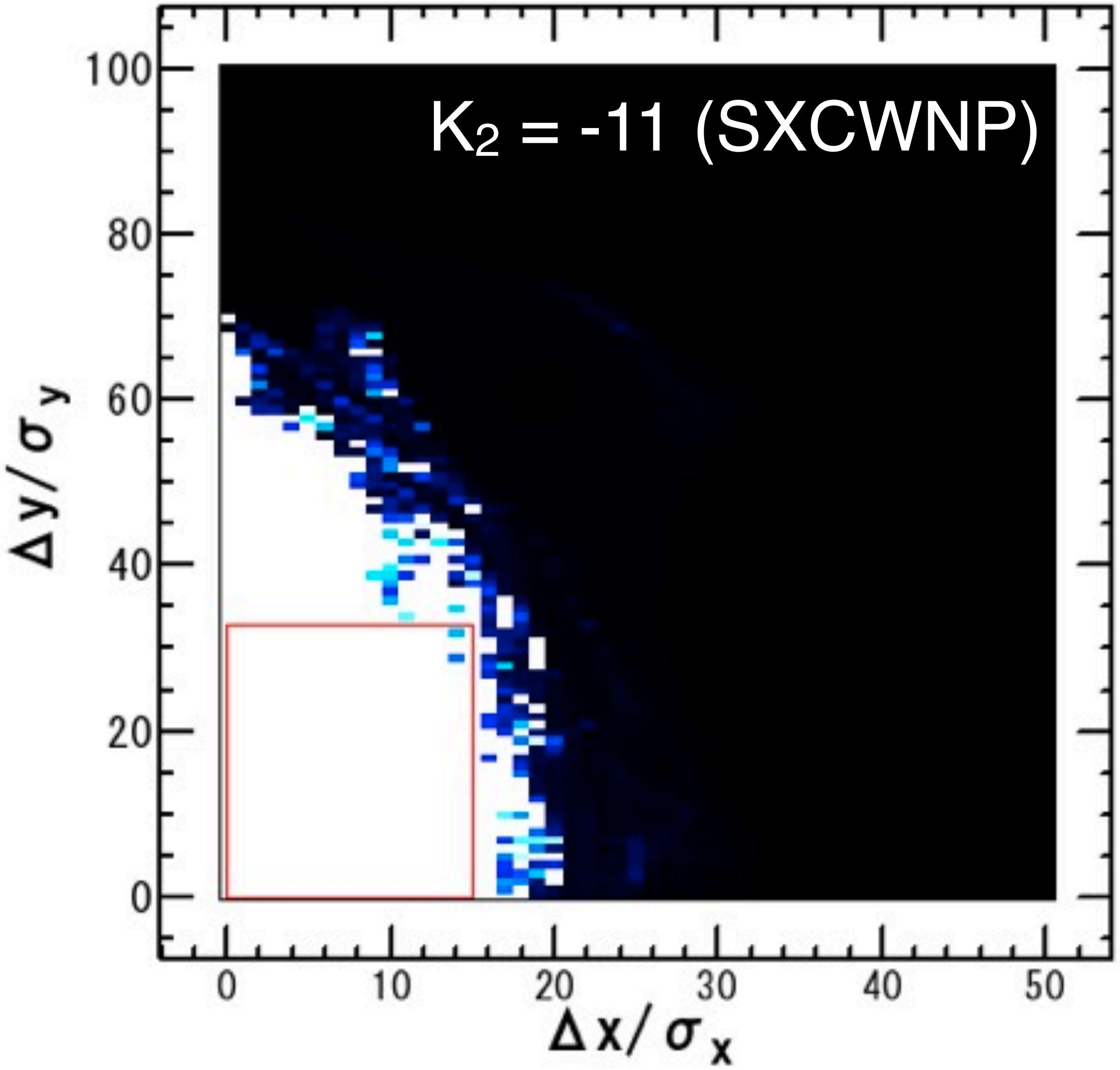


CW Sextupole OFF



stable < $40\sigma_x$

CW Sextupole ON



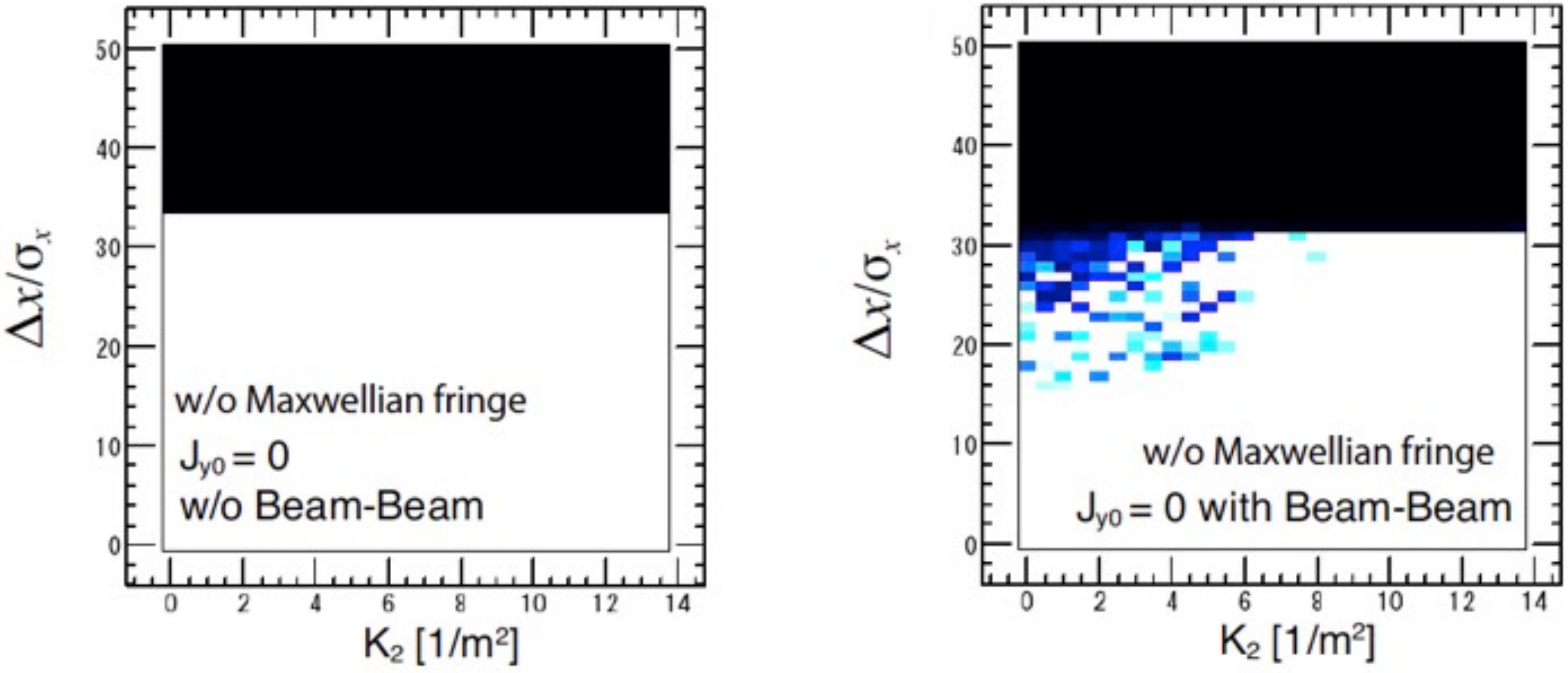
unstable > $17\sigma_x$

Crab-Waist with linearized IR

- Cancellation between crab-waist sextupoles does not work because the transfer map is not linear between them.
- The sources of nonlinear terms are fringe field of the final focus quadrupole and kinematic terms from the drift space in the vicinity of IP.

80% of nominal is enough.

almost linearized lattice in IR



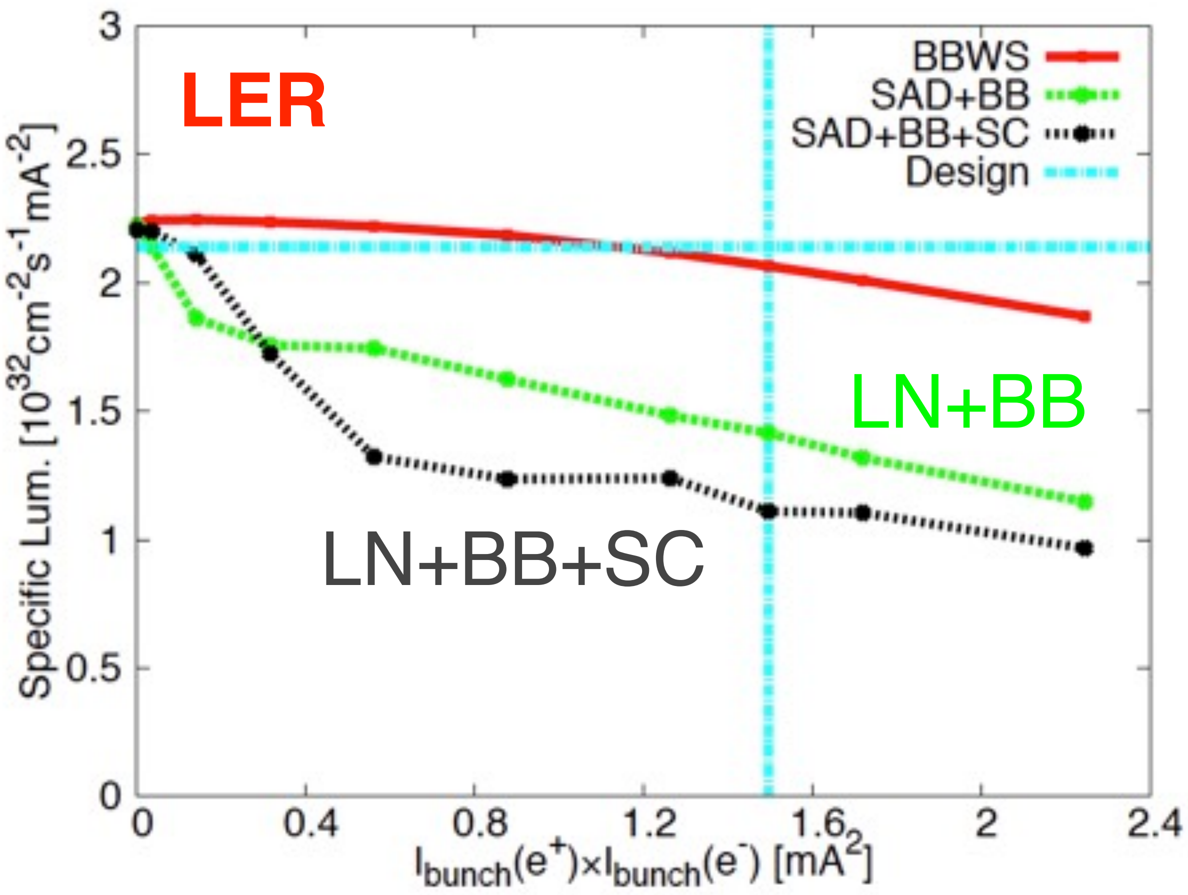
Space Charge and Beam-Beam Tune Shift

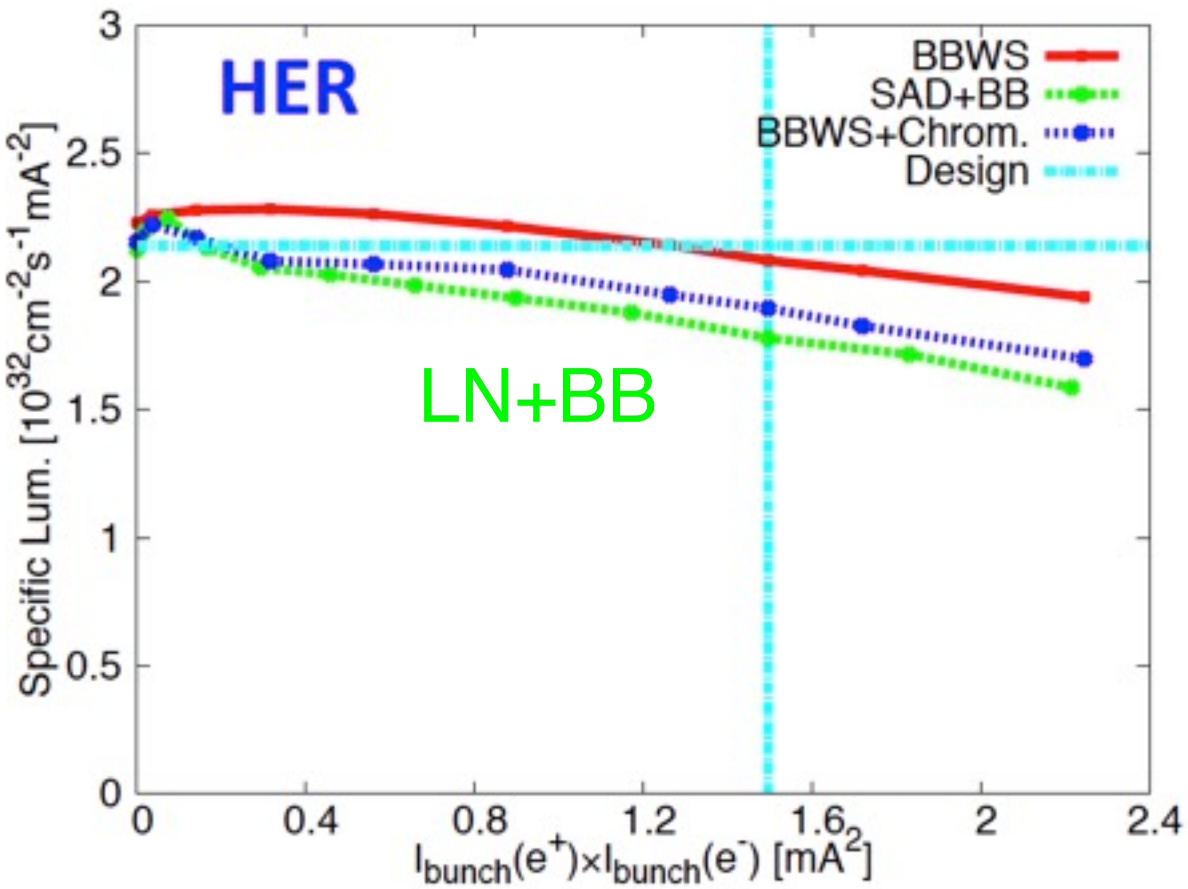
Same order between Beam-Beam and space-charge
Opposite signs

D. Zhou

	SuperKEKB		**KEKB**	
	LER	**HER**	**LER**	**HER**
Energy [GeV]	4	7	3.5	8
ε_x [nm]	3.2	4.6	18	24
ε_y [pm]	8.64	11.5	180	240
ξ_x	0.0028	0.0012	0.127	0.102
ξ_y	**0.088**	0.081	0.129	0.090
$\Delta\nu_x$	-0.0027	-0.0004	-0.0005	-0.00003
$\Delta\nu_y$	**-0.094**	-0.012	-0.0072	-0.0004

Lattice Nonlinear + Beam-Beam + Space Charge





Weak-strong simulation

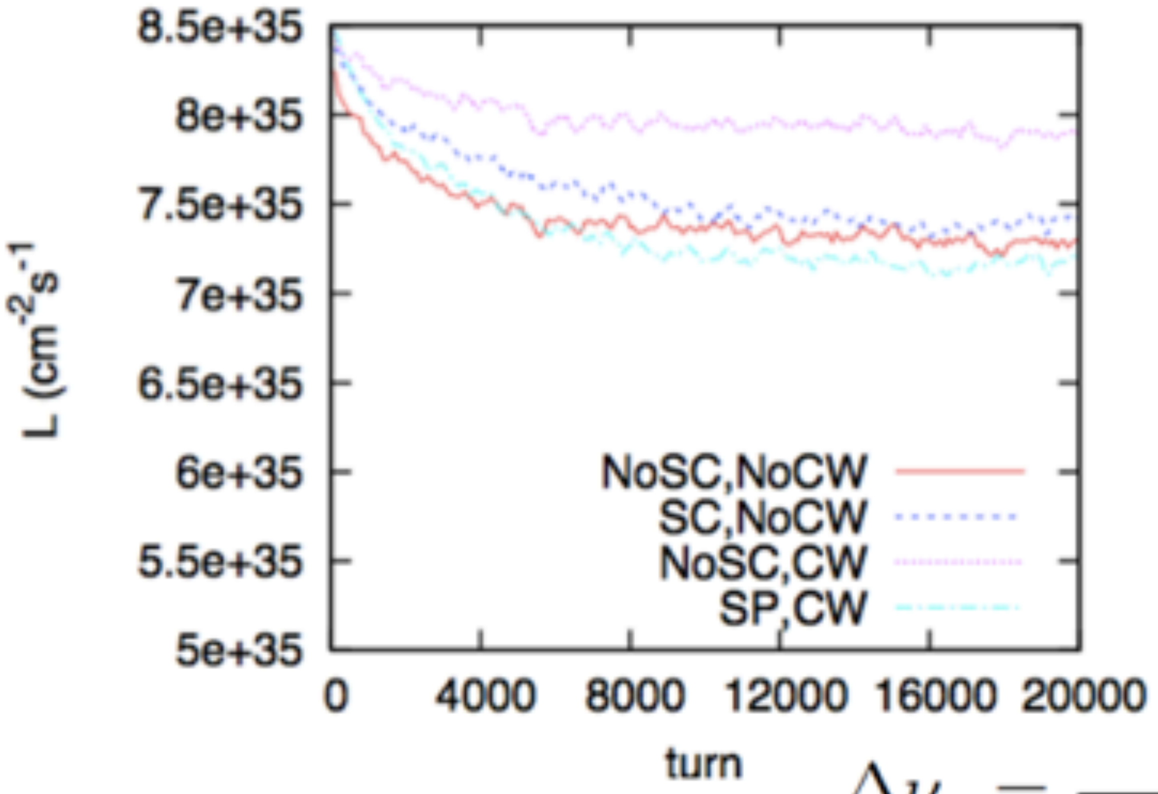
D. Zhou

LN + BB implies significant luminosity loss.
Vertical emittance is very sensitive to Beam-Beam perturbation.
SC compensates BB luminosity loss at low current in LER.

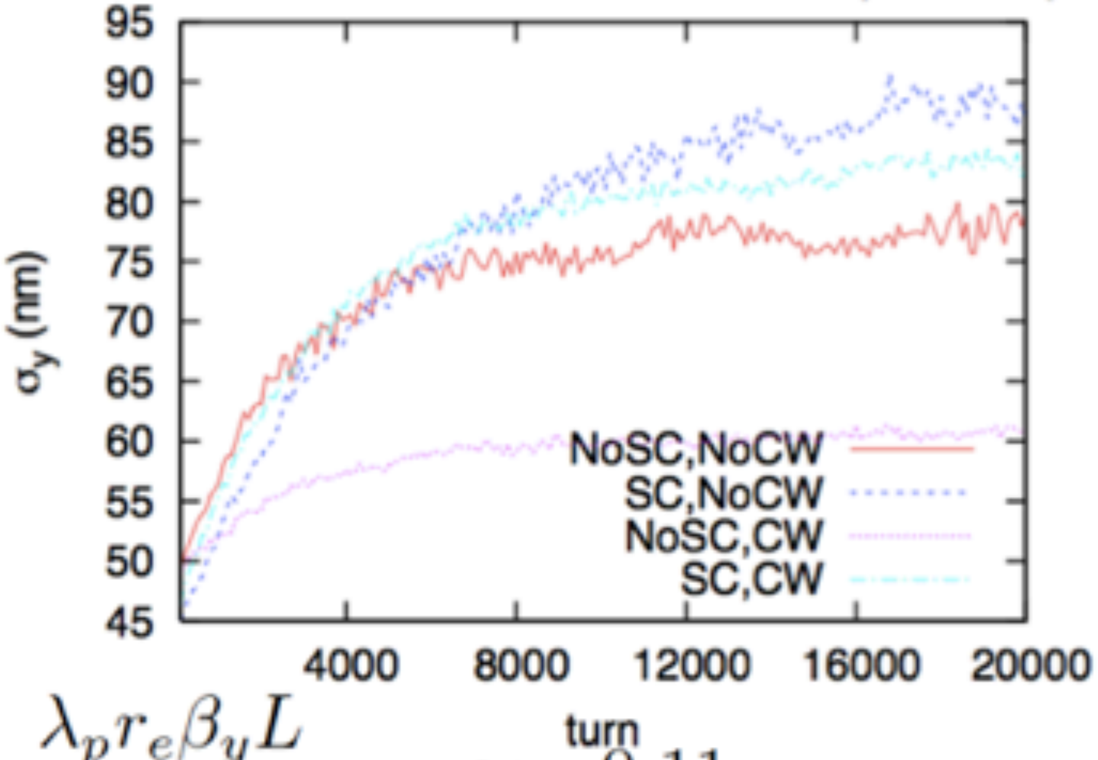
Serious beam dynamic issue still remains.

Beam-Beam with Space Charge

- ➤ **Independent simulation (BBWS+SC) showed SC effects are not serious, but:**
  - No lattice nonlinearity
  - Simple model for SC (Only consider tune spread due to SC)



K.Ohmi to M. Zobov, Mar.27,2012



$$\Delta\nu_y = \frac{\lambda_p r_e \beta_y L}{2\pi\gamma_p^3 \sigma_y(\sigma_x + \sigma_y)} \approx -0.11$$

Schedule

Phase-1: February 2016 - July 2016.

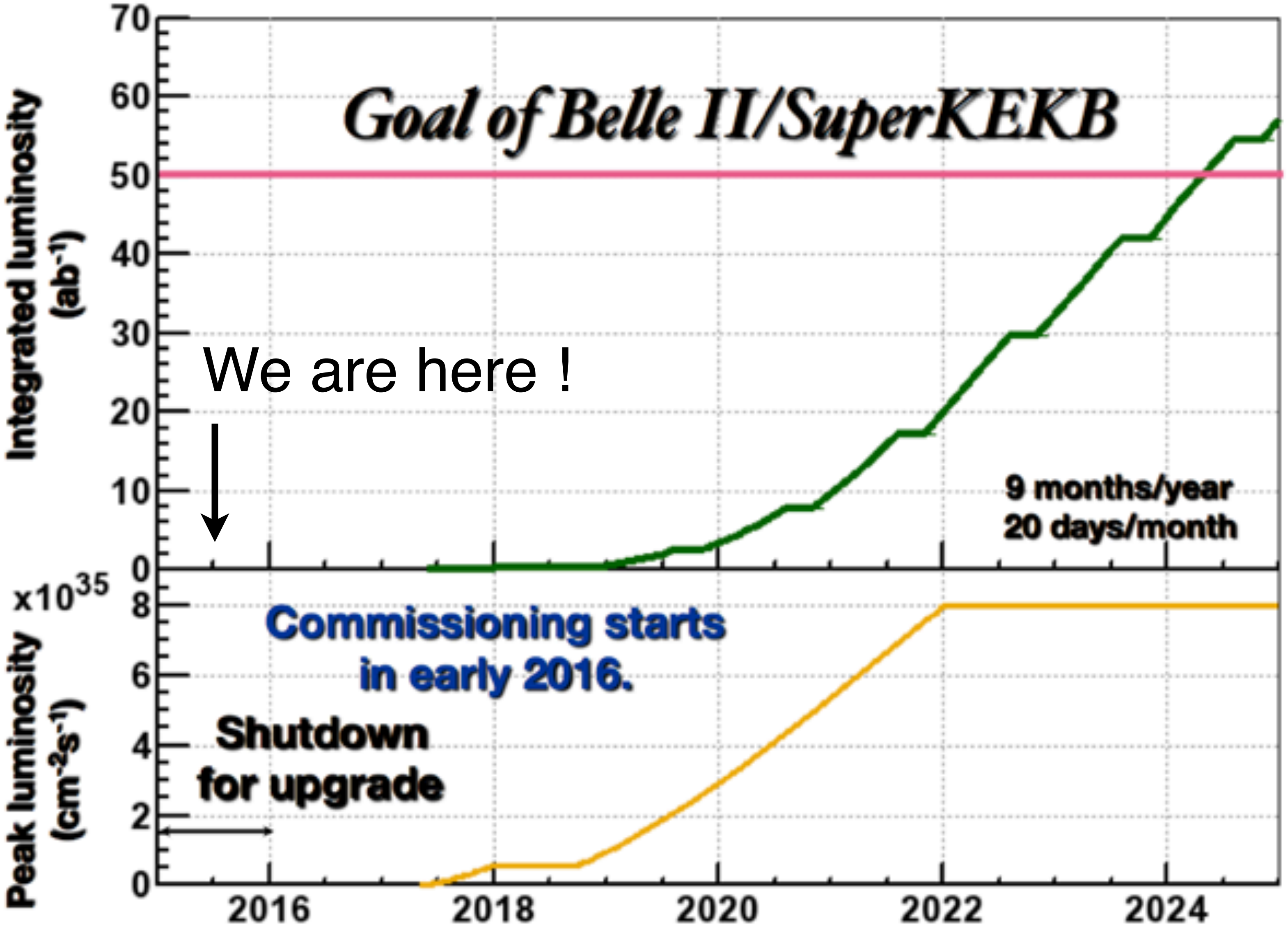
No final focus system, vacuum scrubbing, low emittance tuning

Phase-2: May 2017 - Dec. 2017

QCS without vertex detector, the first collision, L > 10^{34}

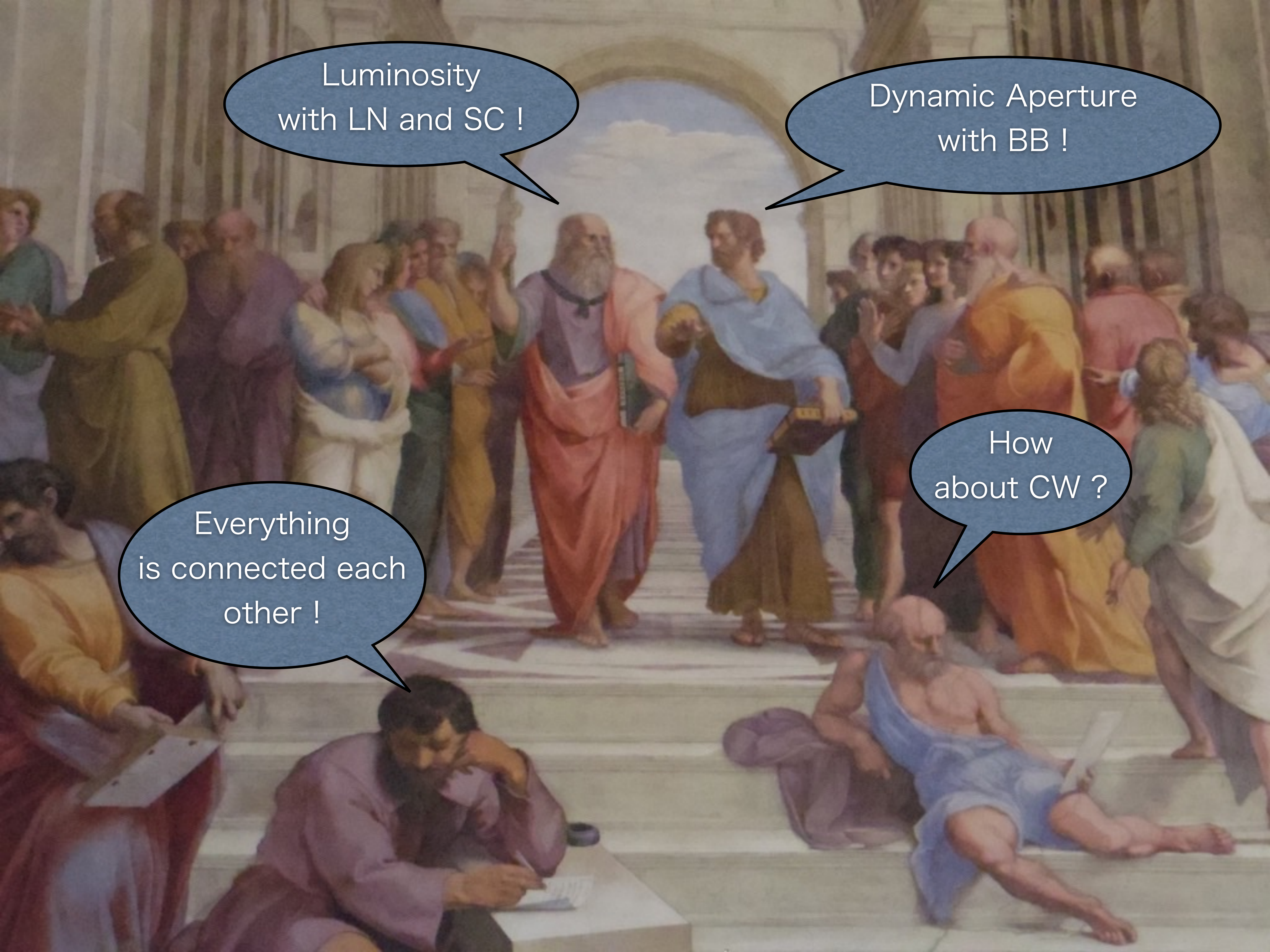
Phase-3: October 2018 -

Physics run with full detector, squeezing beta and increasing currents



Summary

- Accelerator construction is on going.
- We have prepared and installed most of the components.
- There are a few serious issues on beam dynamics to be fixed.
  - Especially, dynamic aperture with Beam-Beam and luminosity degradation due to the interference of Beam-Beam, lattice nonlinear, and space charge.
  - Not solved so far.
- SuperKEKB is a challenge of the low emittance collider and the nano-beam scheme to achieve the highest luminosity at e+e- B-Factory.


Luminosity with LN and SC !
Dynamic Aperture with BB !
How about CW ?
Everything is connected each other !

No Photo
of
The Last Judgement....

Backup