Upgrade plan overview

Y. Ohnishi

The ninth KEKB Accelerator Review Committee
February 16-18, 2004
KEK

Letter of Intent

- LoI consists of physics, detector, accelerator part.
- We submit accelerator part of LoI to KEKB Review committee (complete LoI to LCPAC) :

  "Accelerator Design for a
  Super B Factory at KEK"

- LoI is in draft stage, however, almost finished.
- This talk is overview of LoI, but all contents can not be covered.

Design strategy

- Target luminosity is 2-5 x 10^{35} $cm^{-2}s^{-1}$.
  - Original target luminosity is 10^{35} $cm^{-2}s^{-1}$ even if crab-crossing is failed.
- Re-using components of KEKB as much as possible
- Maintaining acceptable detector backgrounds
- Continuous injection and a powerful injection system
- Low beta function at IP
- Finite-crossing and crab-crossing scheme
- High beam currents

Machine parameters

Parameter		LER	HER	Unit
Beam currrent	I	9.4	4.1	A
Number of bunches	n_b	5018		
Horizontal beta at IP	β_x	20		cm
Vertical beta at IP	β_y	3		mm
Bunch length	σ_z	3		mm
Emittance	ε_x	24		nm
Coupling	κ	0.75		%
Crossing angle	θ_x	30 (crab-crossing)		mrad
Momentum compaction	α_p	2.7×10^{-4}	1.8×10^{-4}	
RF voltage	V_c	15	20	MV
Synchrotron tune	ν_s	0.031	0.019	
Vertical beam-beam	ξ_y	0.14 (0.28)		
Luminosity	L	2.5 (5)		$\times10^{35}$ cm^{-2} s^{-1}

Beam-beam parameter is obtained from simulations : strong-strong (weak-strong)

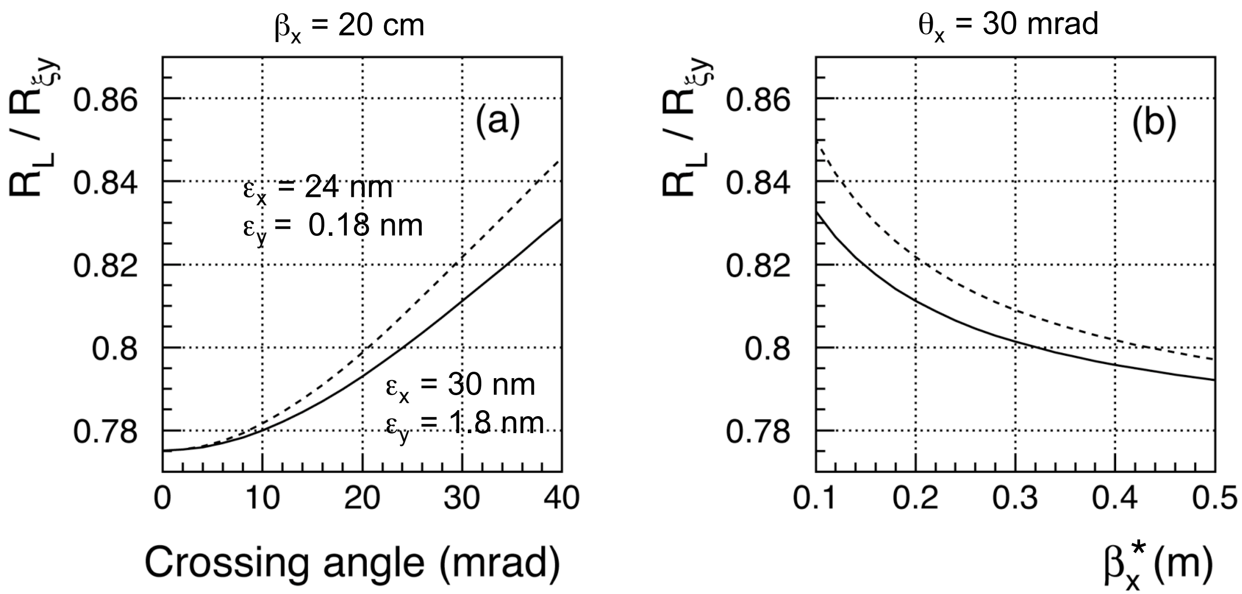
Luminosity considerations

- Fundamental formula for luminosity :

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

- Flat beam : $1 + \sigma_y^*/\sigma_x^* \sim 1$
- Reduction factors : $R_L/R_{\xi y}$ (part 1)
- Beam-beam parameter : ξ_y (part 2)
- Vertical beta function at IP : β_y^* (part 3)
- Beam current : I (part 4)

Part 1 Luminosity reductions



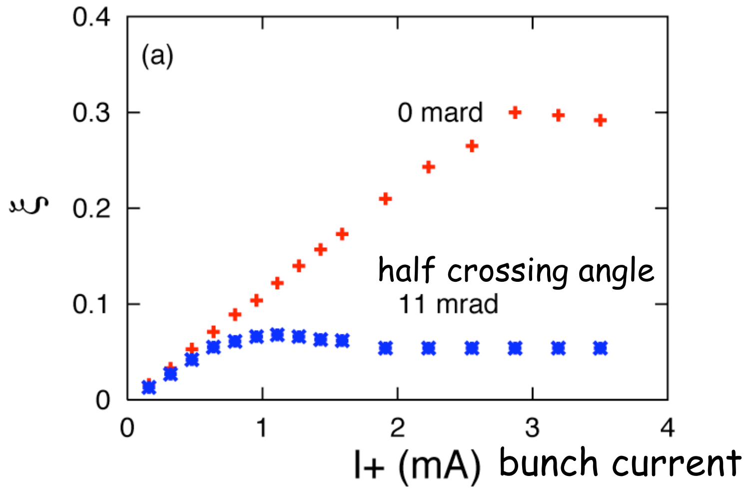
- The ratio of $R_L/R_{\xi y}$ is larger as crossing angle increases.
- The ratio of $R_L/R_{\xi y}$ is larger as β_x^* decreases.
- The ratio is not big change. $R_L/R_{\xi y}$~ 0.8. The change is ~5% at most in a range of machine flexibility.
- Fundamental parameters : β_y^*(and σ_z), ξ_y, I

Part 2 Beam-beam parameters

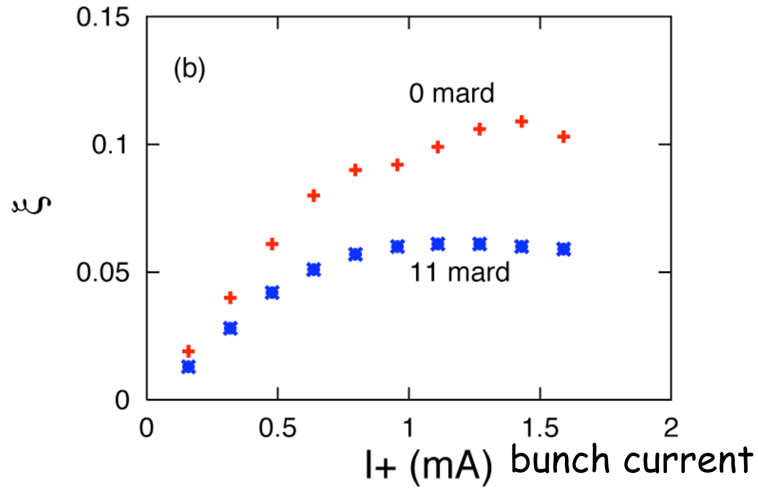
- Beam-beam parameter is not a free parameter.
- Finite-crossing angle scheme achieves 0.05 from KEKB experiences.
- Beam-beam limit is 0.05 ?
- Numerical simulations may help to understand or predict the beam-beam limit .
- Colliding beam, more than 10^{11} particles, can not be simulated even though using Super-Computer.
- Models are needed and/or must be assumed.
- Weak-strong simulation
  - Gaussian model (beam shape fixed with Gaussian)
- Strong-strong simulation
  - PIC model (beam given by macro-particles; arbitrary shape)

Head-on VS finite-crossing

W-S



S-S

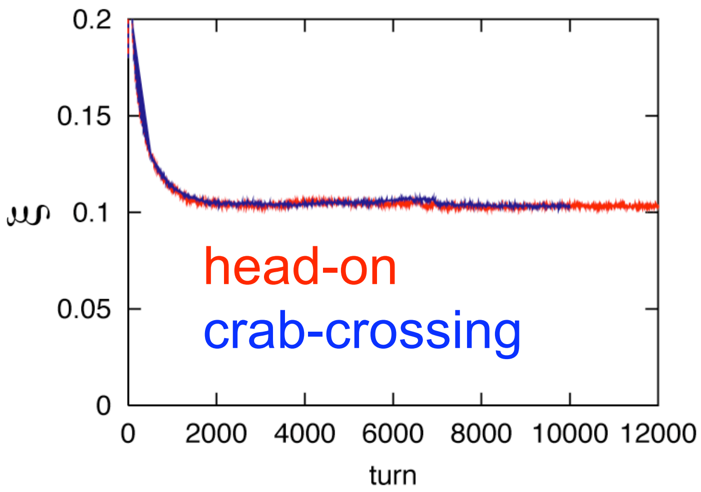


- Beam-beam limit is ~0.05 for finite-crossing collision from the both simulations. (Not so difference between 11 and 15 mrad)
- Head-on collision much improves beam-beam parameter.
- Discrepancy between W-S and S-S is a factor of 2 for head-on collision.

Crab-crossing

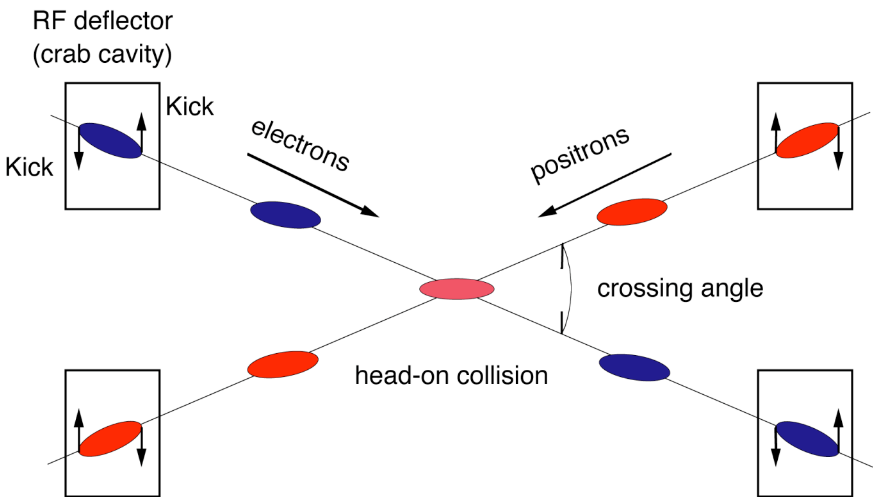
Crab-crossing can achieve the same performance as head-on ?

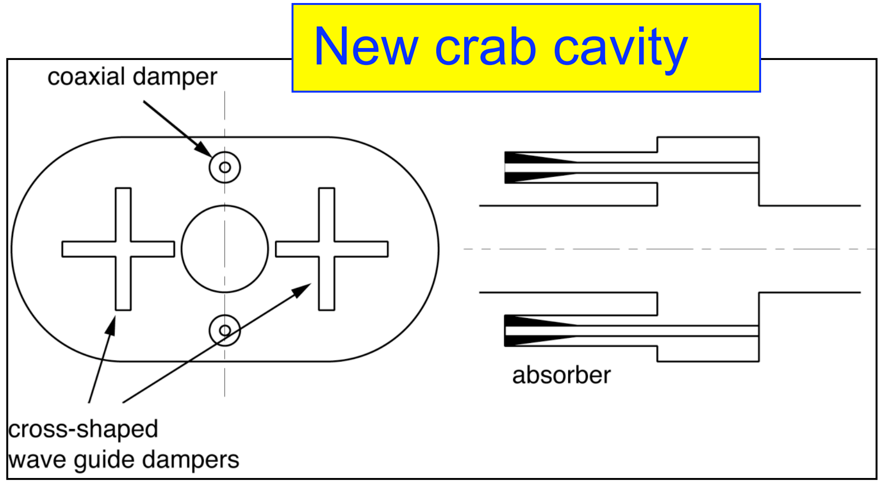
Non-linear term ?



- Finite-crossing angle can provide much benefits;
  - Simple IR design, avoiding parasitic collision etc.
- Crab-crossing restores full luminosity of head-on collision.
- *Crab cavity is needed to achieve higher luminosity.*
- Beam-beam parameter of 0.14 is expected. (S-S)

Crab cavity future plans





- Superconducting crab cavity with squashed cell and coaxial beam pipe (I_b = 1~2 A)
- We will start at KEKB-HER with a single crab cavity in the end of 2005.
- Check hardware and modify if necessary.
- Then we will install one crab cavity in LER in 2006 summer.
- Beam will be crabbed in the whole ring. Is this OK ? HOM, RF cavity ?
- If everything is OK, luminosity becomes twice higher than before ?
- Simultaneously, we develop new crab cavity for 10 A.

Part 3 Vertical beta function at IP

- Move final focus quadrupoles closer to IP for low beta. → β_x^* / β_y^*=20 cm / 3 mm.
- Physical aperture
  - Beam injection

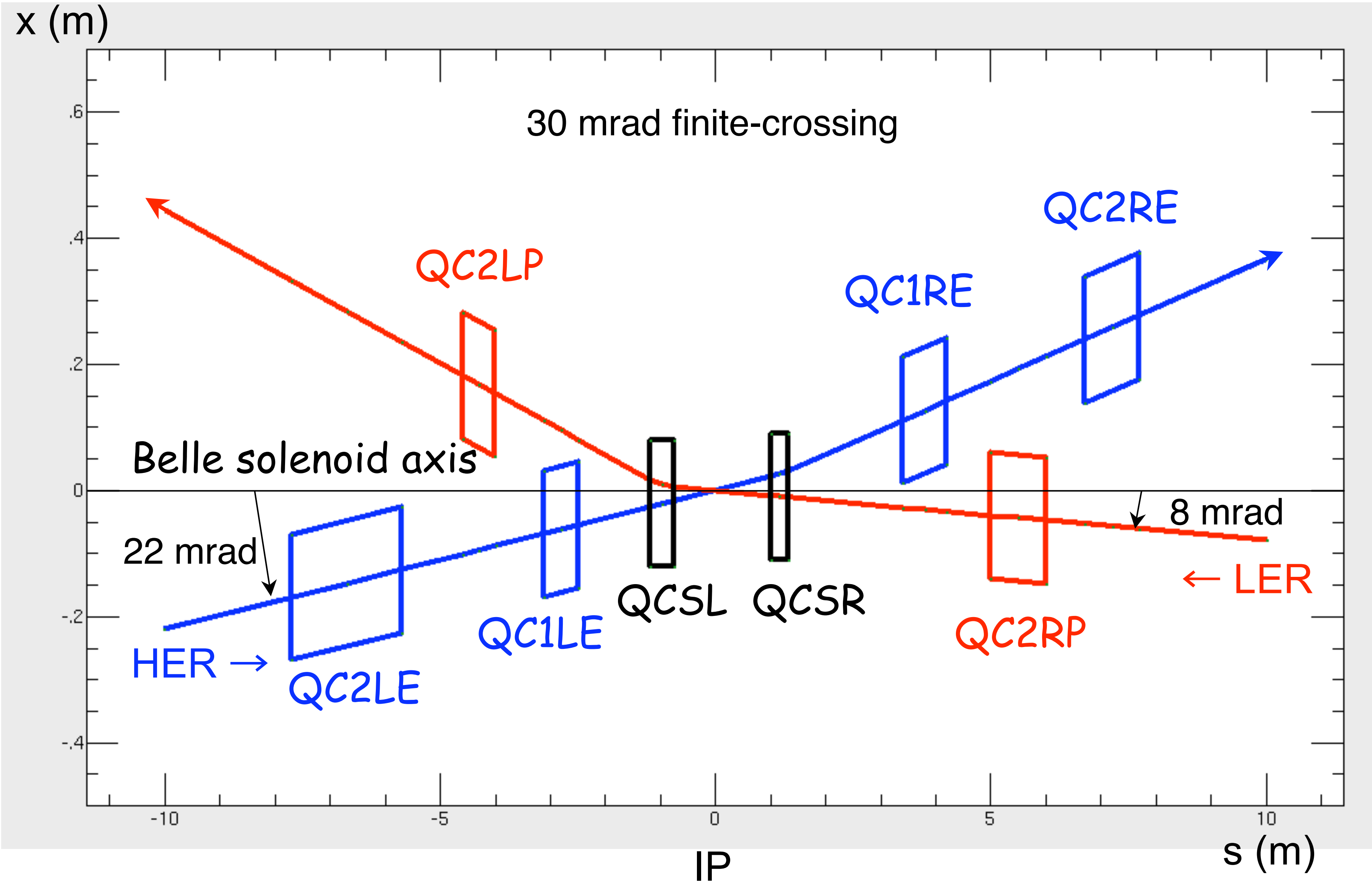
Magnet aperture

- Dynamic aperture
  - Beam injection / Lifetime

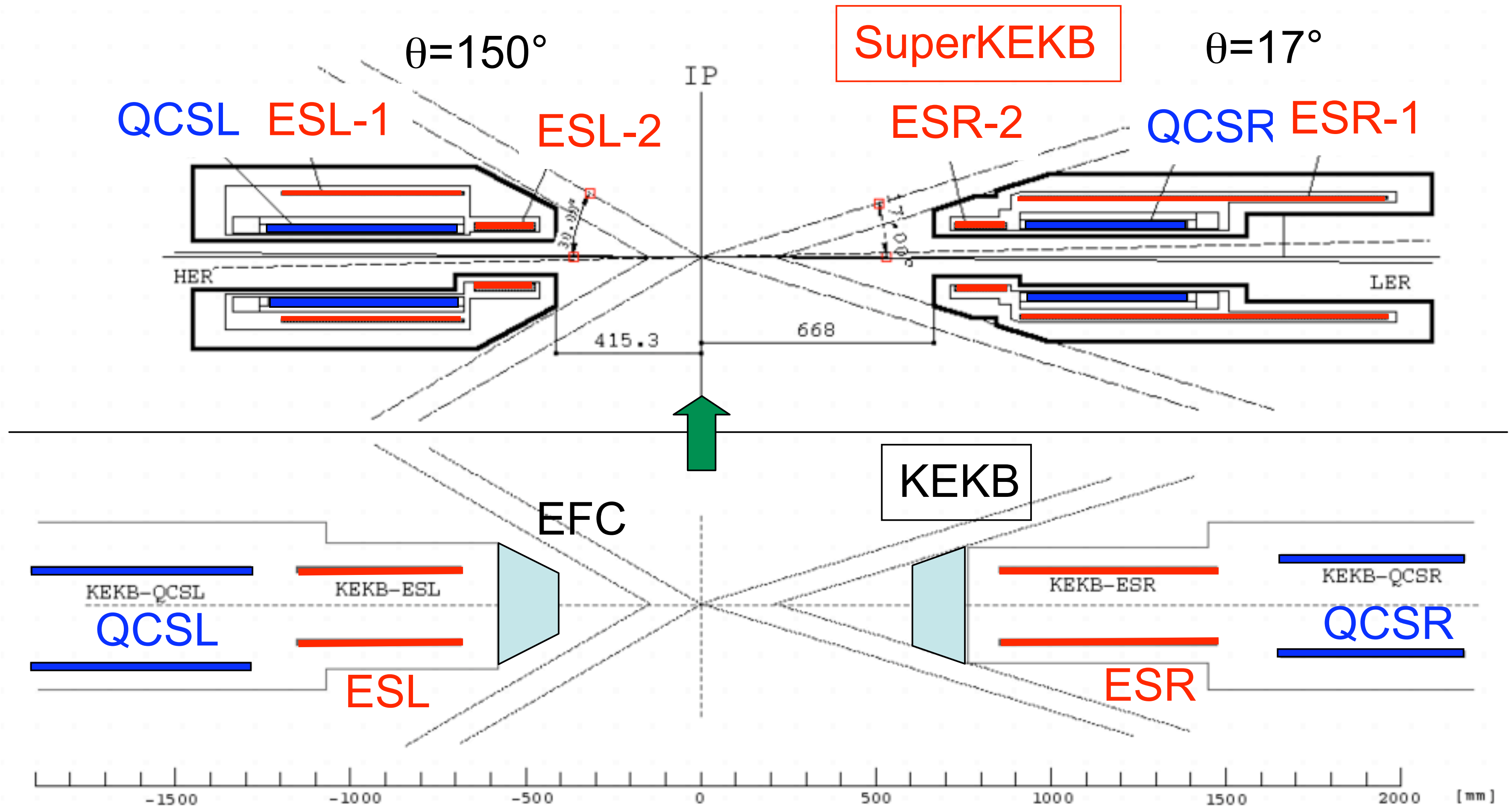
Good magnetic field quality
Small leakage field

- Crossing angle
  - Beam separation / Magnet design
- Synchrotron radiation from IR magnets
  - Heating of components / Detector background

IR magnet layout for SuperKEKB



QCS for SuperKEKB and KEKB



Move QCS closer to IP and compensation solenoid (ES) is divided into two parts; one is overlaid with QCS, the other is in front of QCS.
(Magnetic force on ES becomes weak.)

IR aperture requirements

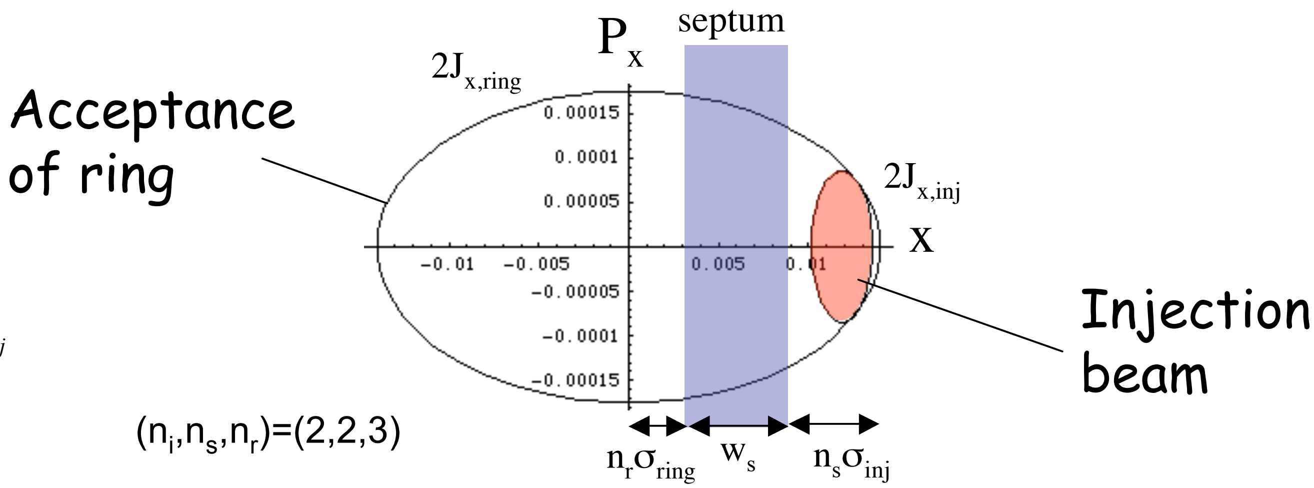
- Required acceptance depends on linac beam emittance

$$\frac{x^2}{\beta_{ring}} + \beta_{ring} p_x^2 = 2J_{x,ring}$$

$$\frac{(x-x_i)^2}{\beta_{inj}} + \beta_{inj} p_x^2 = 2J_{x,inj}$$

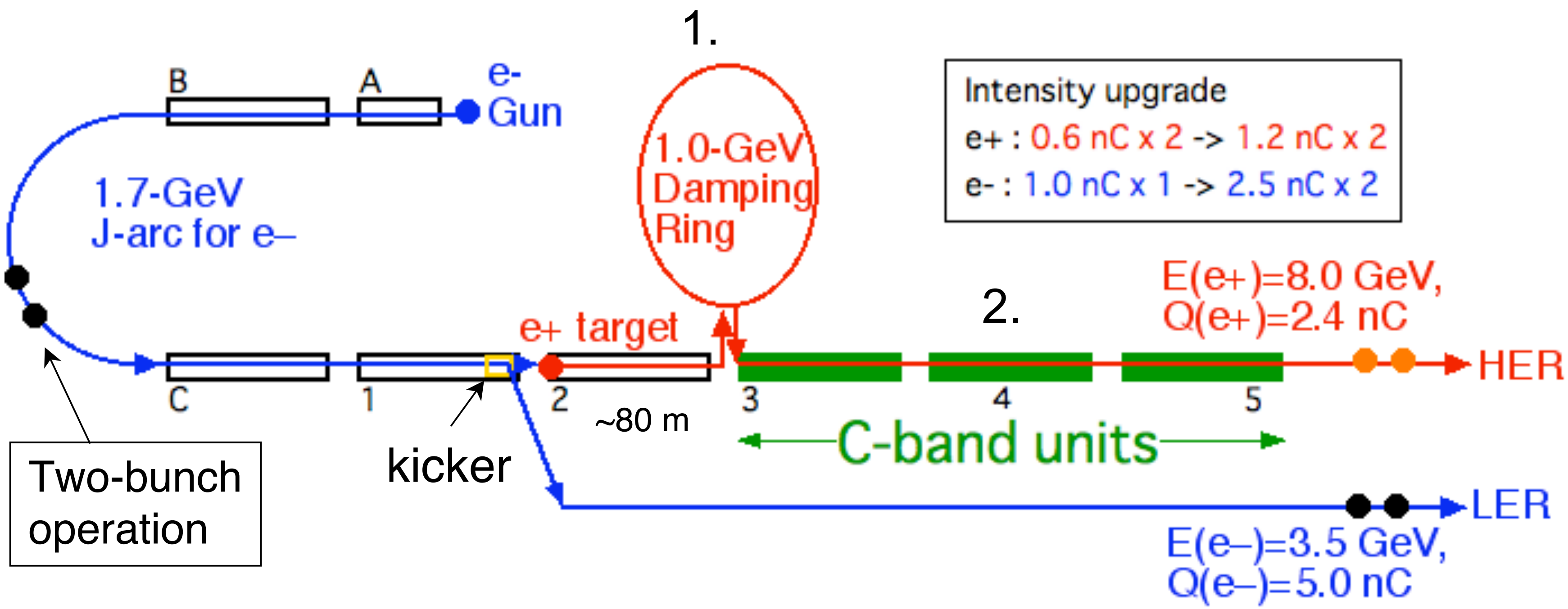
$$x_i = n_r \sigma_{ring} + w_s + n_s \sigma_{inj}$$

$$2J_{x,inj} = n_i^2 \varepsilon_{inj}$$



- Smaller beam emittance is preferable.
- Positron damping ring (DR) will be constructed prior to IR upgrade.

Injector linac for SuperKEKB



1. Positron dumping ring (1 GeV)
2. Positron energy upgrade with C-band for energy exchange (e^- LER / e^+ HER)

Electron cloud
Injection rate

IR aperture requirements (cont'd)

e^+ Damping Ring ⇒ IR upgrade ⇒ Linac energy upgrade

	LER	HER
Energy (GeV)	3.5	8
Inj. beam	e+ with DR	e-
$\varepsilon_x/\varepsilon_y$ (m)	1.4×10^{-8}	2×10^{-8}

→ Energy Exchange

	LER	HER
Energy (GeV)	3.5	8
Inj. beam	e-	e+ with DR
$\varepsilon_x/\varepsilon_y$ (m)	4.6×10^{-8}	6.3×10^{-9}

HER transverse aperture :
$A_x=1.9\times10^{-6}$ m
(1.5×10^{-6} m due to inj. error)
$A_y=8\times10^{-8}$ m

LER transverse aperture :
$A_x=2.6\times10^{-6}$ m
(1.8×10^{-6} m due to inj. error)
$A_y=1.8\times10^{-7}$ m

e^- beam determines IR aperture.

IR magnet design

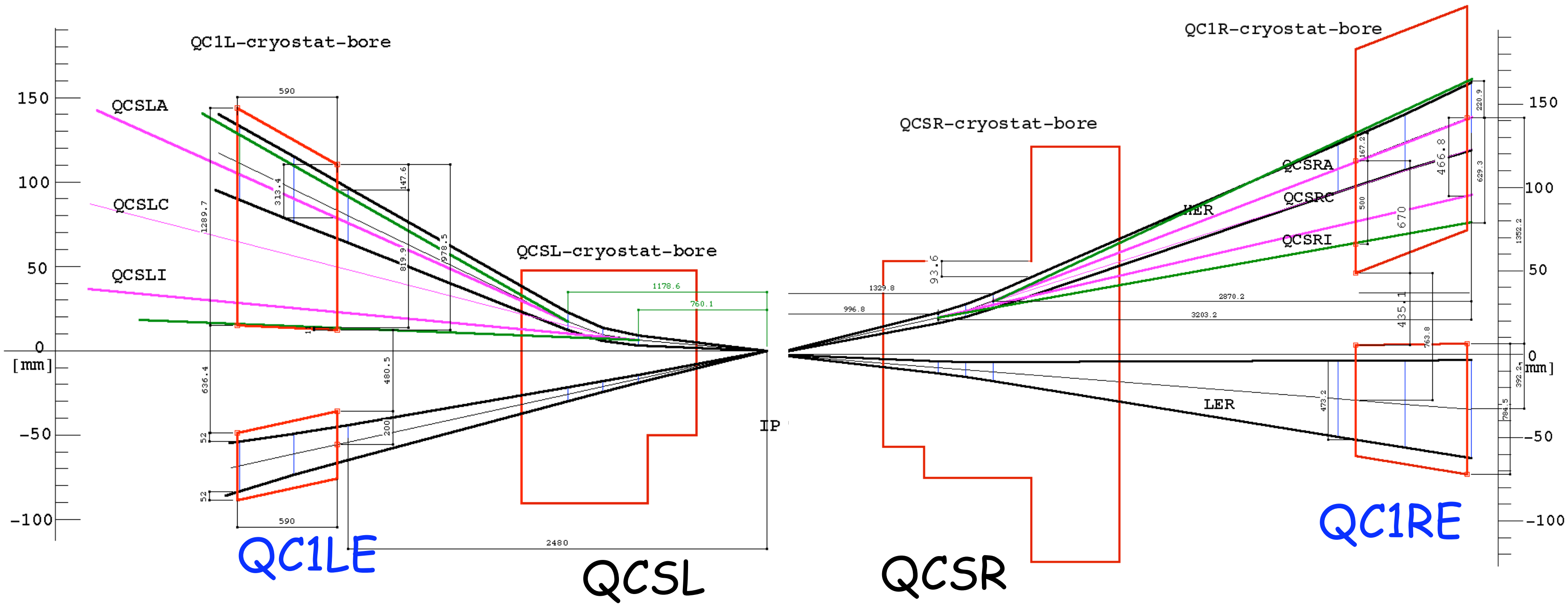
- QCS (FFQ) and compensation solenoid (ES)
  - We consider that spatial constraints and electro-magnetic force on ES for magnet design.
- Synchrotron lights from QCS
  - Effects of dynamic beta and dynamic emittance
  - Orbit displacement from design orbit (estimated from KEKB experience)
  - P_{SR}=65 kW from QCSL / 179 kW from QCSR
- QC1 (vertical focusing for e^-)
  - Two options : superconducting or normal magnet
  - SR from QCS.
- QC2 (horizontal focusing for e^- or e^+)
  - normal magnet
  - SR from QCS.

QCS and QC1 *(superconducting magnet)*

Crossing angle=30mrad, β_x=20cm
beam envelope & synchrotron radiation(SR)

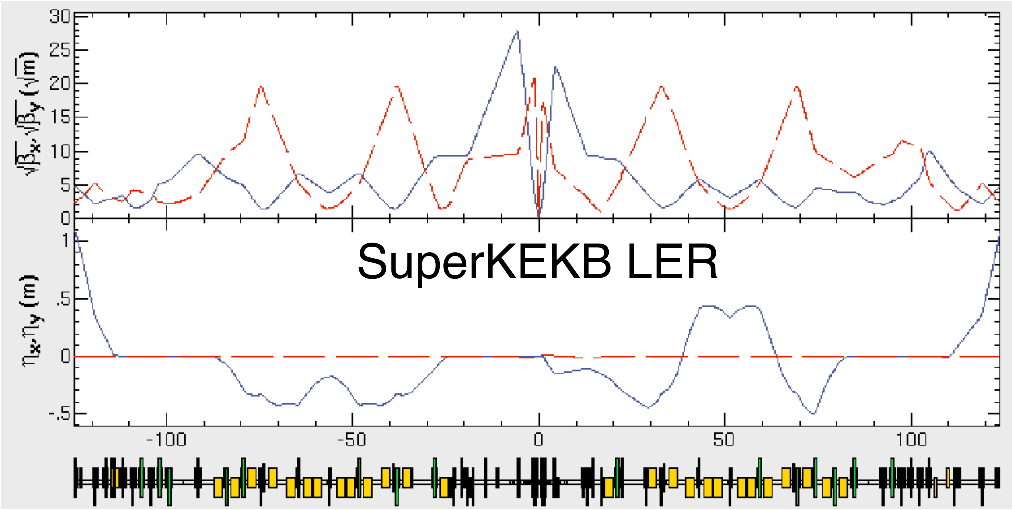
pink : SR fans (design orbit)
green : SR fans (inc. dynamic effects and orbit displacement)

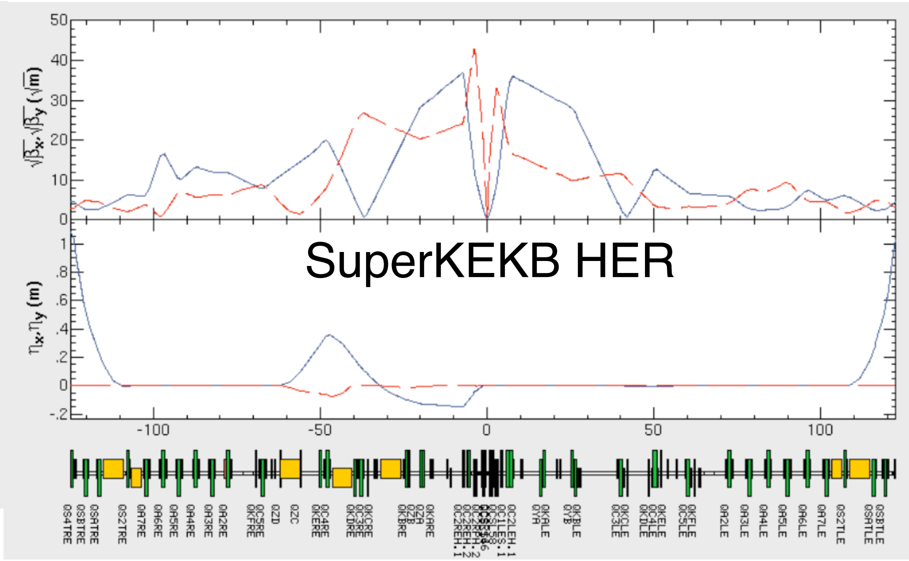
Synchrotron light passes through cryostat-bore



Left side Right side

IR optics





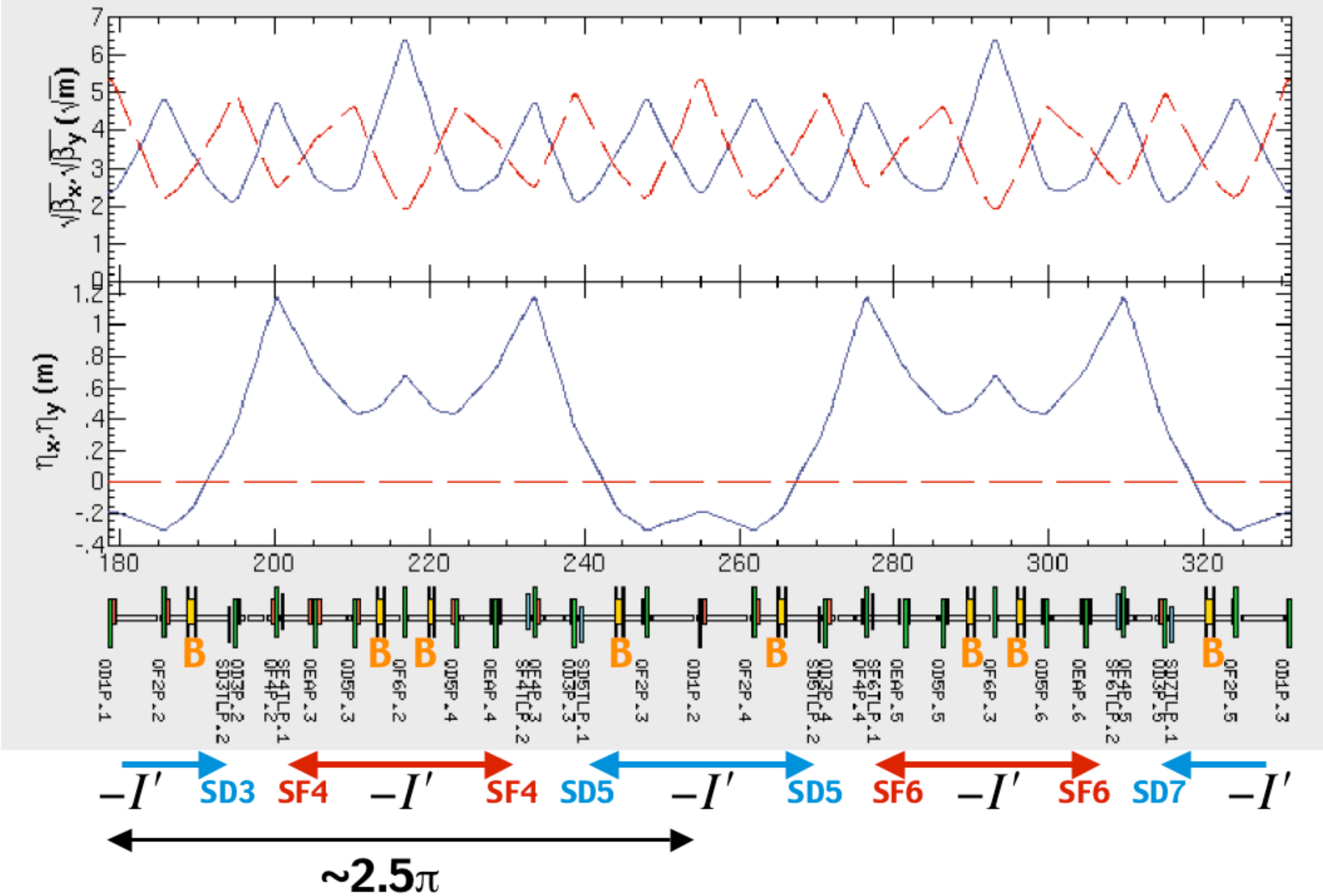
LER IR optics with local chromaticity correction

	LER	
	KEKB	SuperKEKB
β_x^* (cm)	59	20
β_y^* (mm)	5.8	3
β_x max (m)	225	729
β_y max (m)	625	400

	HER	
	KEKB	SuperKEKB
β_x^* (cm)	56	20
β_y^* (mm)	7.0	3
β_x max (m)	484	1600
β_y max (m)	1225	2025

2.5π cell and non-interleaved chromaticity correction

LER arc section



Two sextupole magnets in a pair are connected with -I' transformer.
Nonlinearities from sextupoles are cancelled. → Large dynamic aperture
Wide emittance range : 10~36 nm and negative momentum compaction is available.

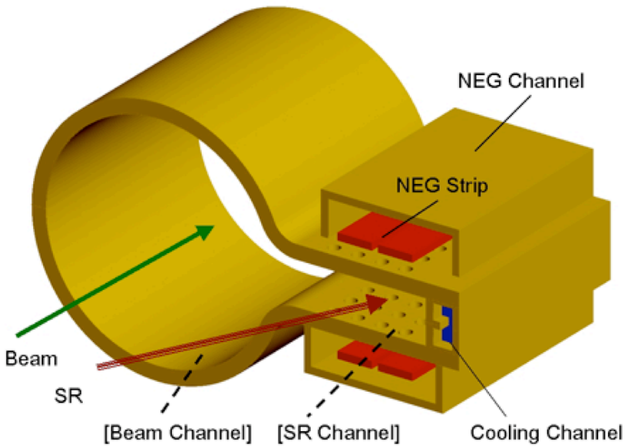
Part 4 Beam current

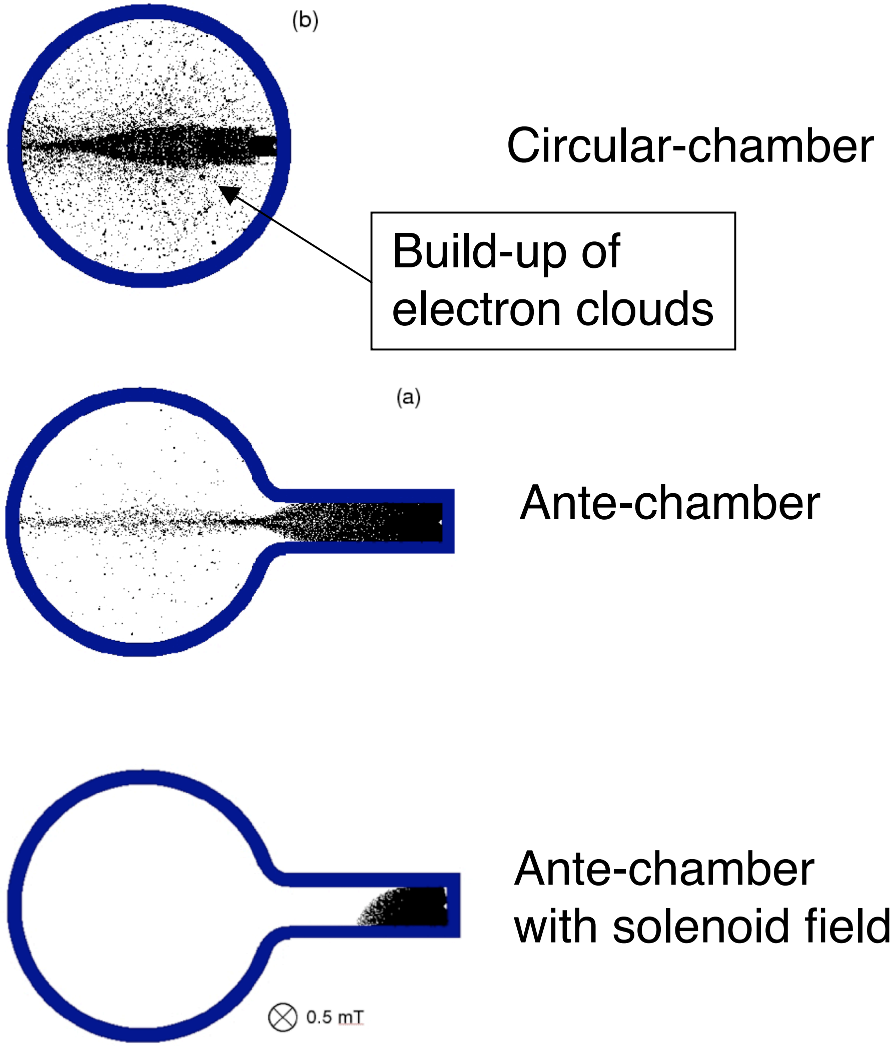
- High beam currents **LER 9.4 A and HER 4.1 A**
  - RF power — Increase number of cavities
  - SR — Ante-chamber
  - HOM heating — Modify HOM damper
  - Cooling system
  - Beam instabilities
    - Fast ion instability — 3.5 GeV e^- OK ?
    - Electron cloud instability — Feedback system; Ante-chamber, Solenoid coils, Energy exchange ?
    - etc.
  - Short bunch length ($\sigma_z < \beta_y^*$)
    - HOM heating
    - Touschek lifetime
    - Coherent synchrotron radiation (CSR) — Increase number of bunches; Chamber height ?
  - Injection
    - Powerful injector, continuous injection — C-band e^+ damping ring

RF system

- KEKB RF system will be used as much as possible.
- ARES in LER
- ARES + SCC in HER
- Need improvements
  - Modified LER-ARES decreases CBI growth time (0.3 ms to 1.6 ms). Increase energy ratio of $U_{storage}/U_{accelerating}$ from 9 to 15.
  - New HOM dampers
  - New RF couplers
  - Number of RF system will be doubled.

Vacuum system





- Ante-chamber and solenoid coils in both rings.
- Absorb intense synchrotron radiation.
- Reduce effects of electron clouds.

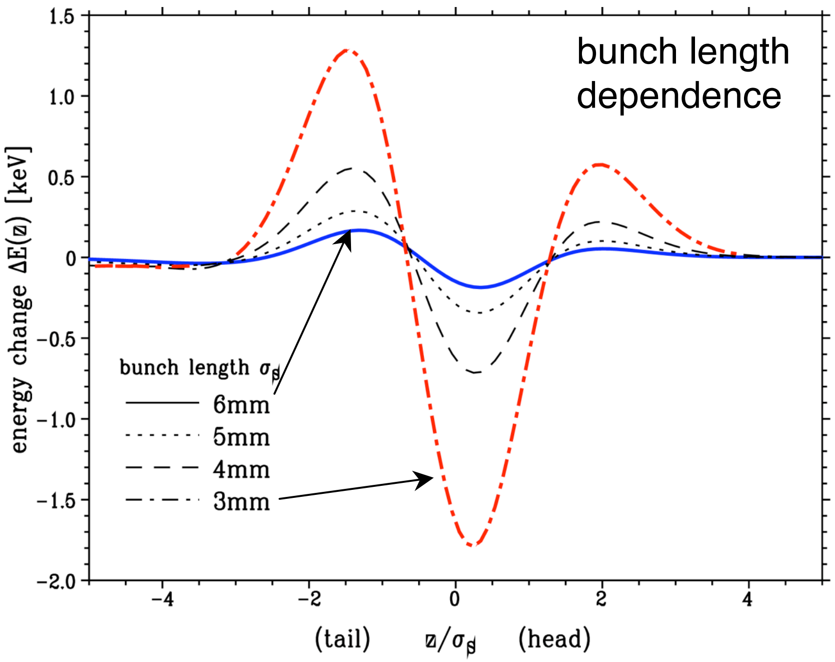
Beam instrumentation

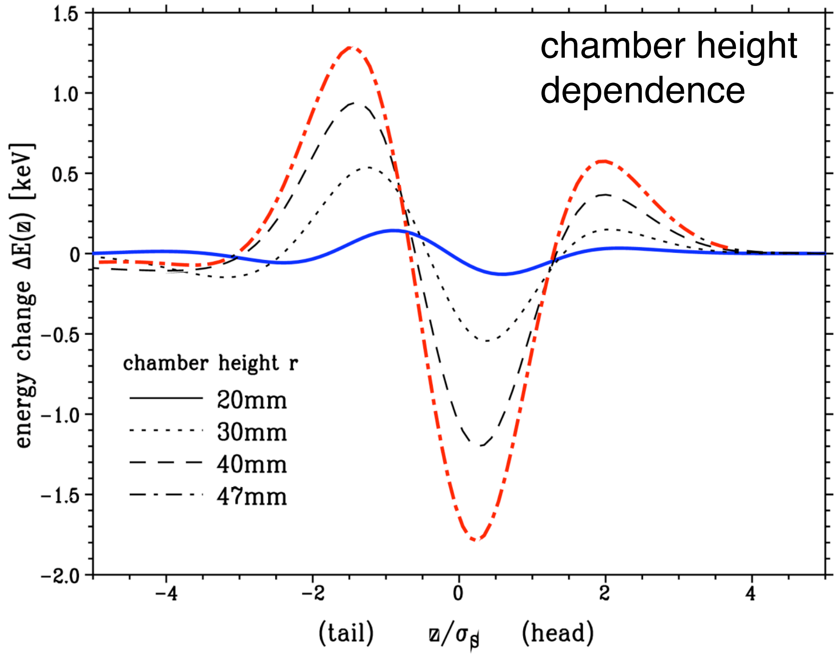
- Beam position monitors
- Bunch-by-bunch Feedback system
  - Transverse
  - longitudinal (Coupled-bunch instability due to RF cavities)
- Gated tune meters
- Synchrotron radiation monitors
  - HER/LER/DR
  - We monitor beam size to optimize luminosity.

Inevitable instruments

Coherent synchrotron radiation

Energy change as a function of z/σ_z KEKB LER/ 2.6A (5120)





- Numerical simulations with mesh (T.Agoh and K.Yokoya)
  - Analytic formula is not reliable due to strong shielding. $\lambda_c \propto \sqrt{h^3/\rho} \approx 2.5$ mm
- Loss factor estimation :
  - No synchrotron oscillation and no interference between bends.
  - 1 V/pC for 6 mm bunch length (LER)
  - 10 V/pC for 3 mm bunch length (LER) ⇔ 30~40 V/pC in the ring

Conclusion

- ARES and SCC modified to store 9.1 A and 4.1 A.
- IR should be designed to satisfy requirements of low beta at IP, physical and dynamic aperture, SR, detector backgrounds, etc.
- We need precise impedance estimations concerned with HOM.
- We need reliable simulations to estimate beam instabilities, FII, ECI, CSR, etc.
- To overcome electron clouds is the most important issue.
- Factor of 10^{35} $cm^{-2}s^{-1}$ depends on whether crab-crossing is success or not.
- The luminosity of 10^{35} $cm^{-2}s^{-1}$ is a new frontier of the next generation of B factory.
- SuperKEKB is quite challenging.