SuperKEKB Project

Hiroshi Sugimoto
SuperKEKB Beam Optics Group

Beam Optics Group
H. Koiso, Y Ohnishi, A. Morita, H. Sugimoto, K. Oide

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  - Final focusing magnet
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  - …

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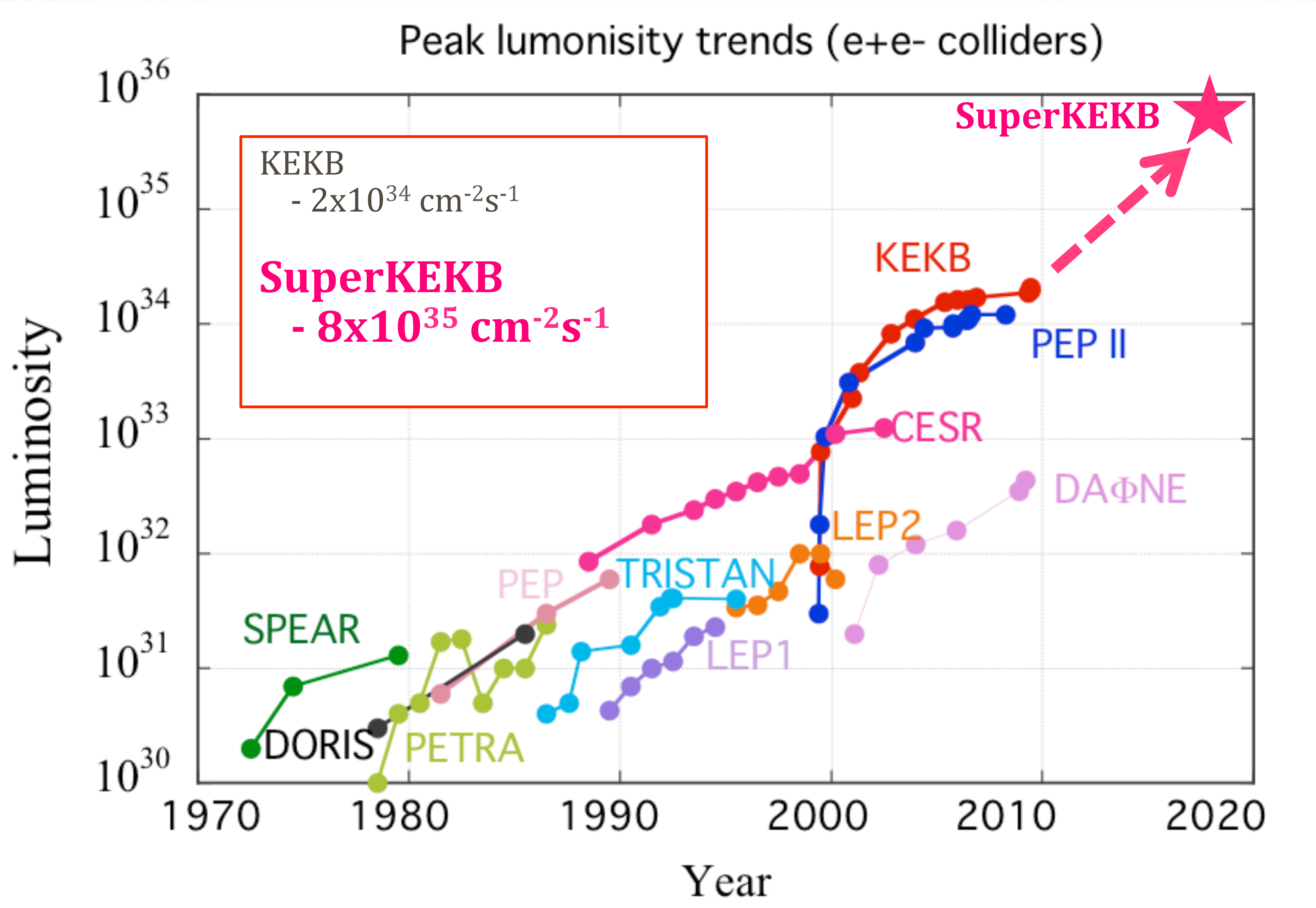
SuperKEKB Overview

World Luminosity Trends



To Get x40 Higher Luminosity

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

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

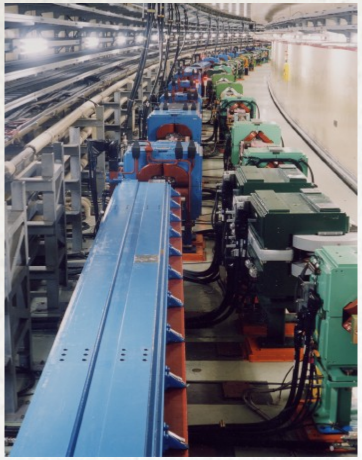
- Vertical β function at IP: 5.9 → 0.27/0.30 mm (e^+ / e^-) (× 20)

- Beam current: 1.7/1.4 → 3.6/2.6 A (× 2)

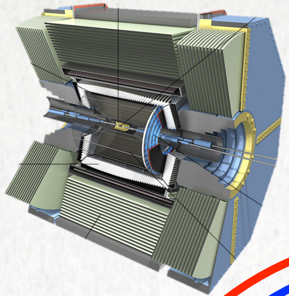
- Beam-beam parameter: .09 → .09 (× 1)

- Beam energy: 3.5/8.0 → 4.0/7.0 GeV

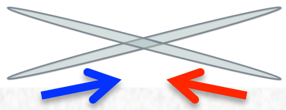
SuperKEKB

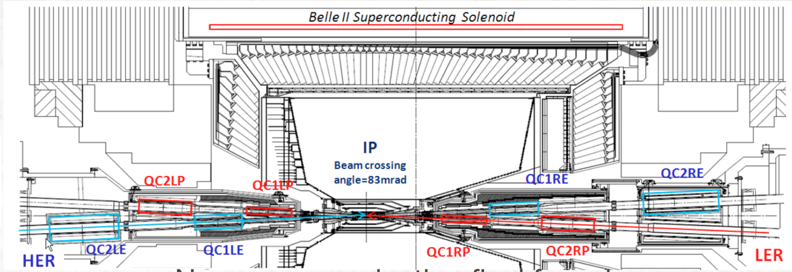


Upgrade to Belle II detector



Colliding bunches





New superconducting final focusing magnets near the IP

e^+ 3.6A

e^- 2.6A

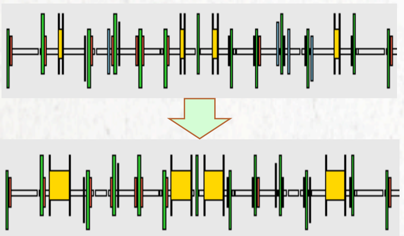
KEKB to SuperKEKB

- Nano-Beam scheme
  - extremely small β_y^*
  - low emittance
- Beam current double

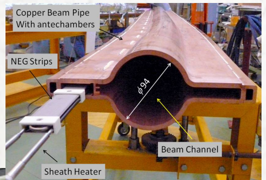
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

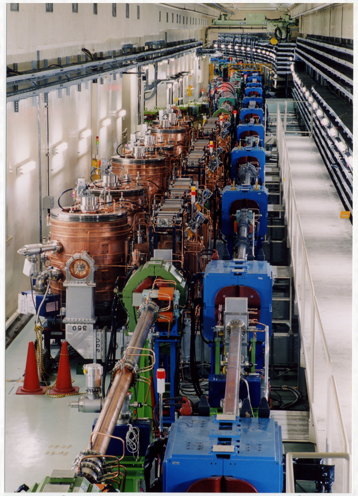
40 times higher luminosity
2.1×10^{34} --> 8×10^{35} $cm^{-2}s^{-1}$

Redesign the lattice to squeeze the emittance (replace short dipoles with longer ones, increase wiggler cycles)



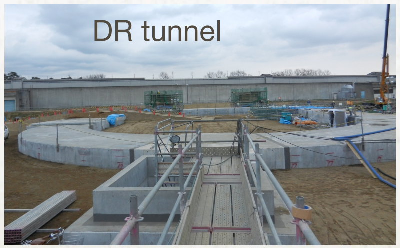
Replace beam pipes with TiN-coated beam pipes with antechambers





Reinforce RF systems for higher beam currents

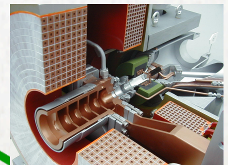
Improve monitors and control system



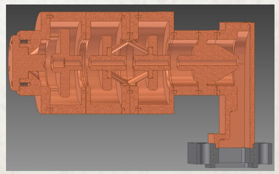
New e+ Damping Ring

Injector Linac upgrade

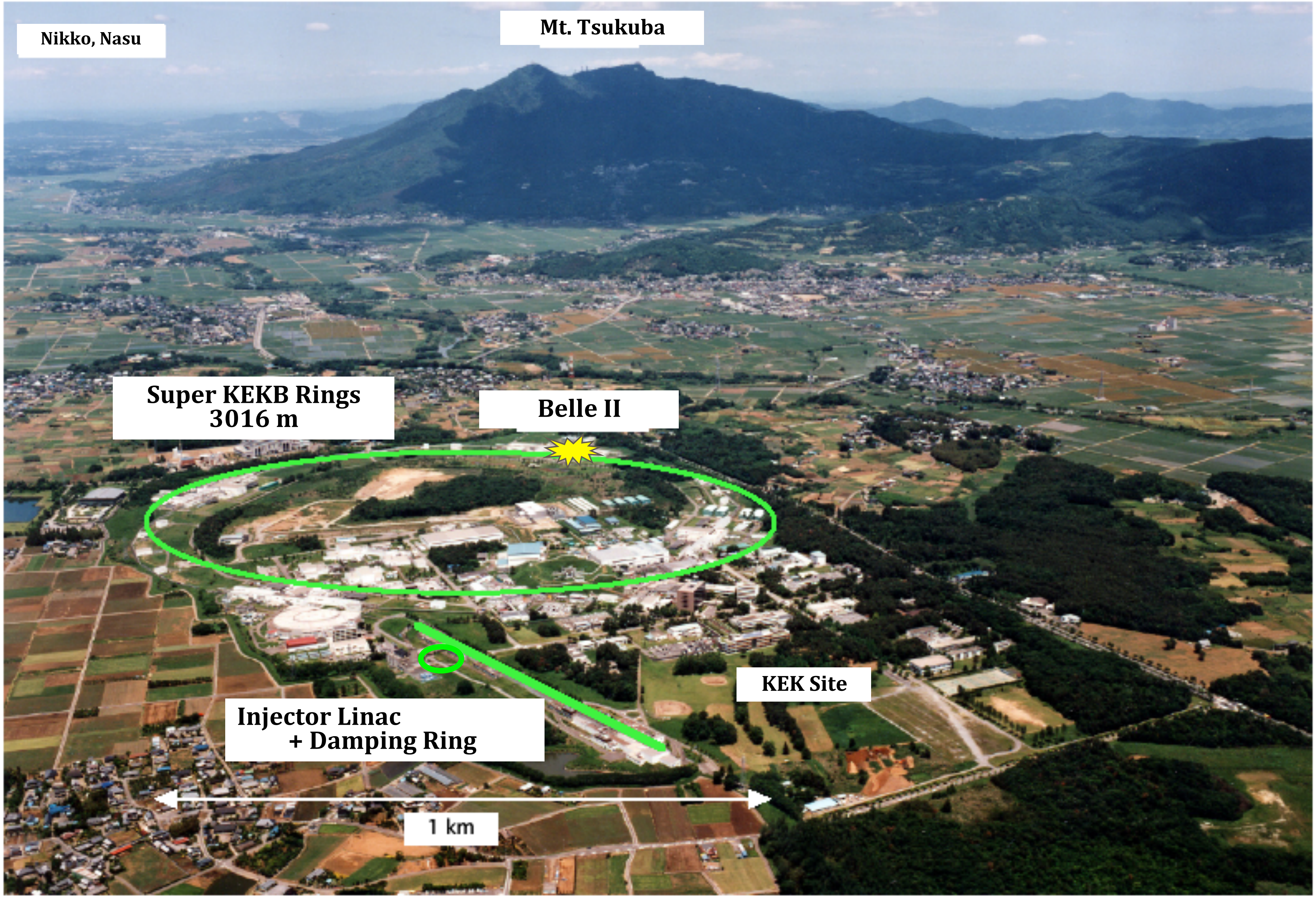
Upgrade positron capture section



Low emittance RF electron gun



SuperKEKB Site



KEKB and SuperKEKB Parameters

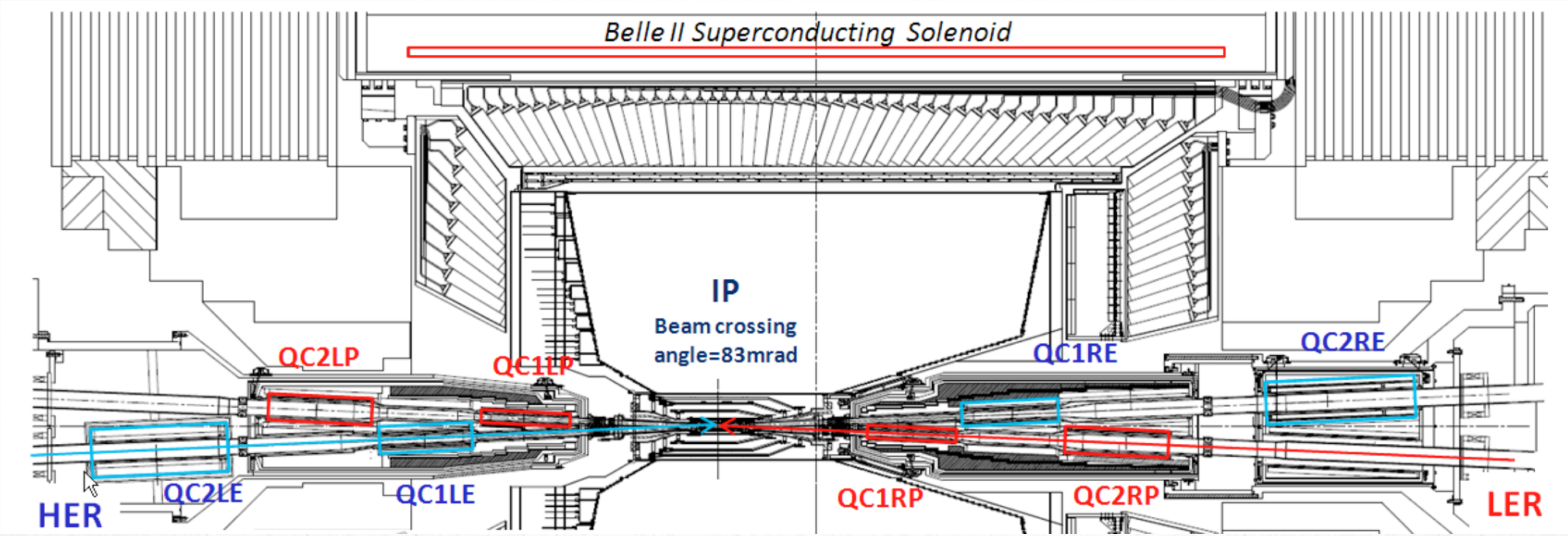
parameters		KEKB(@record)		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7.007	GeV
Crossing angle (full)	ϕ	22		83		mrad
# of Bunches	N	1584		2500		
Horizontal emittance	ε_x	18	24	3.2	4.6	nm
Emittance ratio	κ	0.88	0.66	0.27	0.28	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
Max. beam currents	I_b	2.0	1.4	3.6	2.6	A
Beam-beam param.	ξ_y	0.129	0.090	0.0881	0.0807	
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}**		**$cm^{-2}s^{-1}$**

Intra-beam scattering is included.

Construction Status

- Overview -

Final Focusing Magnets System (QCS)

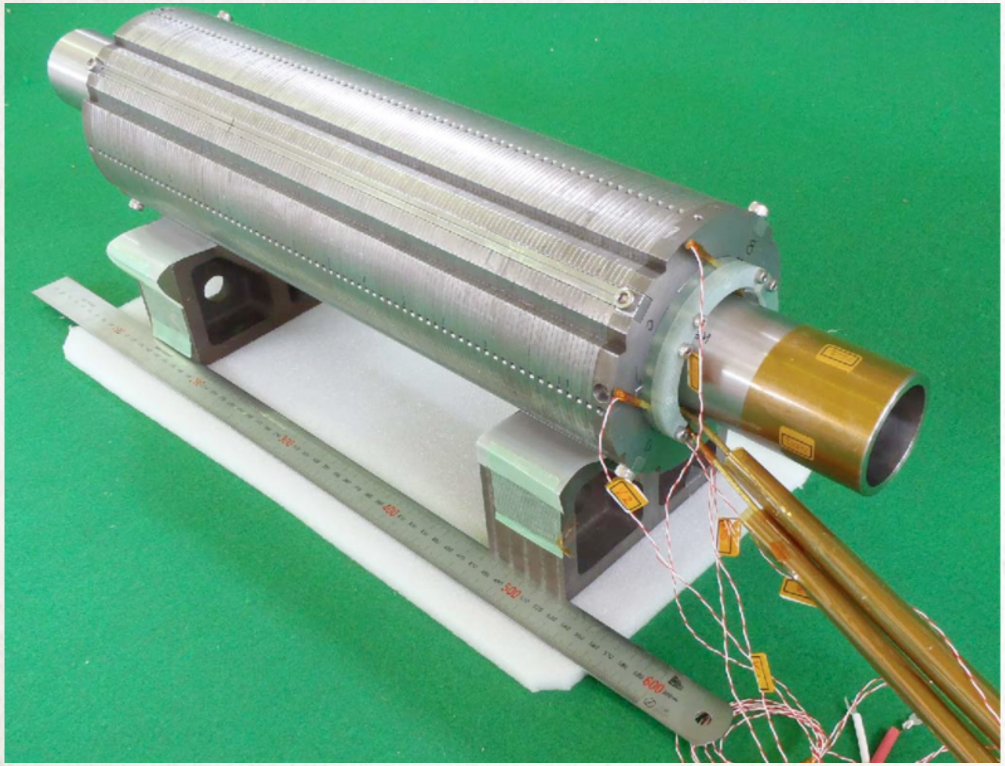


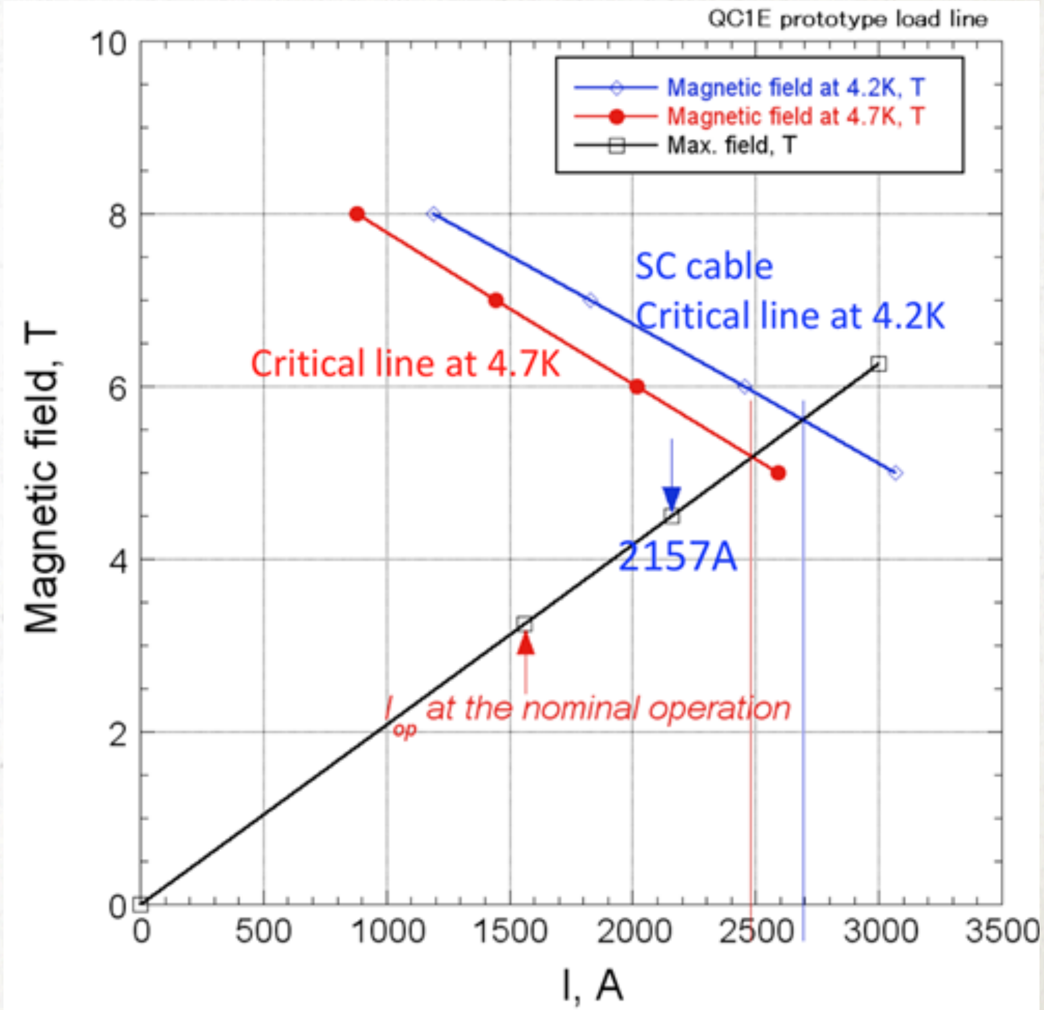
- Eight final focus QCS with 40 corrector coils are to be used.
- Fabrication of QCS-L started in July 2012, and will be completed in JFY2013.
- Fabrication of QCS-R is scheduled in JFY2013 and 2014.
- Corrector coils are being wound at BNL under BNL/KEK collaboration.
- Prototype magnet was made at KEK. Test results show sufficient margin for operation.

QCS Prototype Test

- Successfully tested without any quench up to 2157A, well over the design current (1560A) for nominal operation.

QC1LE prototype magnet



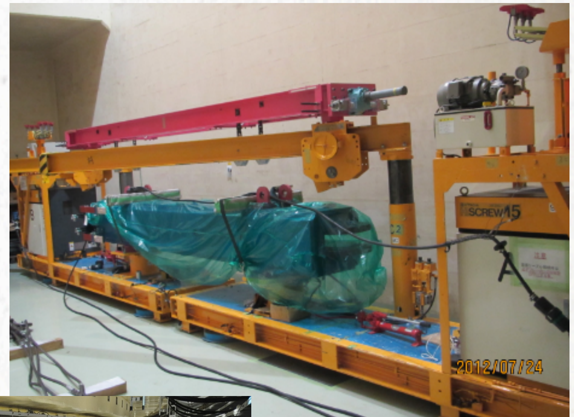


Sufficient margin for operation

Installation of 100 new LER 4m Bending Magnets Completed

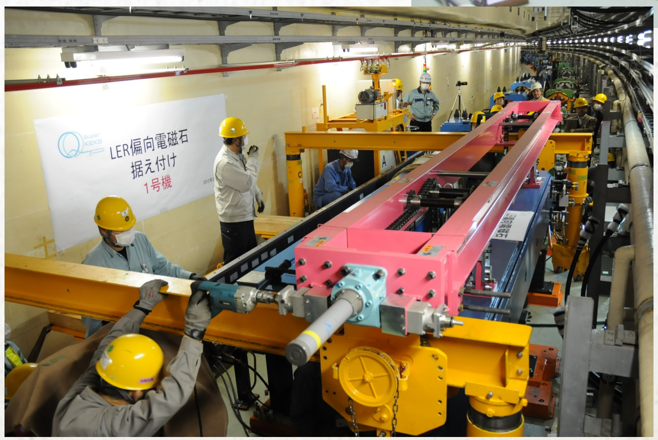
field measurement

move into tunnel



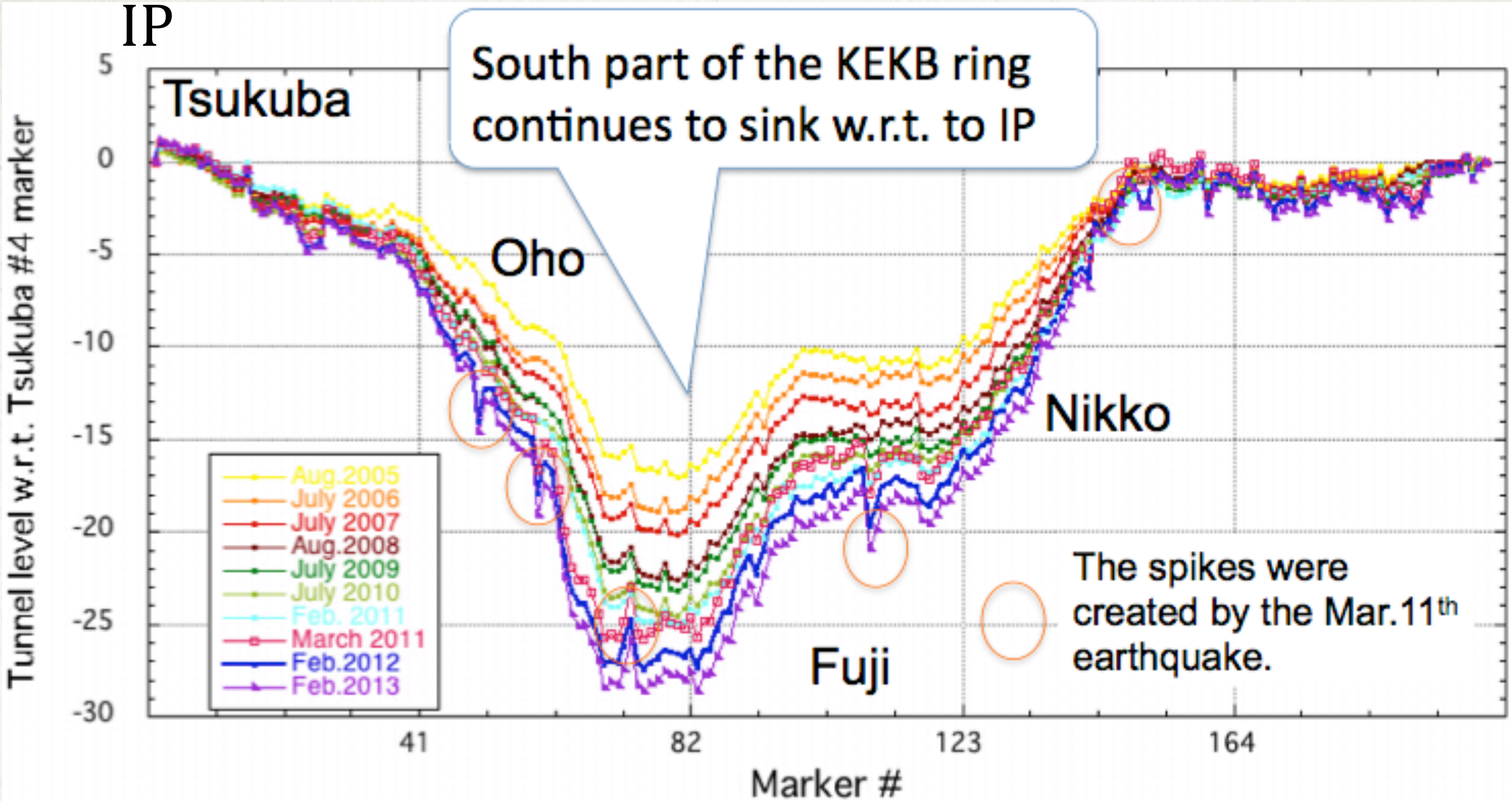
carry on an air-pallet

carry over existing HER dipole



installation done

Tunnel Level Survey & Alignment Strategy

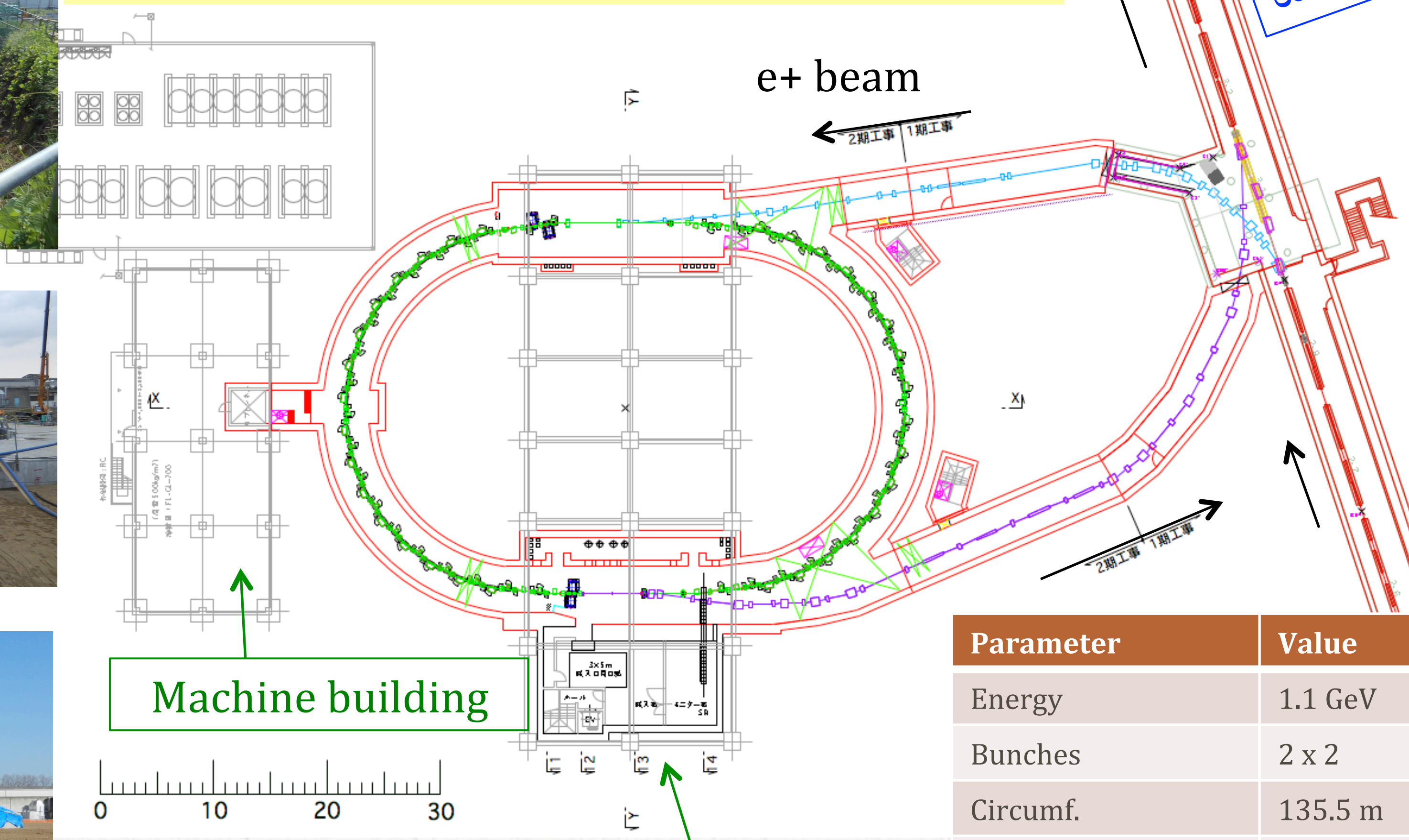


- We have carried out simulation of low emittance tuning by importing the above data in our simulation code.
- With series of simulation runs, we have decided not to flatten out the tunnel level but to smooth it out.

New Damping Ring for Positron

DR tunnel construction

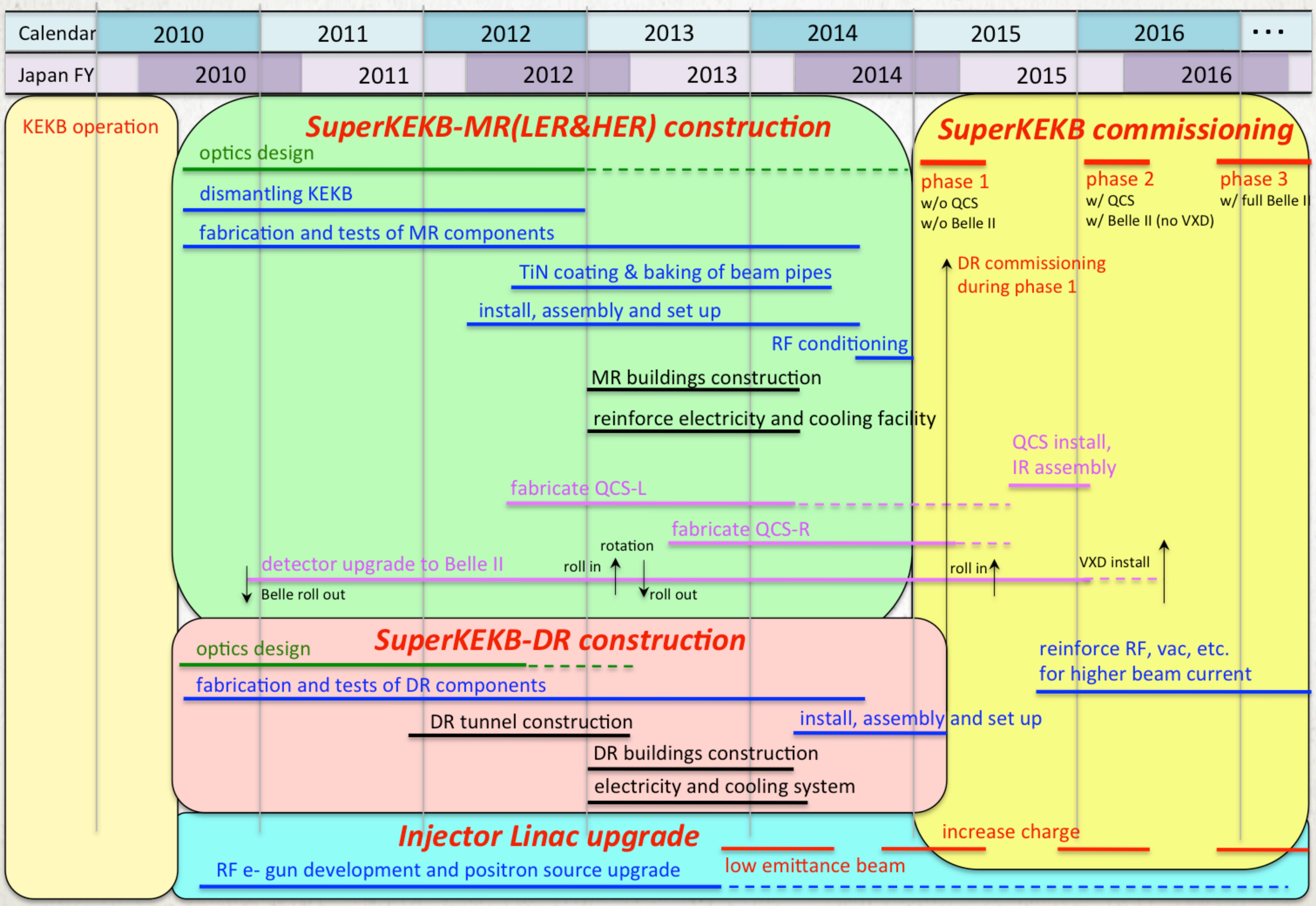
- Fabrication of accelerator components ongoing
- Installation will start in 2014.
- DR commissioning will start in 2015.



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

Schedule

- Main ring commissioning will be started early 2015.



Other Topics

- There are lots of recent progresses not addressed here. Details are found, for example, in

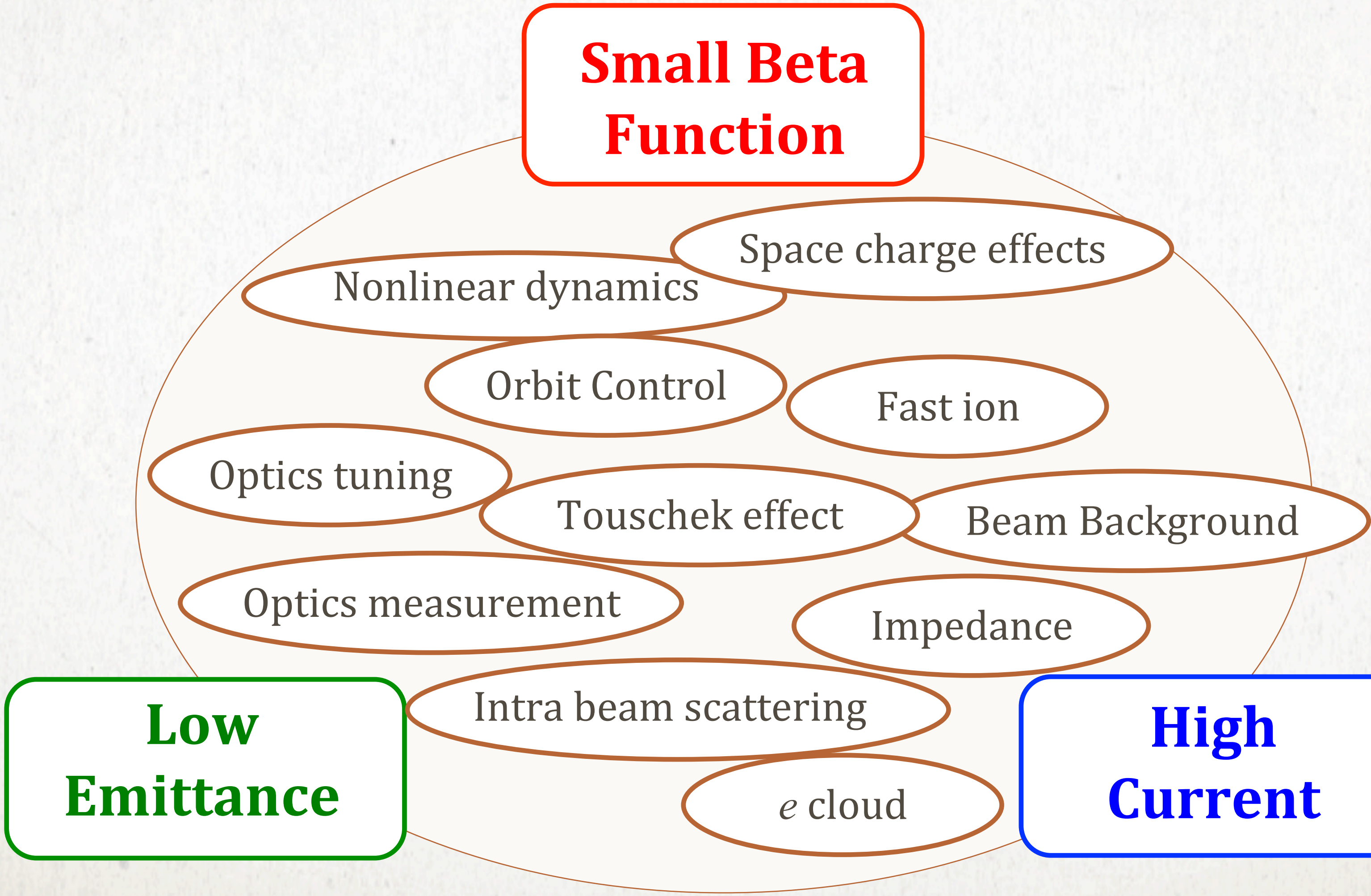
  http://www-kekb.kek.jp/MAC/2013/

  - Vacuum system
  - Magnet system
  - Monitor and control system
  - RF system
  - Facilities and infrastructure
  - Damping ring
  - Injector Linac upgrade
  - Etc.

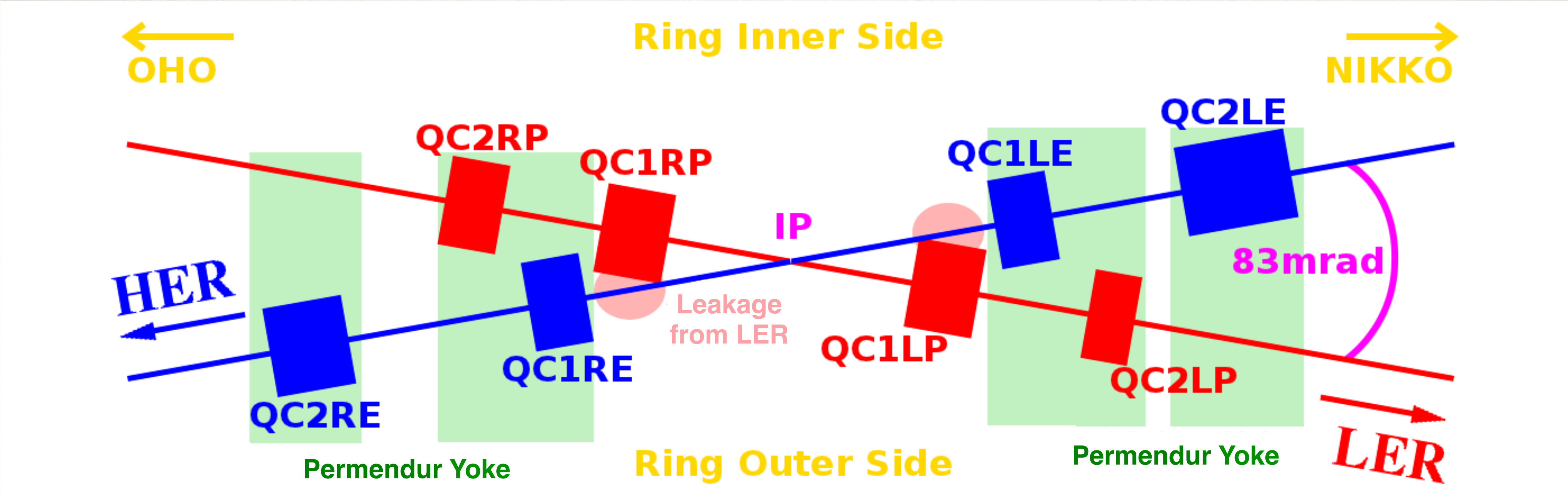
Optics&Beam Dynamics

Optics&Beam Dynamics Issues

- There are lot of challenging subjects should be more seriously considered than KEKB machine.
- All these subjects are originated from three keywords.



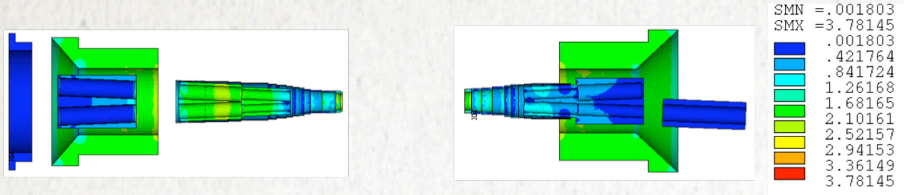
Interaction Region (IR) Design

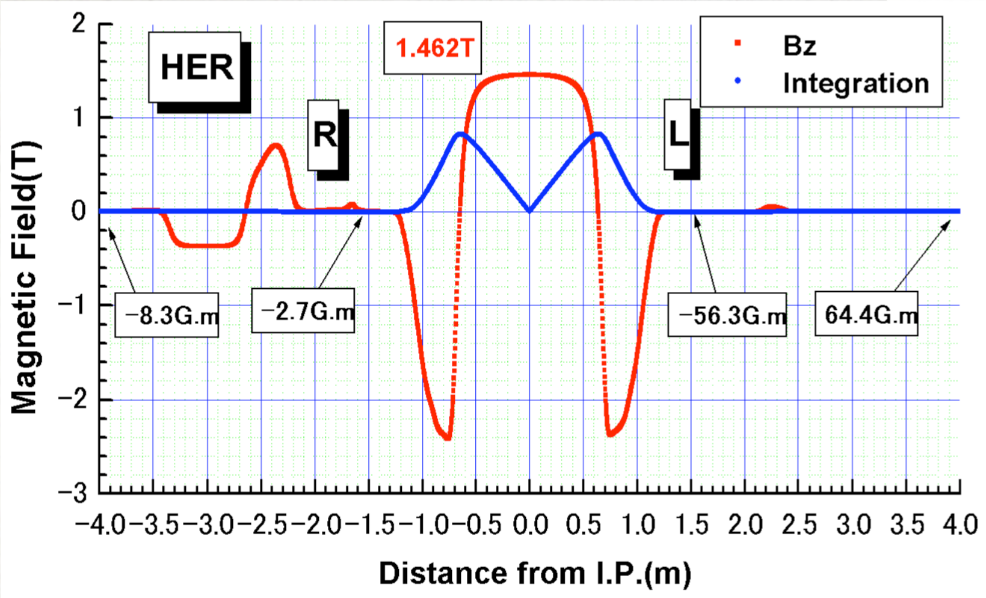


- All quadrupoles except for QC1P have permendur yoke for preventing field leakage to the another beam line
- Canceller coils are installed for HER beam line to suppress leakage filed from LER QC1 magnet.
- All magnet have super-conducting corrector coils.
  - Normal&Skew Dipole, Skew Quad
- Octcupole and sextupole coils are also available.

Interaction Region Modeling

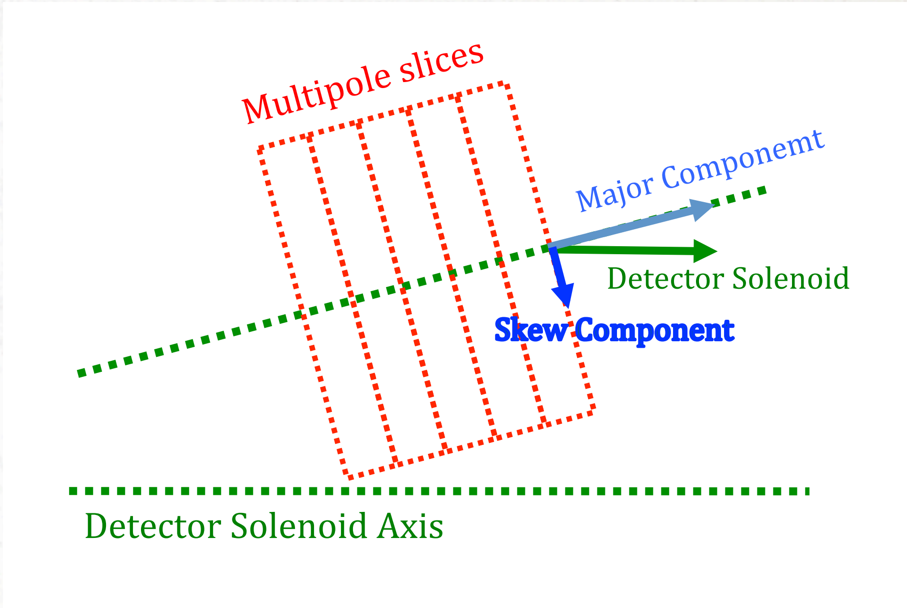
3D Field Calculation





Import

Optics Calculation



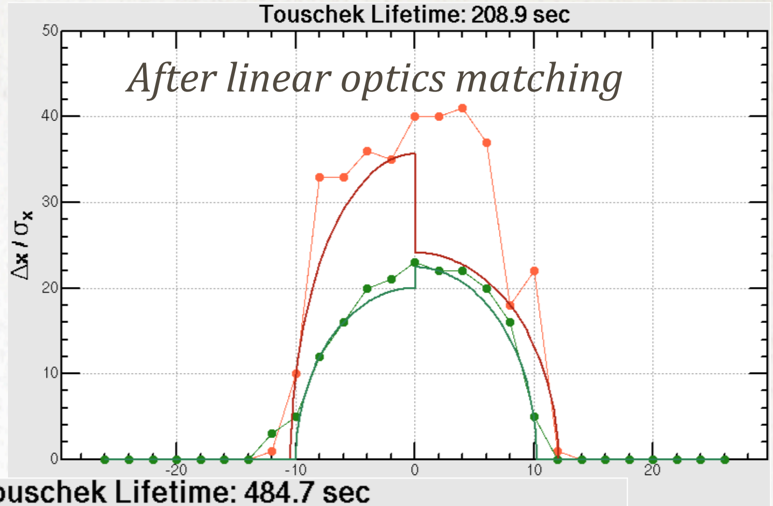
- 3D Magnetic field is modeled by series of multipole slices attached to the beamline.
- Their strengths are obtained from multipole expansion of 3D field data.

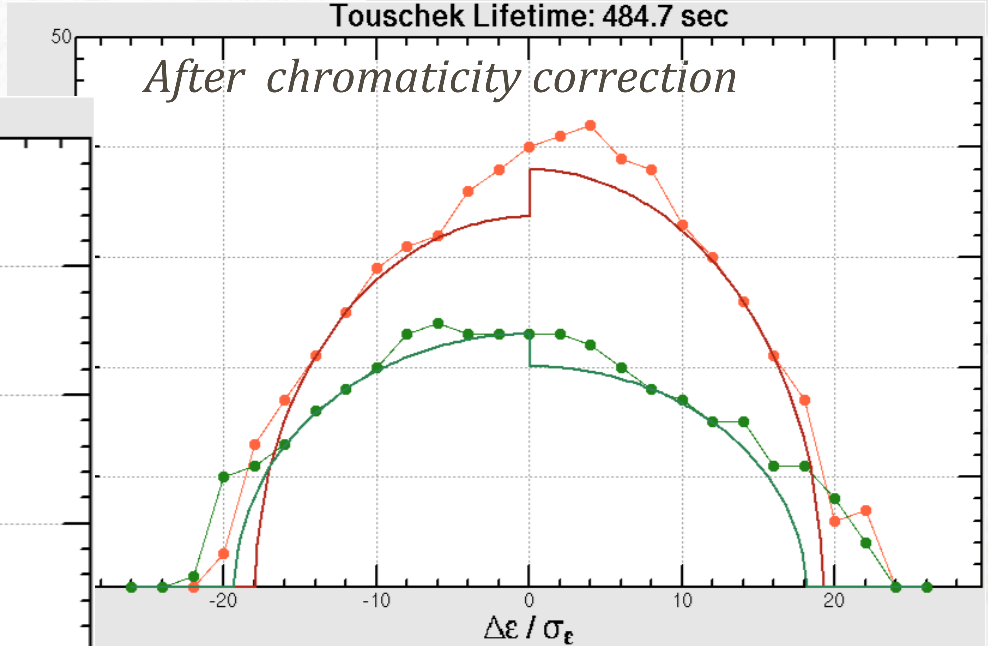
$$\boldsymbol{B} = \nabla\phi \qquad \phi(r,\theta,z) = \Im\left[\sum_{n=0}^{\infty} r^n e^{in\theta} \sum_{m=0}^{\infty} \frac{(-1)^m \, n! r^{2m}}{4^m m! \, (n+m)} \frac{d^{2m}}{dz^{2m}} d_n(z)\right]$$

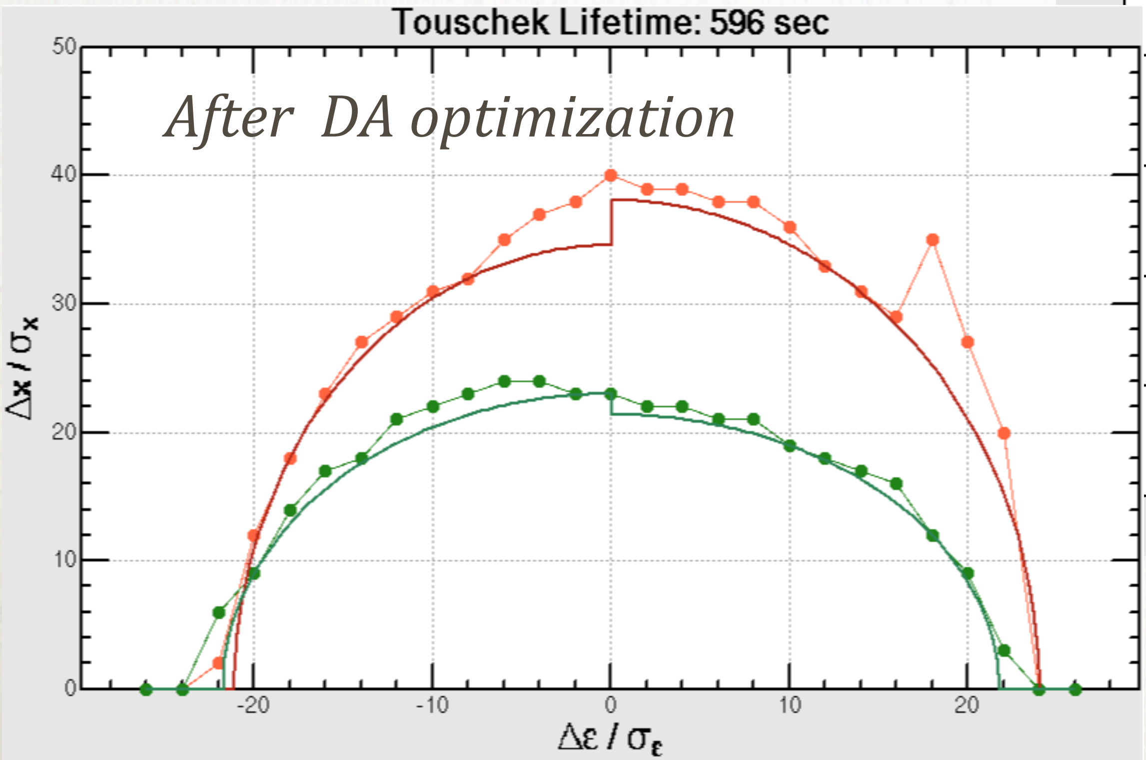
Touschek Lifetime Optimization

Typical Optimization Step

1. Linear optics matching
2. Chromaticity correction
3. Down-hill simplex method.







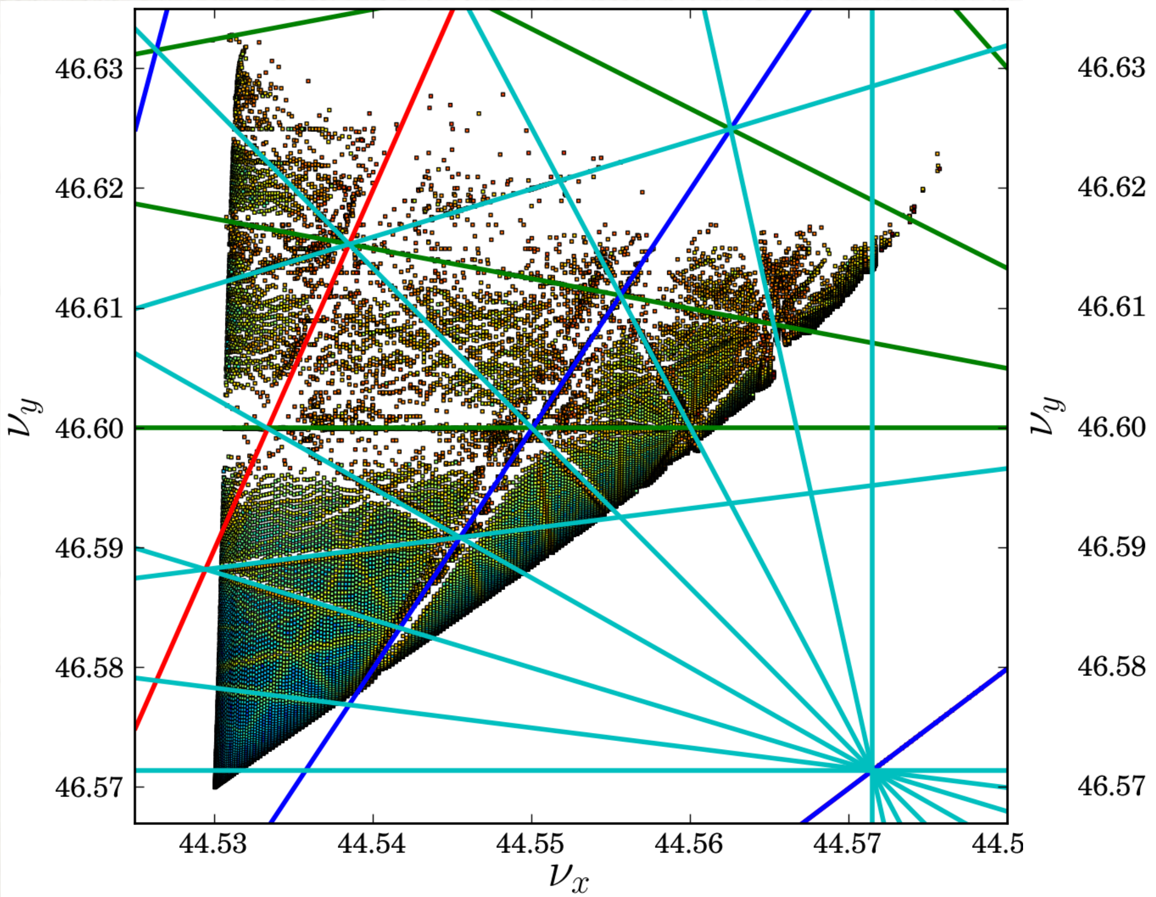
- 54 sextupole families are effectively used in DA optimization.

Frequency Map Analysis (FMA)

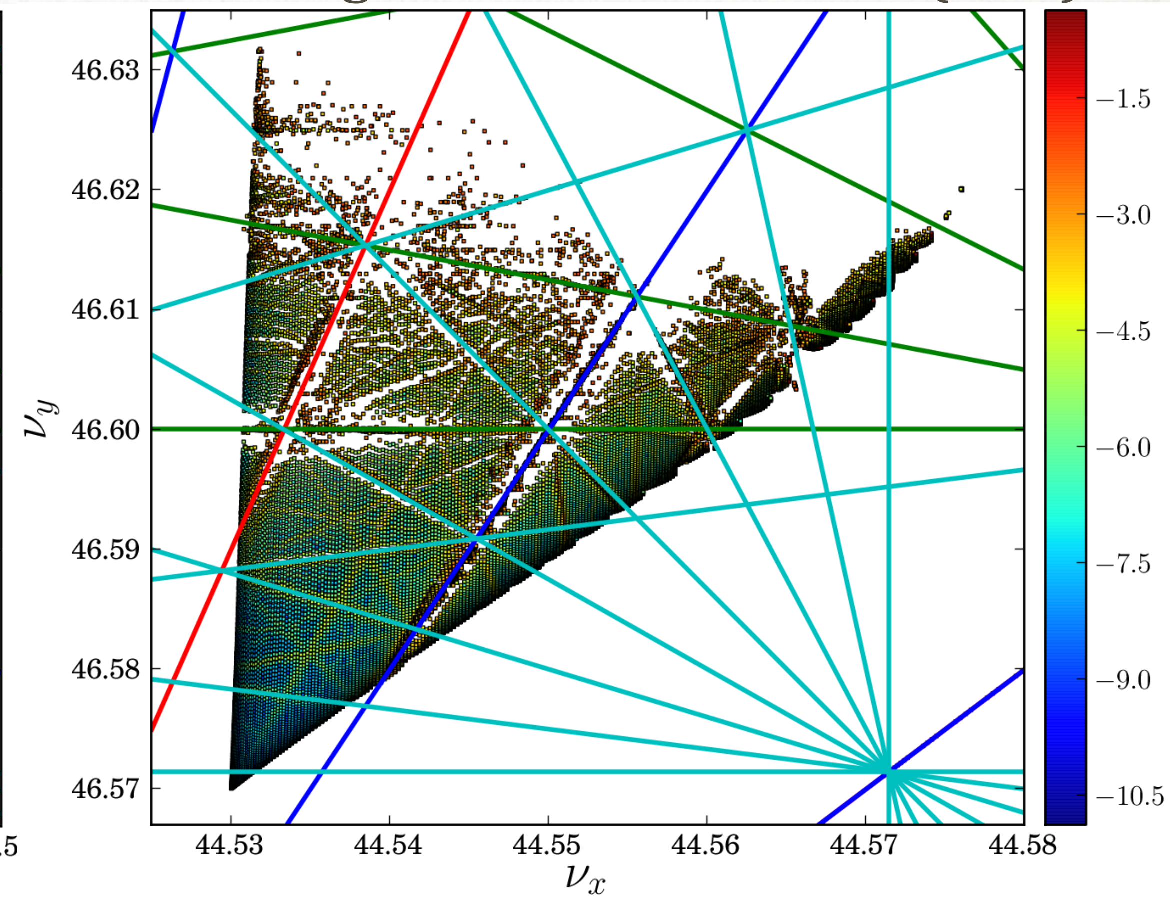
4th order
5th order
6th order
7th order

- FMA is also used to check optics stability.

Lack of a corrector coil (LER)

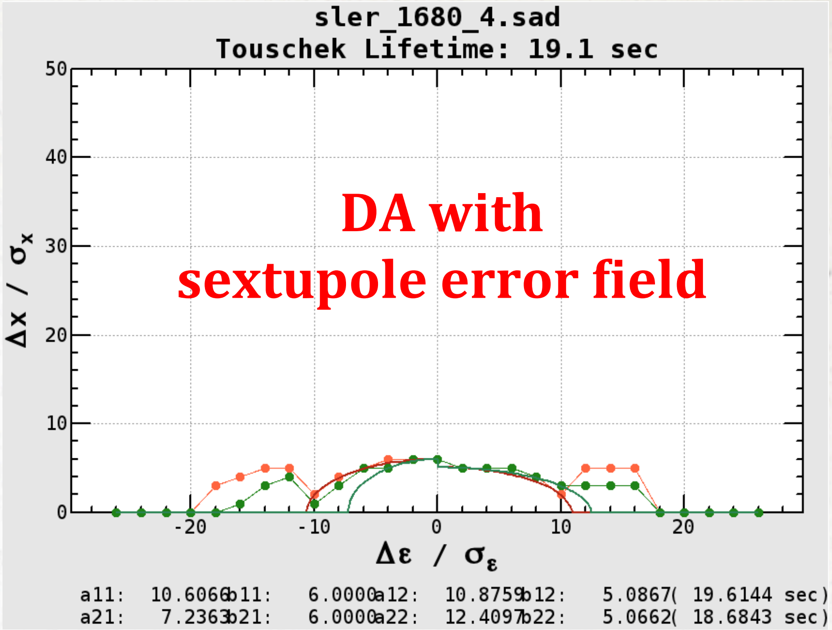


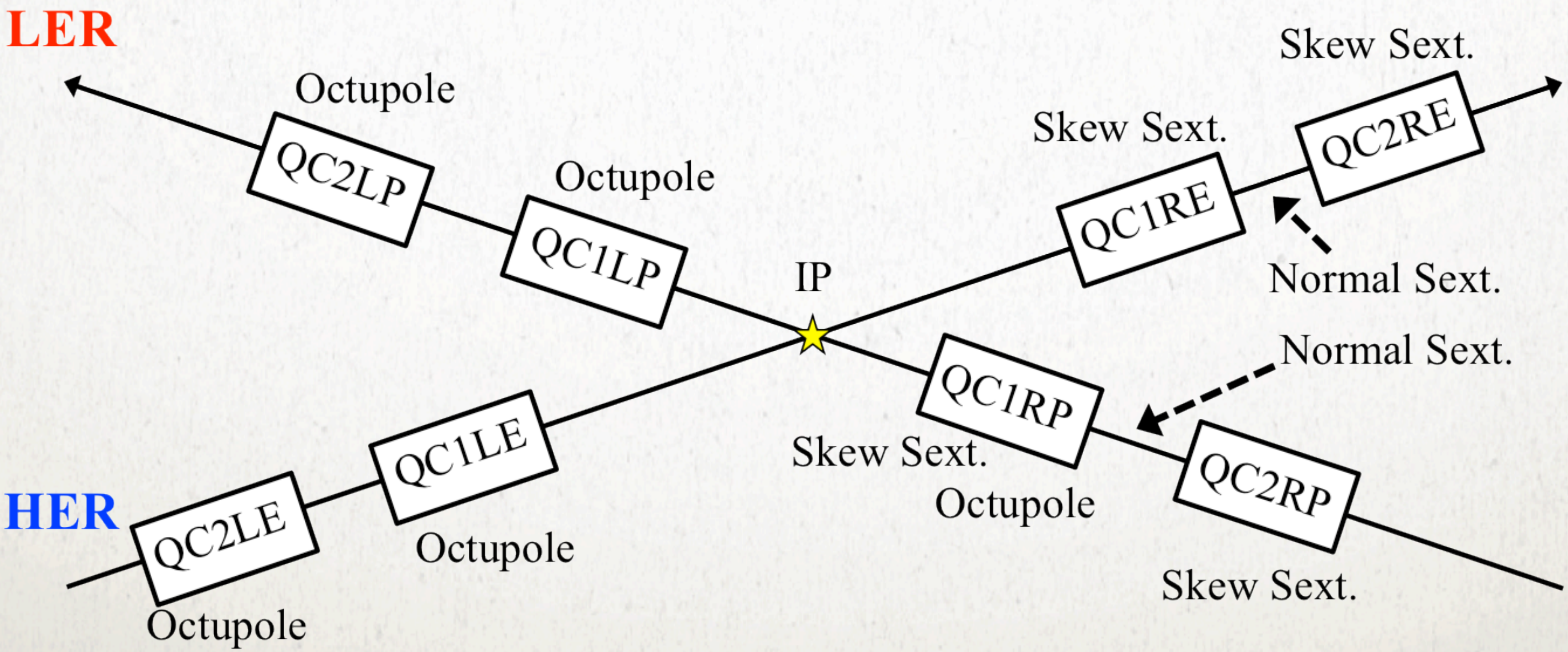
Enough # of corrector coil (LER)



Corrector Coil Arrangement

- A possible sextupole error field in QCS seriously deteriorates the DA.
- Arrangement of sextupole and octupole corrector coils is decided by considering space limitations and possible error fields of QCS.

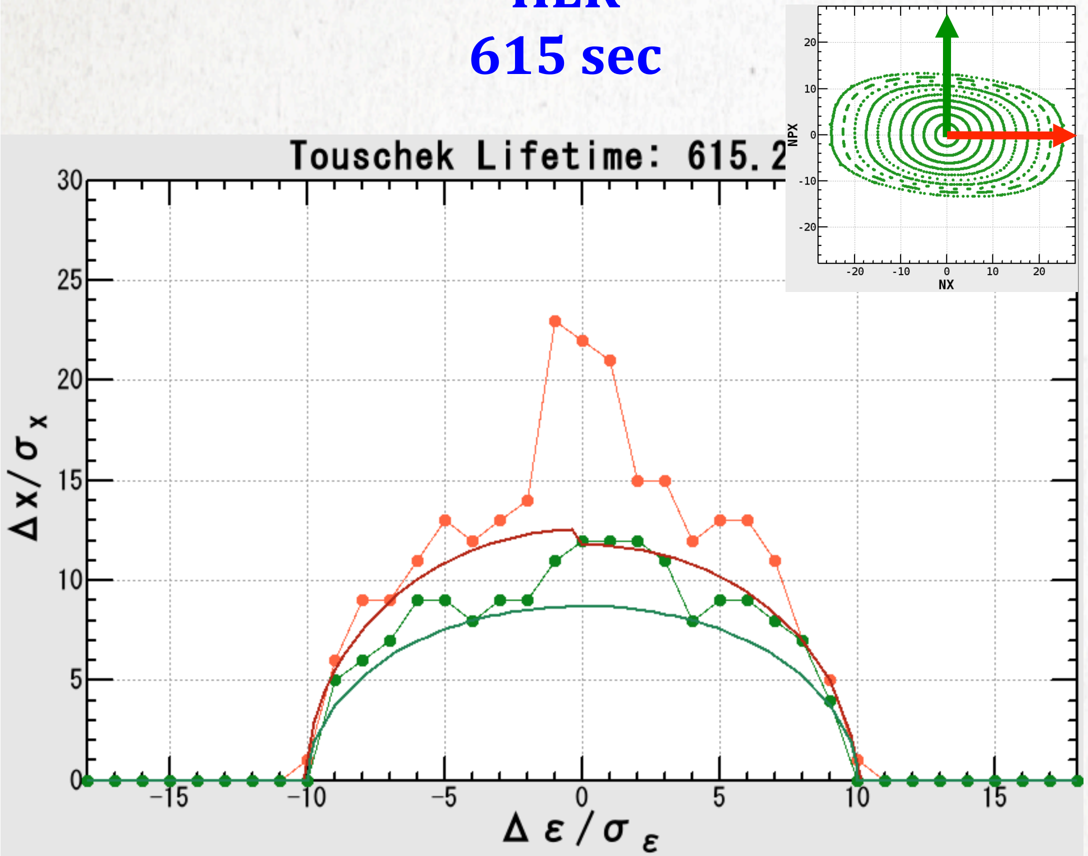




Touschek Lifetime

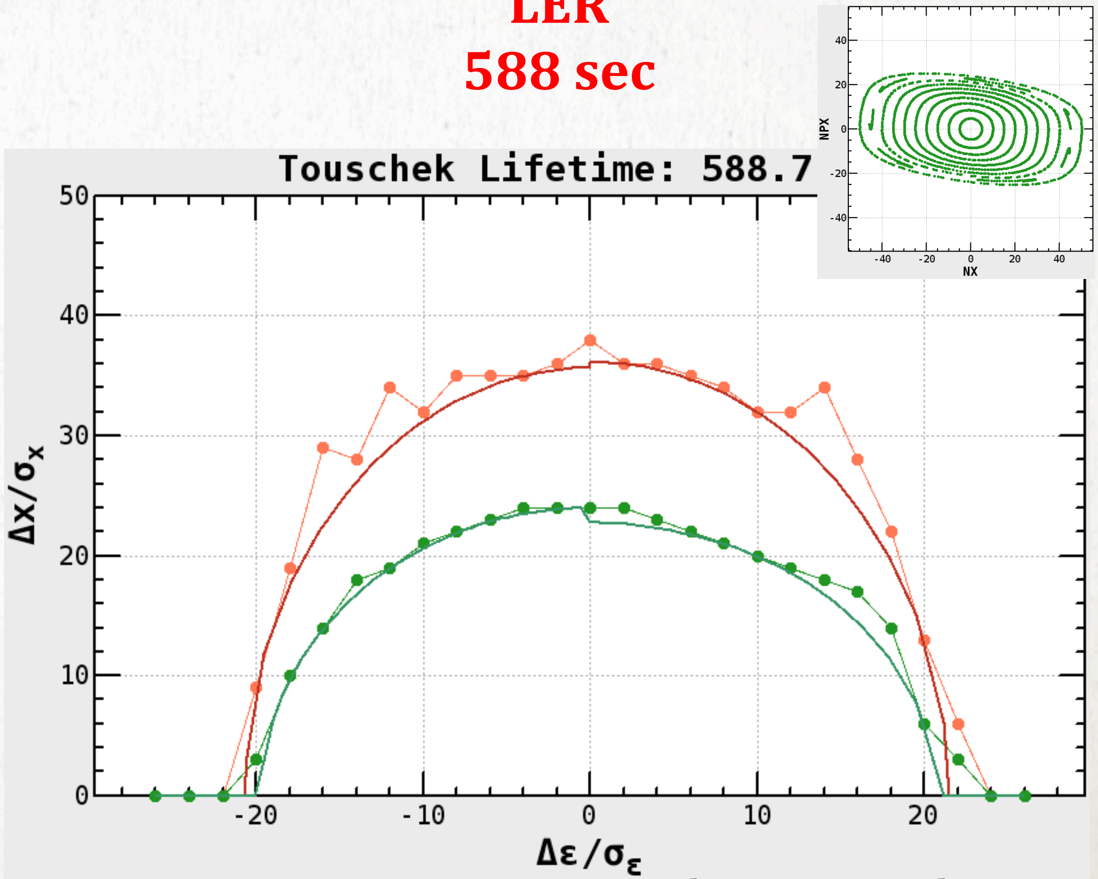
- A large number of feedback cycle between magnet&optics group has been repeated.
- Lifetime of both beams is almost reached the target value, 600 sec.

HER
615 sec



sher_5754.sad

LER
588 sec



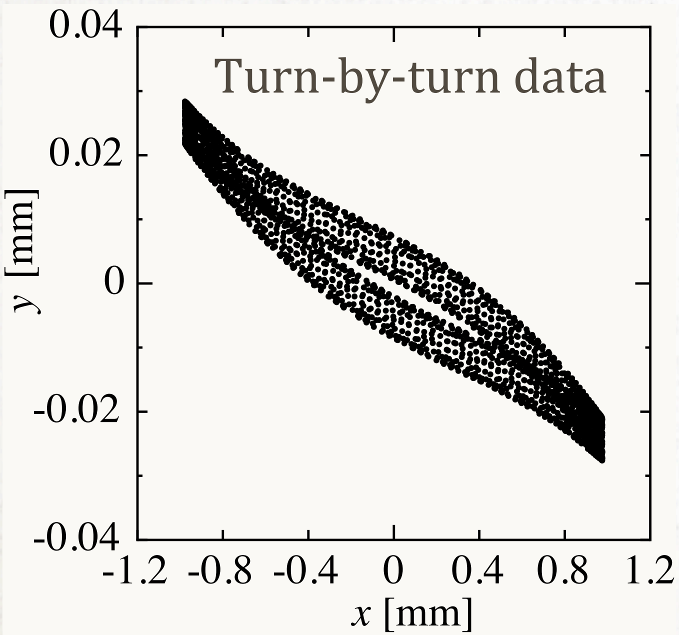
sler_1683.sad

Coupling Correction with turn-by-turn BPMs

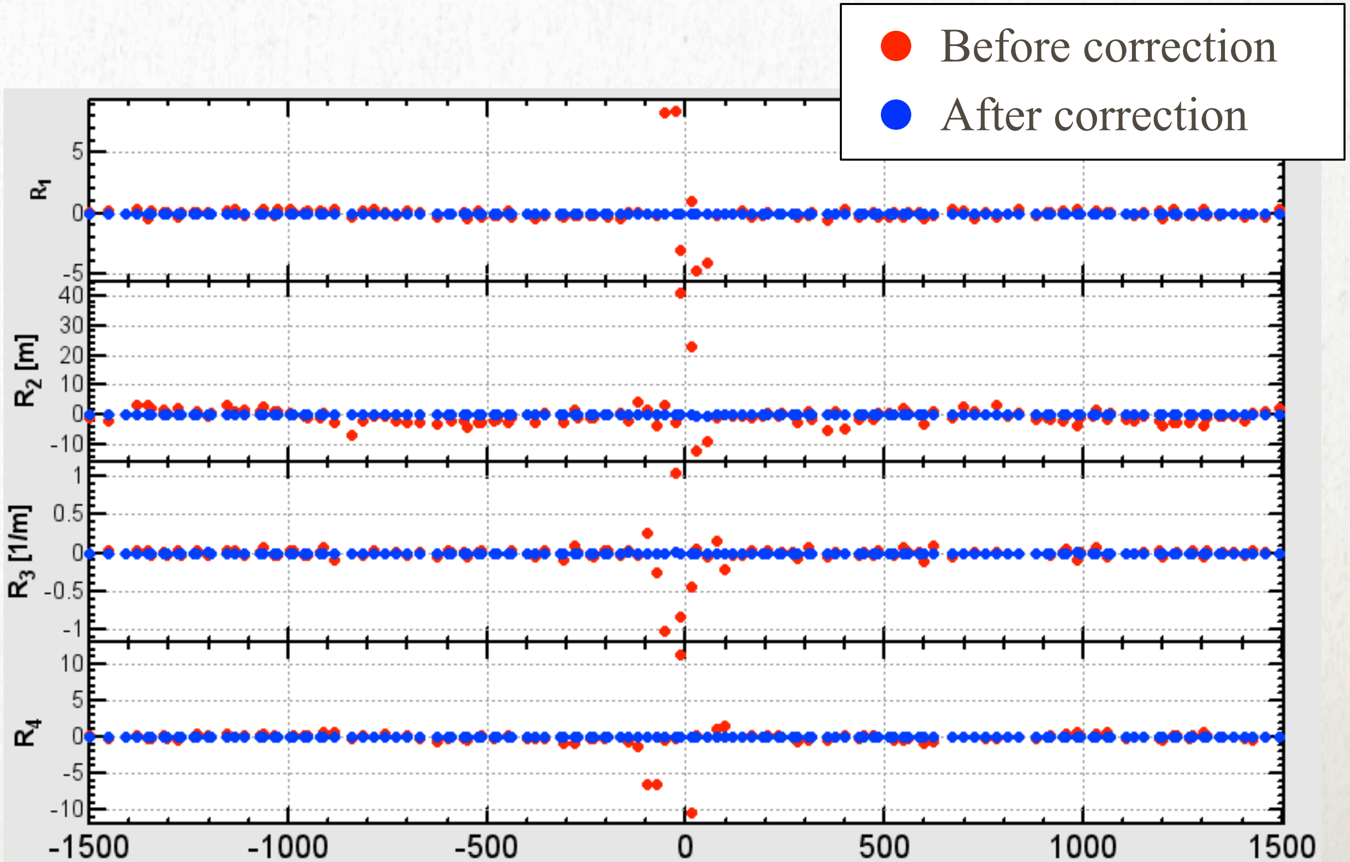
- 135 turn-by-turn BPMs per ring will be available.
- Measurement with a pilot bunch enable us to obtain optics function during beam collision at a high current.

$$\begin{pmatrix} u \\ p_u \\ v \\ p_v \end{pmatrix} = \begin{pmatrix} \mu & 0 & -R_4 & R_2 \\ 0 & \mu & R_3 & -R_1 \\ R_1 & R_2 & \mu & 0 \\ R_3 & R_4 & 0 & \mu \end{pmatrix} \begin{pmatrix} x \\ p_x \\ y \\ p_y \end{pmatrix}$$

Numerical Simulation



$$\begin{pmatrix} R_1 & R_3 \\ R_2 & R_4 \end{pmatrix} = -\mu \Sigma_x^{-1} \begin{pmatrix} \langle xy \rangle & \langle y p_y \rangle \\ \langle y p_x \rangle & \langle p_x p_y \rangle \end{pmatrix}$$



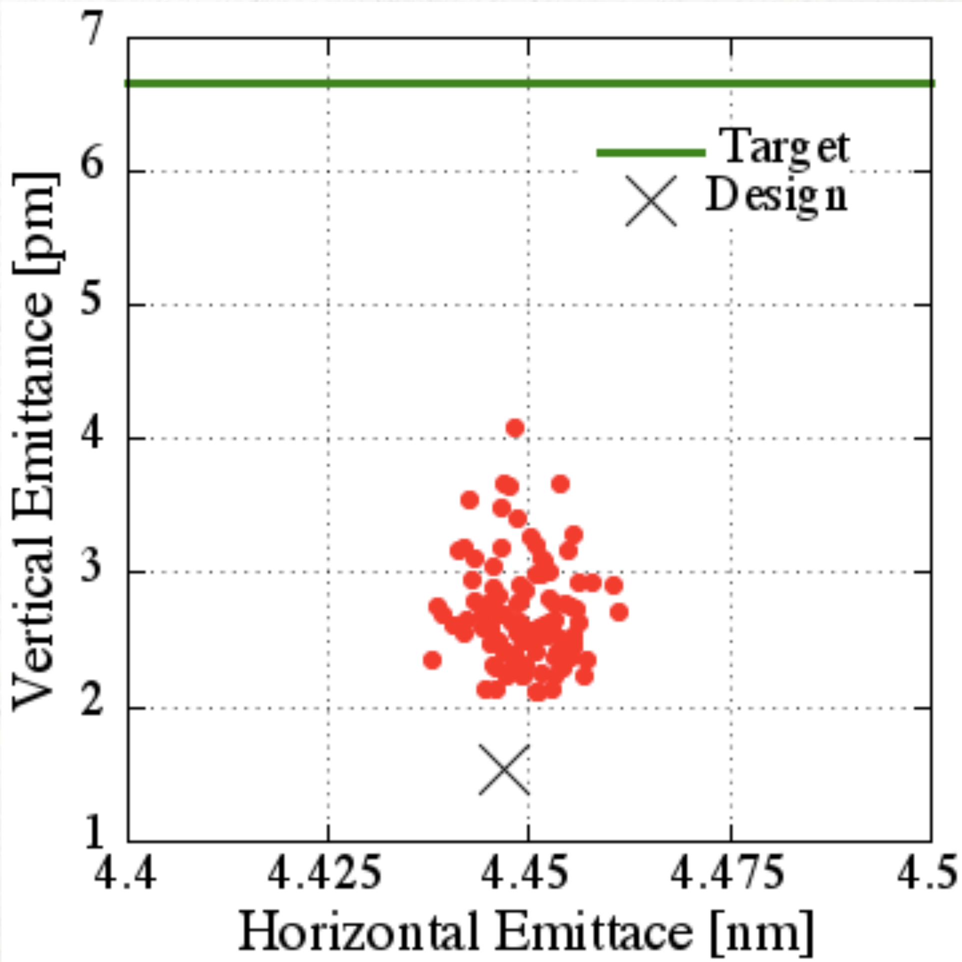
Low Emittance Tuning Simulation

- Optics correction scheme used in KEKB is applied to SuperKEKB error simulation.
- Vertical emittance after the optics correction satisfies our requirement.

Assumed Error

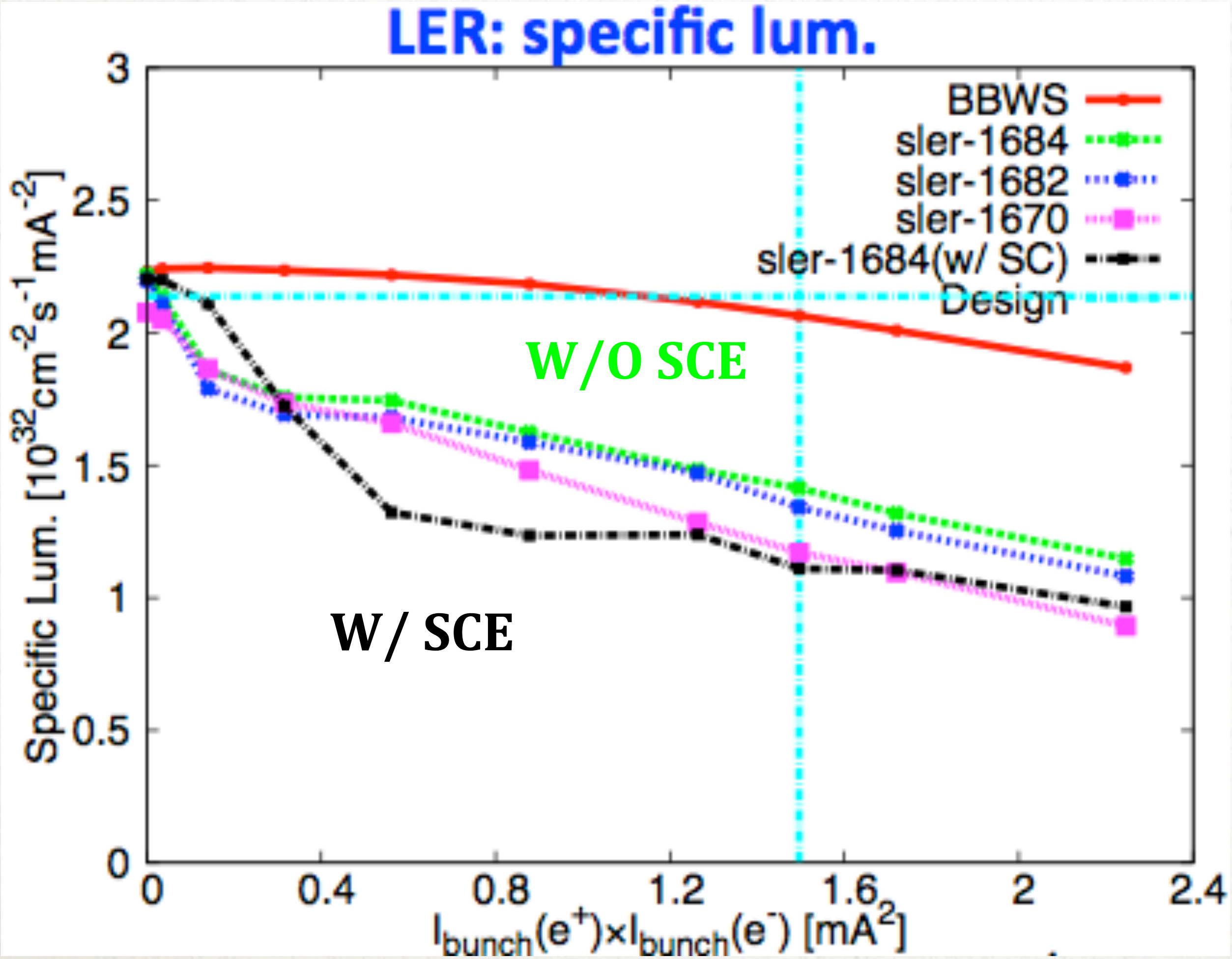
	Δx [μm]	Δy [μm]	$\Delta\theta$ [μrad]	$\Delta K/K$
BEND	0	0	100	0
QUAD	100	100	100	2.5e-4
SEXT	100	100	100	2.5e-4
QCS	100	100	0	0

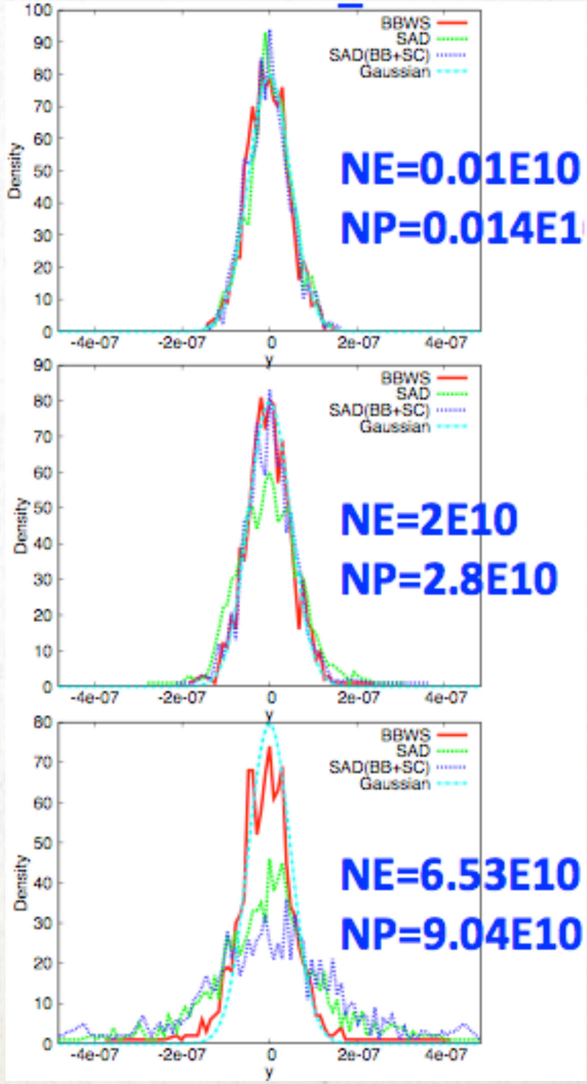
BPM Jitter : 2 μm
BPM Rotation : 10 mrad



Beam-Beam Simulation with Space Charge Effects (SCE)

- Due to the extremely small beta and low emittance, space charge tune shift is same order of beam-beam tune shift.
- Recent numerical studies indicate that SCE causes luminosity degradation.





Courtesy of D. Zhou

Summary

- Construction of SuperKEKB is underway, and the commissioning is scheduled early 2015.

- SuperKEKB is a very challenging machine. There are a lot of issues on beam dynamics.

- In addition to already recognized issues, SuperKEKB operation will bring up unprecedented subjects for high luminosity collider.

Thank you for listening!