Optics and IR design for SuperKEKB

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1/19-22, 2004

Super B Factory Workshop in Hawaii

Machine parameters for SuperKEKB

Parameter		LER	HER	Unit
Beam currrent	I	9.4	4.1	A
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 (18-30)		nm
Coupling	κ	1-6		%
Crossing angle	θ_x	30		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	

- Flexibility of lattice :
  - 10 nm < ε_x < 36 nm
  - $-4\times10^{-4} < \alpha_p < 4\times10^{-4}$ (Negative α_p → advantage for short bunch length)

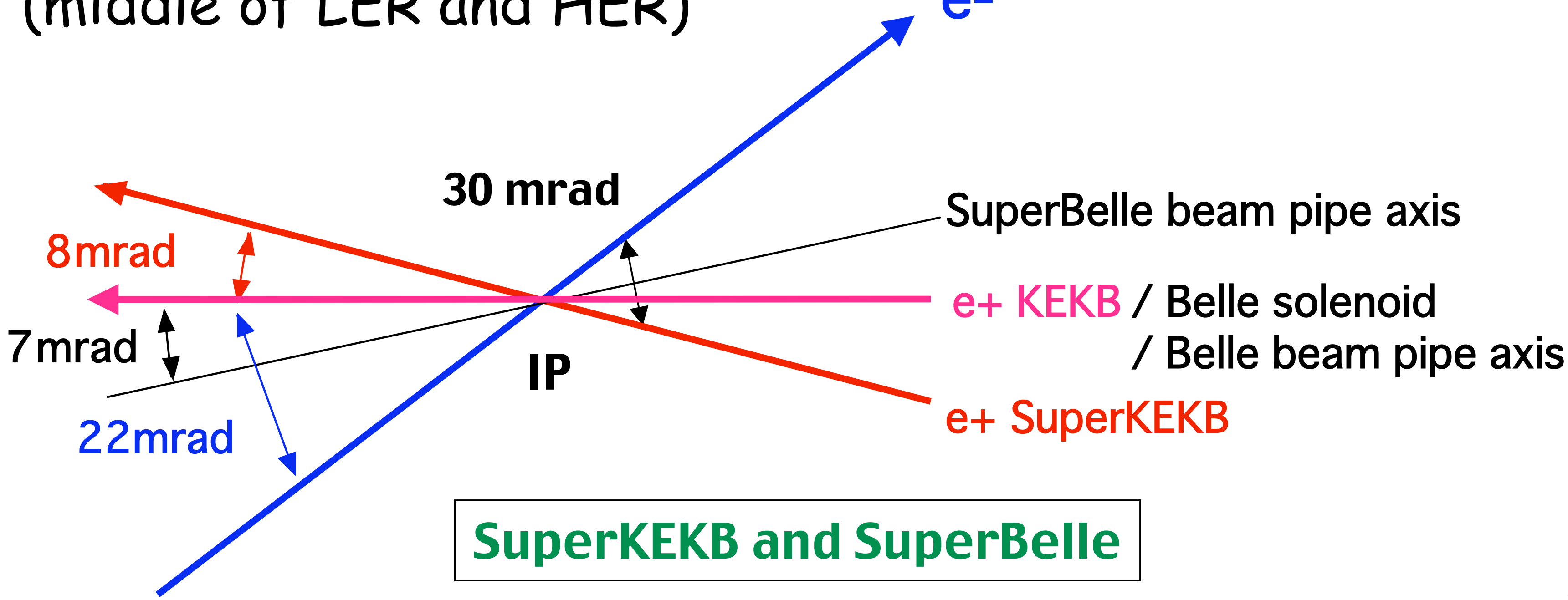
Items considered for IR design

- IR magnets closer to IP
  - Lower beta at IP
- Physical aperture
  - Beam injection
- Dynamic aperture
  - Beam injection / Lifetime
- Crossing angle
  - Beam separation / Magnet design
- Synchrotron radiation from IR magnets
  - Heating of components / Detector background

Magnet aperture (bore)
Good magnetic field quality
Small leakage field

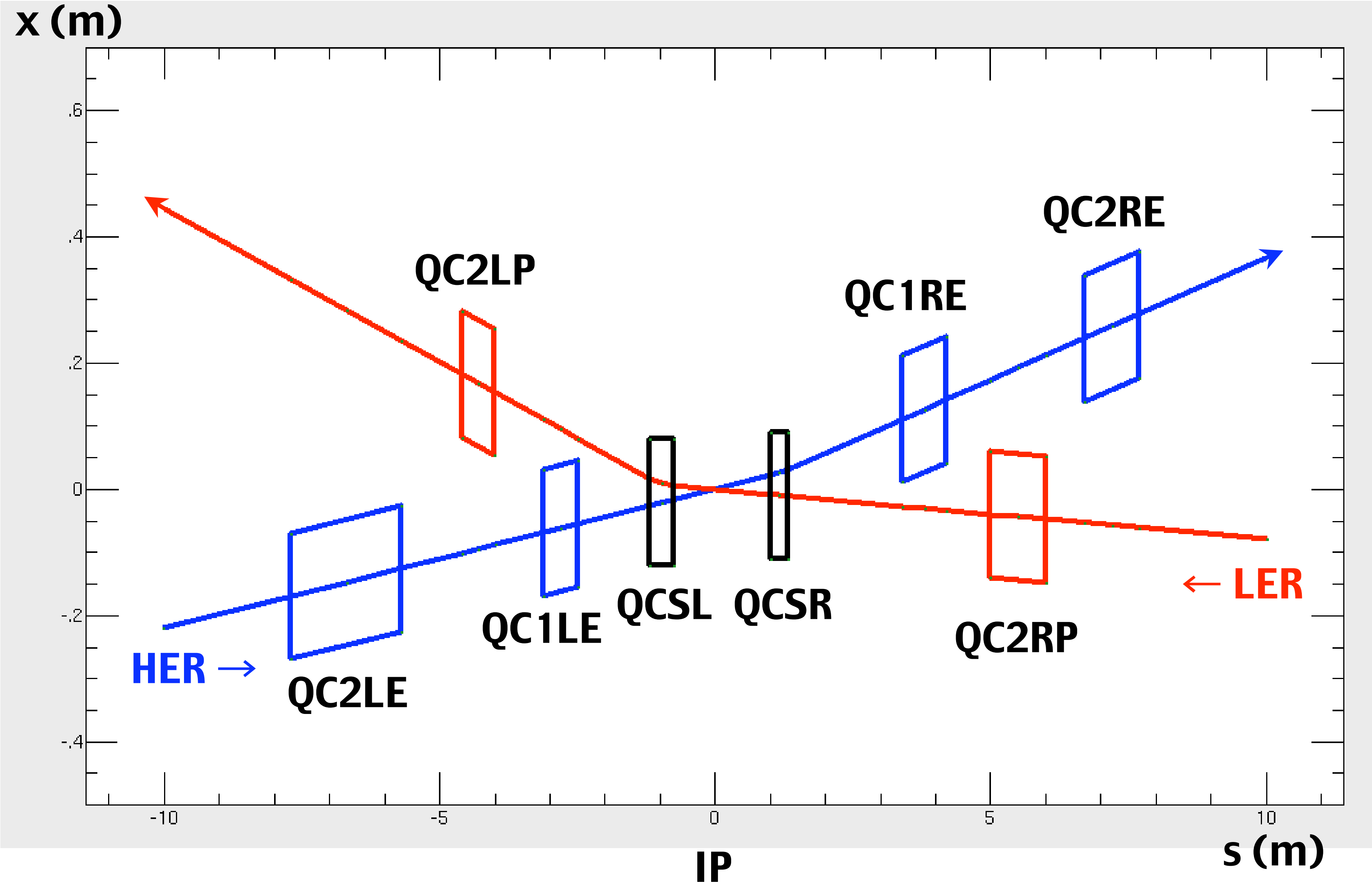
Layout of beam axis and SuperBelle

- No change of HER axis (already has 22 mrad)
- LER axis is rotated by 8 mrad (θ_x=22 -> 30 mrad).
  - minimize rearrangement of magnets
- No rotation of Belle solenoid (translation is allowed)
- Beam pipe and SVD have 7 mrad w.r.t Belle solenoid. (middle of LER and HER)



SuperKEKB and SuperBelle

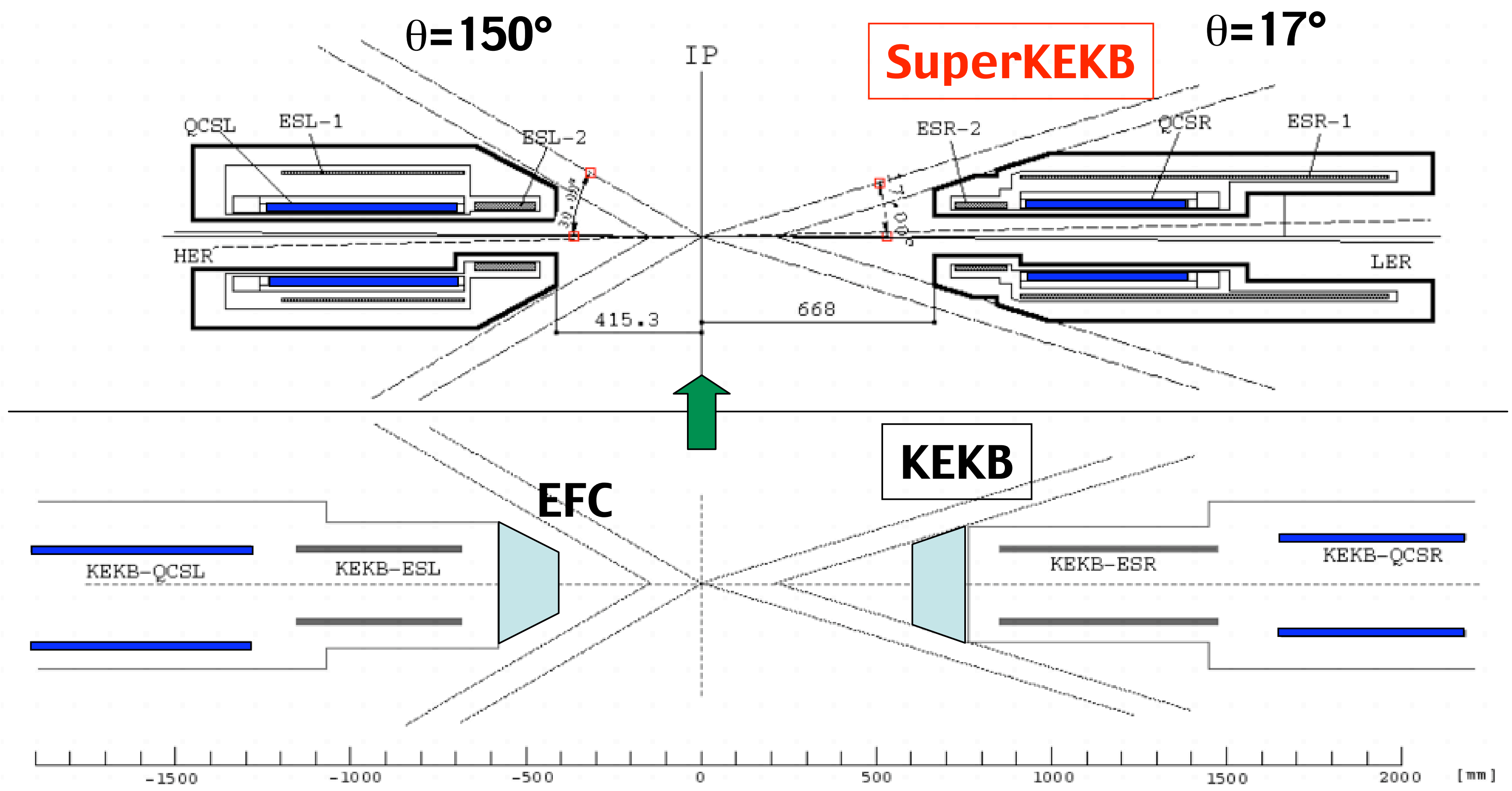
IR magnet layout



Relationship between SuperBelle and SuperKEKB

- Spatial constraints for IR components :
- We assume the same condition as the present Belle and KEKB.
- Except for EFC (extremely forward calorimeter) replaced with a part of compensation solenoid magnets (ES).

QCS for SuperKEKB and KEKB



Move QCS closer to IP and compensation solenoid is divided into two parts, one is overlaid with QCS.

IR aperture requirements

- Required acceptance depends on linac beam emittance

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

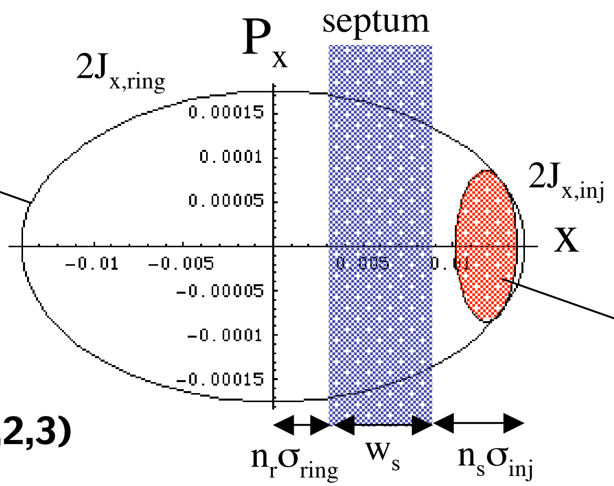
$$\frac{(x - x_i)^2}{\beta_{inj}} + \beta_{inj} p_x^2 = 2J_{x,inj}$$

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

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

Acceptance of ring

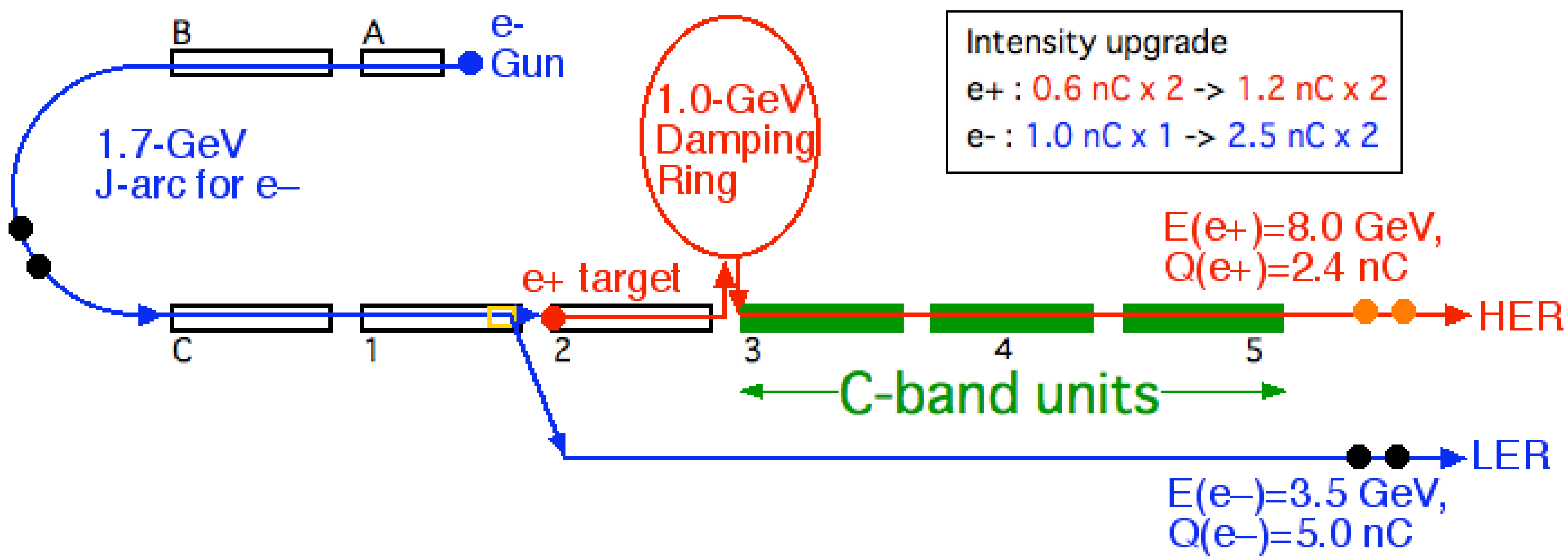
$(n_i, n_s, n_r) = (2,2,3)$



Injection beam

- 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)

IR aperture requirements (cont'd)

Required acceptance depends on linac beam emittance

	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}

	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}

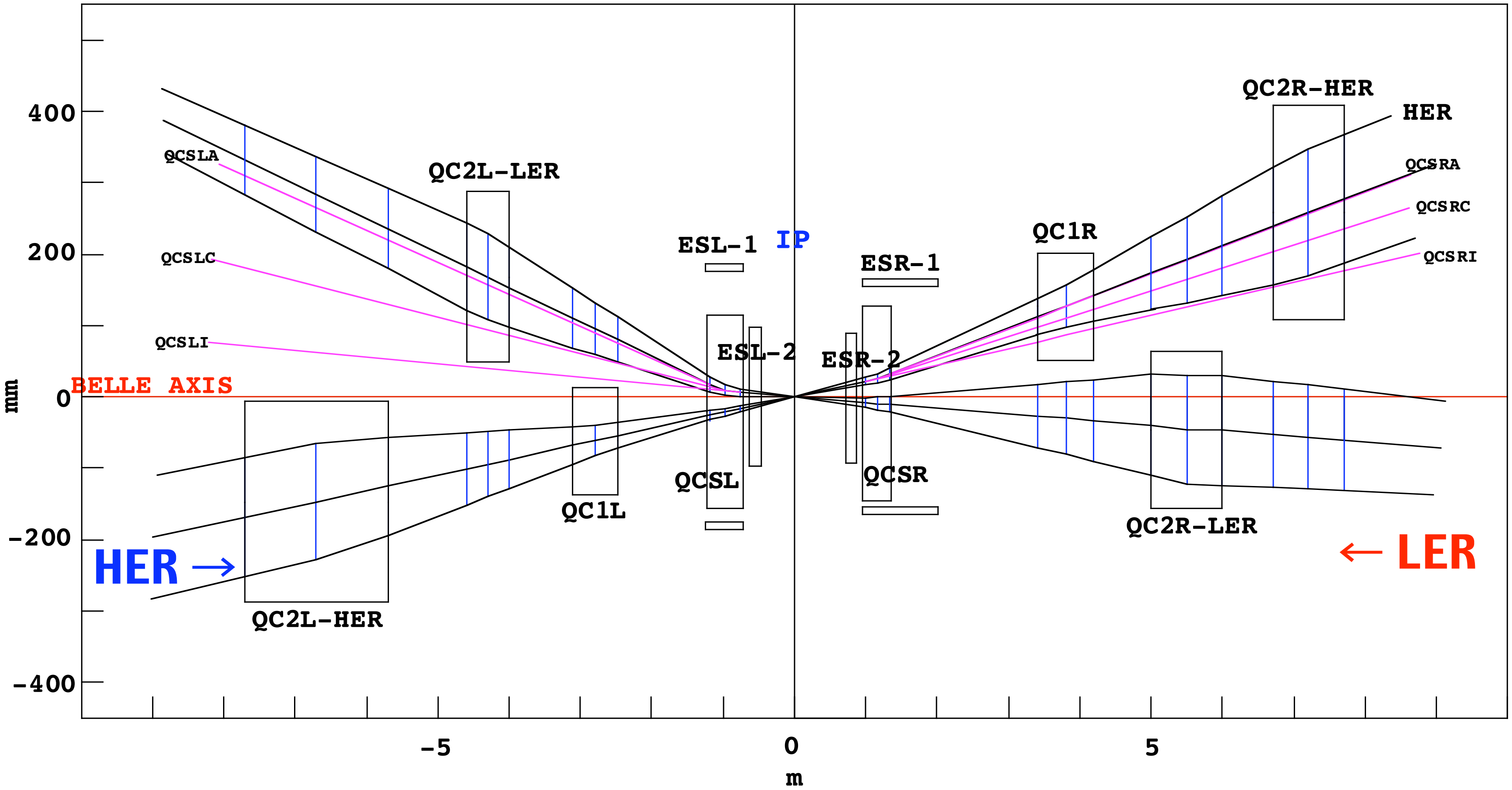
Energy Exchange (adiabatic construction)

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

Beam envelope and IR magnets

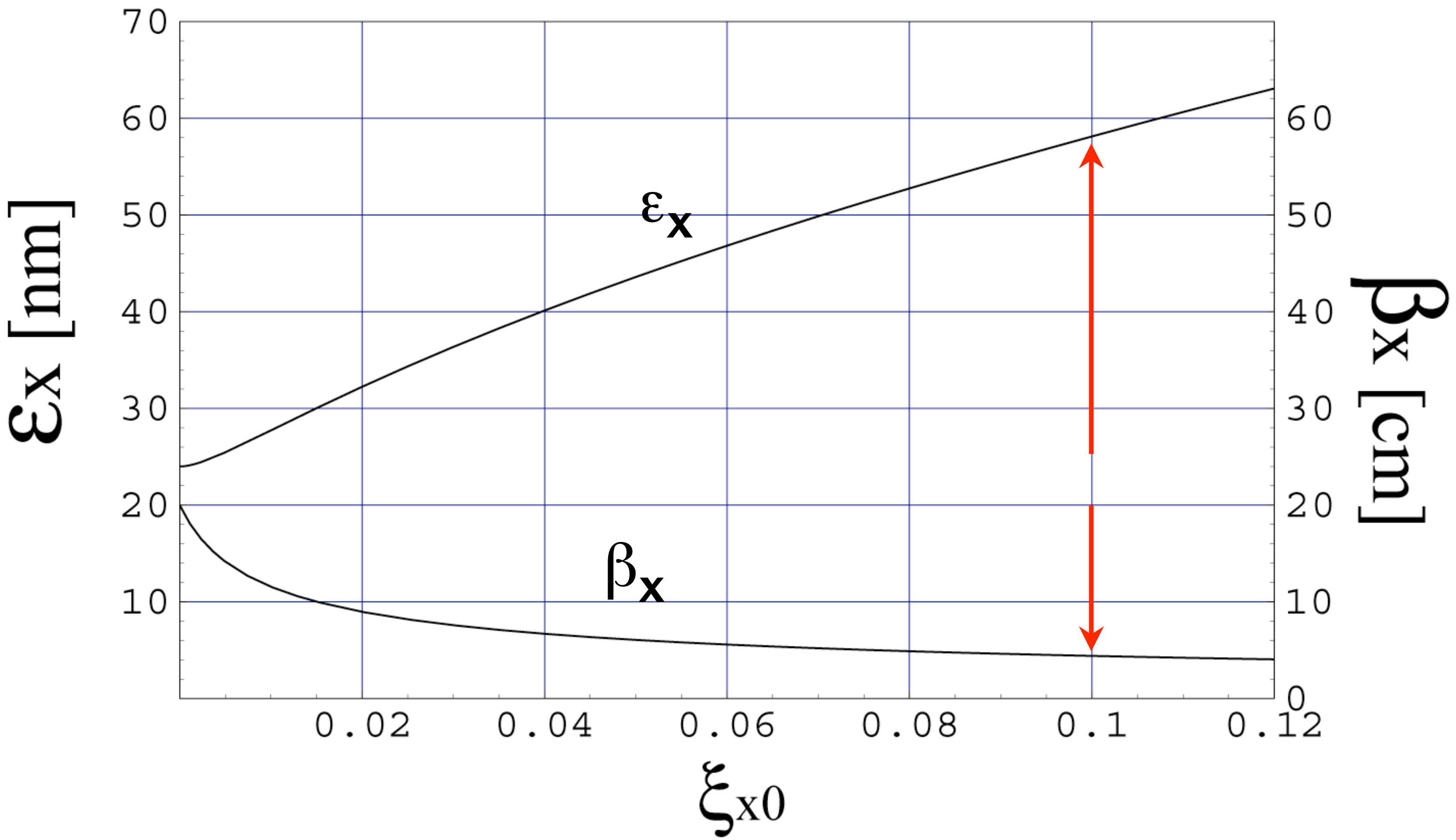
Pos. from the IP	KEKB	Super-KEKB
QCS-R	1920 mm	1163.3 mm
QCS-L	1600 mm	969.4 mm



Design of IR magnets

- QCSL and QCSR with ES
- QC1LE and QC1RE
  - Choice of superconducting or normal magnet
- QC2LP, QC2LE, QC2RP, QC2RE
  - normal magnets
- 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

Dynamic beta and dynamic emittance

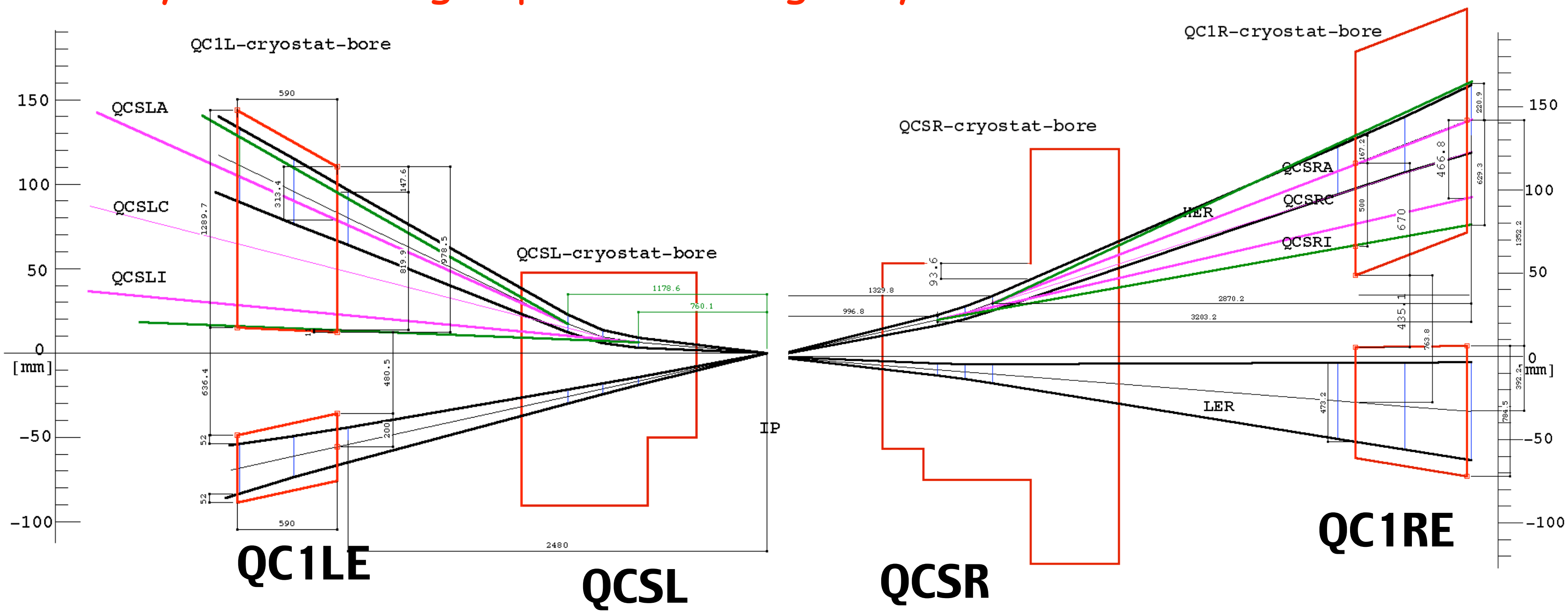


If ξ_x=0.1, ε_x becomes 58 nm.

QCS and QC1(superconducting magnet)

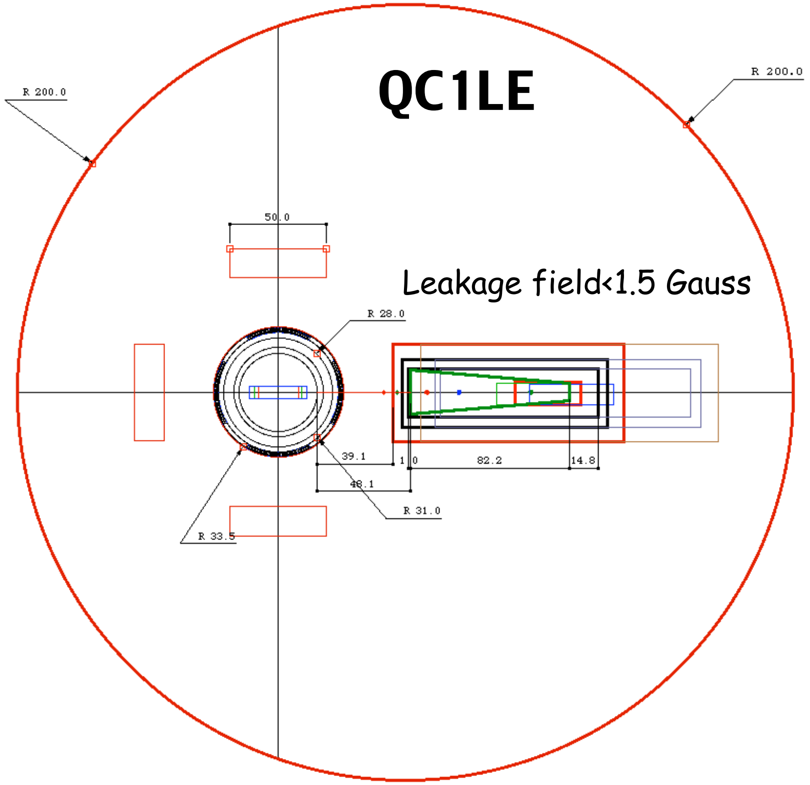
Crossing angle=30mrad, β_x=20cm
beam envelope & synchrotron radiation(SR)

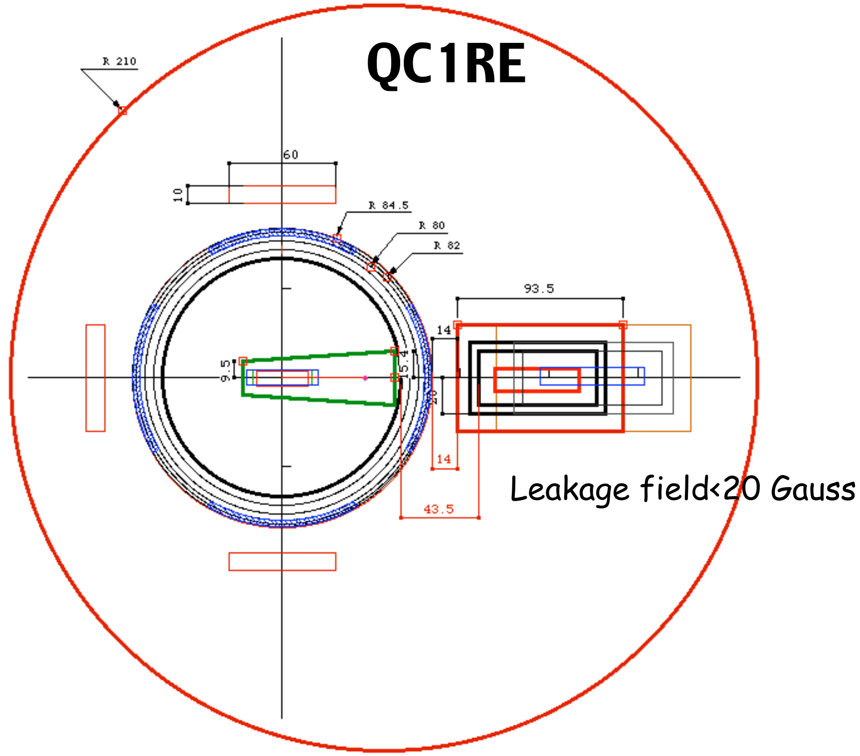
pink : SR (design orbit)
green : SR (inc. dynamic effects and orbit displacement)
Synchrotron light passes through cryostat-bore



Left side Right side

QC1(superconducting magnet)





G=42.86 T/m

L_{eff}=0.232 m

I_{op}=1319A, B_{max}=1.62 T

I_{op}/I_c=59%

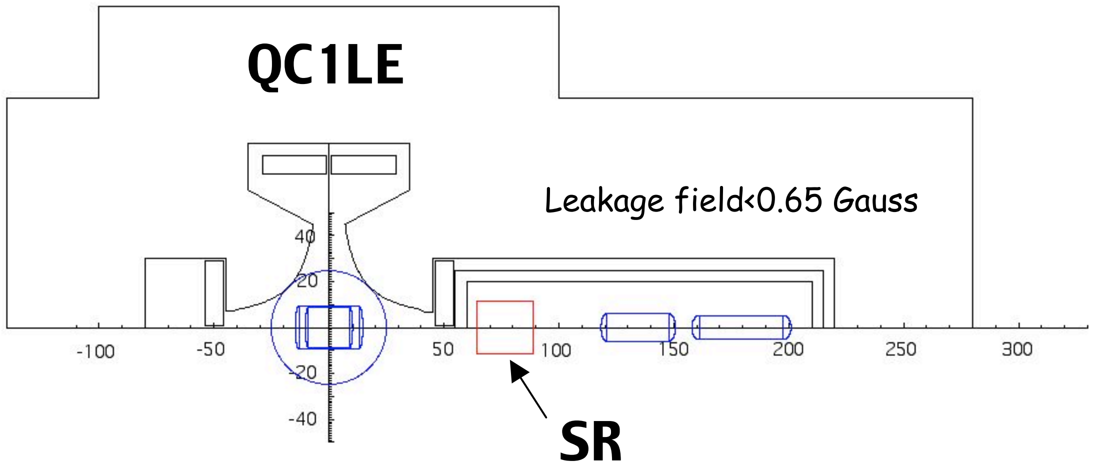
G=34 T/m

L_{eff}=0.266 m

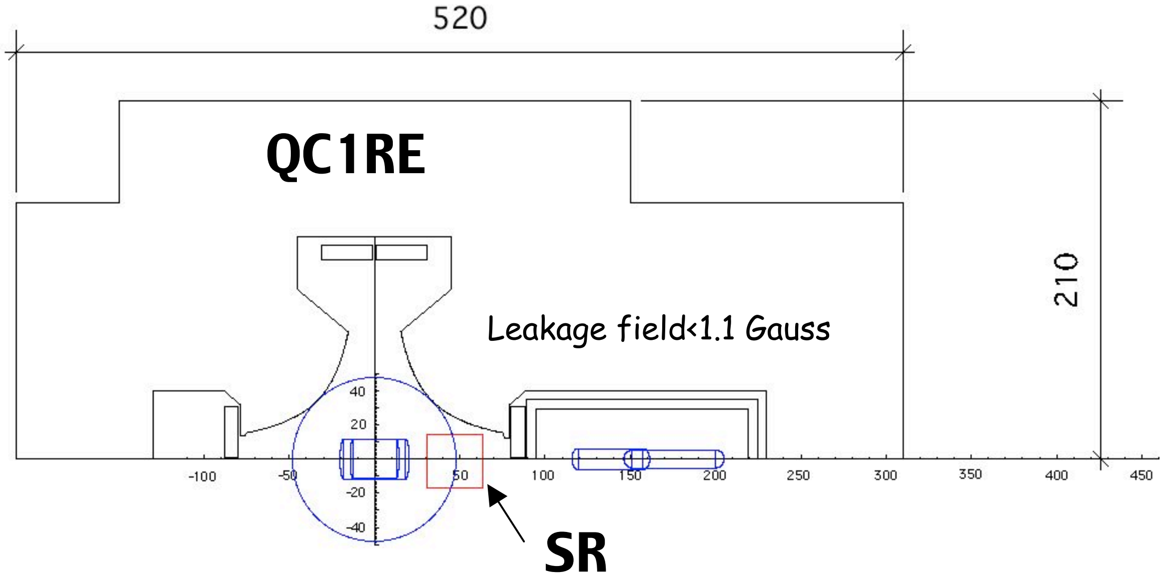
I_{op}=1319 A, B_{max}=3.28 T

I_{op}/I_c=73%

QC1 (normal magnet)

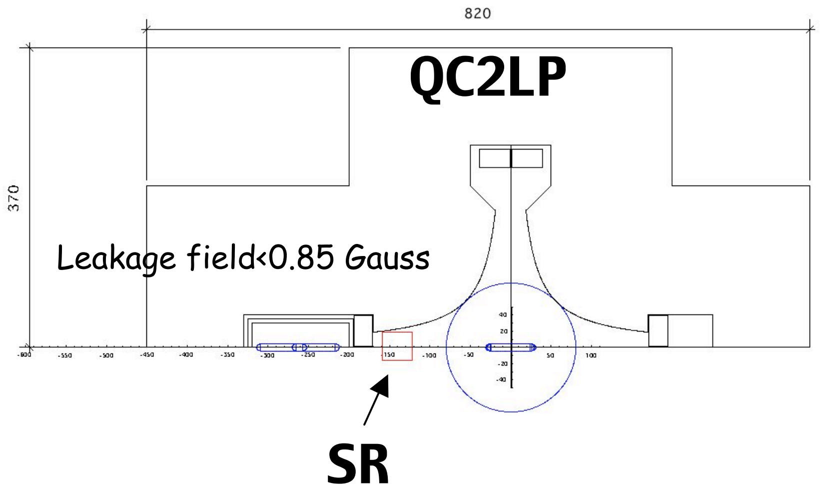


g=15.54 T/m,
L=0.64 m
R_0=25mm
3turn-8x8-ϕ5
3920AT
i=30A/mm^2

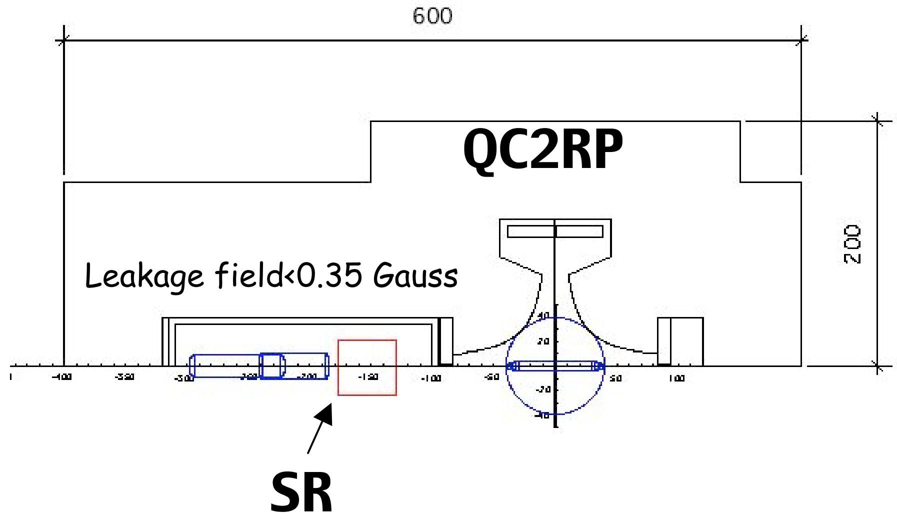


g=12T/m
L=0.75m
R_0=48mm
3turn-9x9-ϕ6
11050AT
i=70A/mm^2

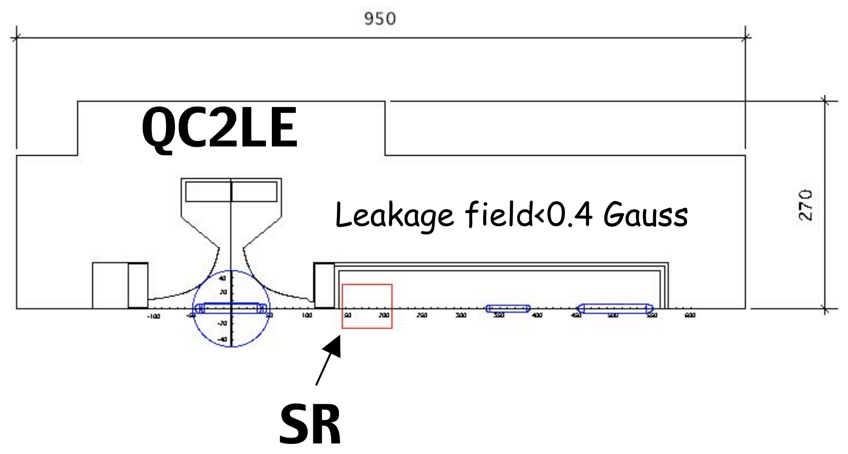
QC2 magnets



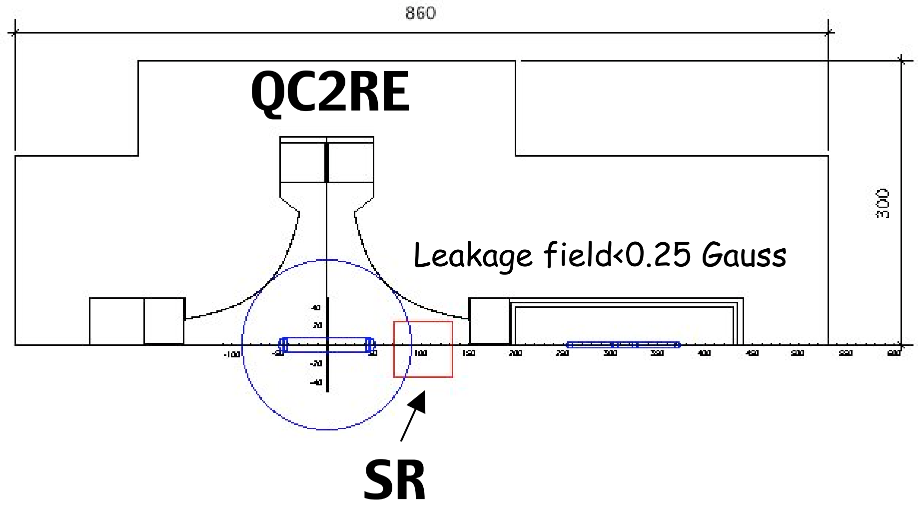
820
370
QC2LP
Leakage field<0.85 Gauss
SR



600
200
QC2RP
Leakage field<0.35 Gauss
SR



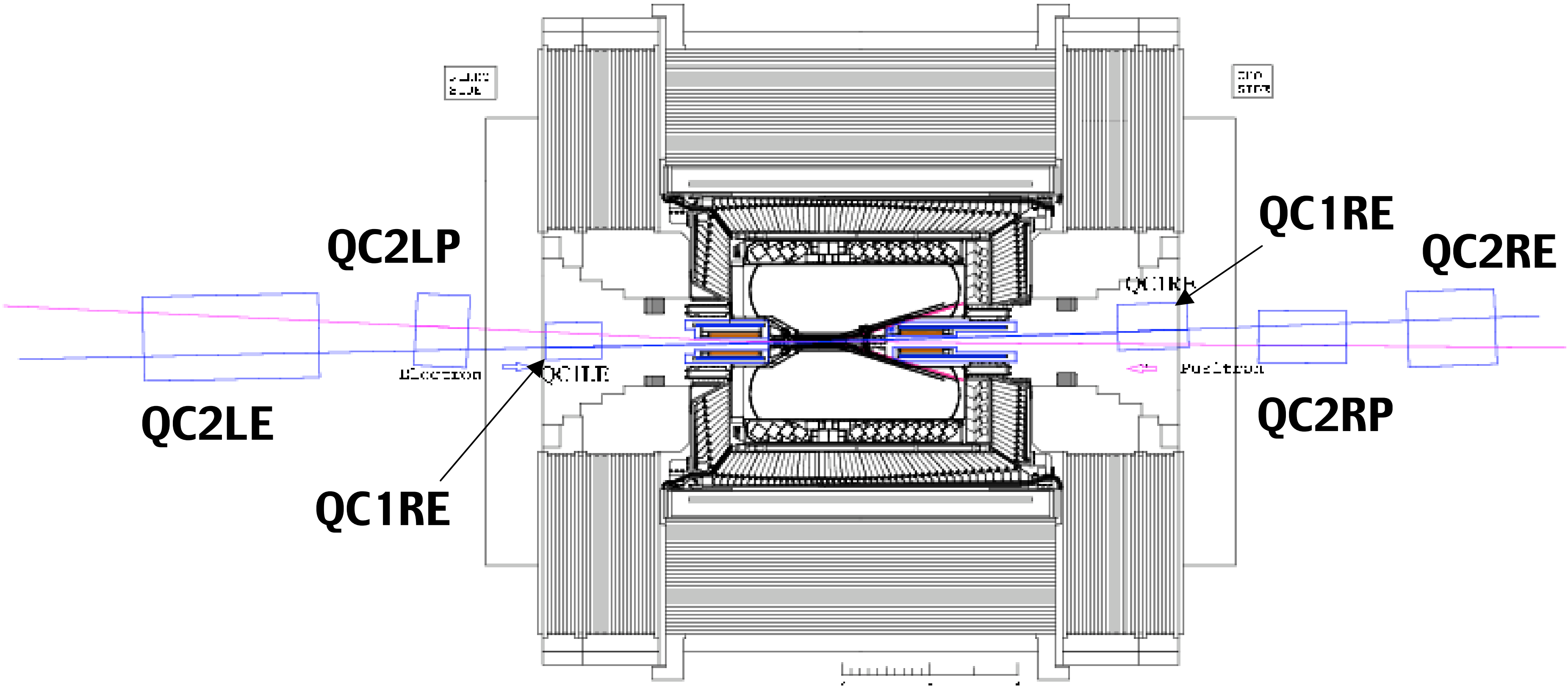
950
270
QC2LE
Leakage field<0.4 Gauss
SR



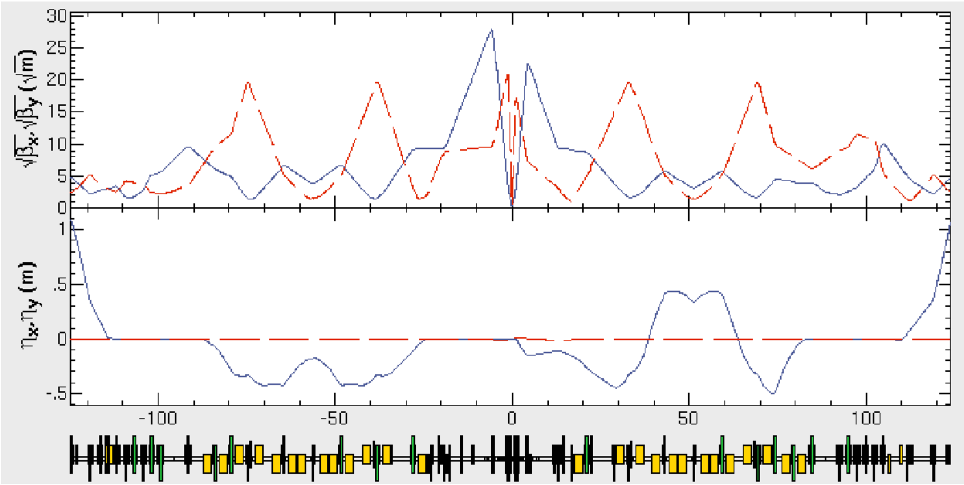
860
300
QC2RE
Leakage field<0.25 Gauss
SR

IR magnets and Belle detector

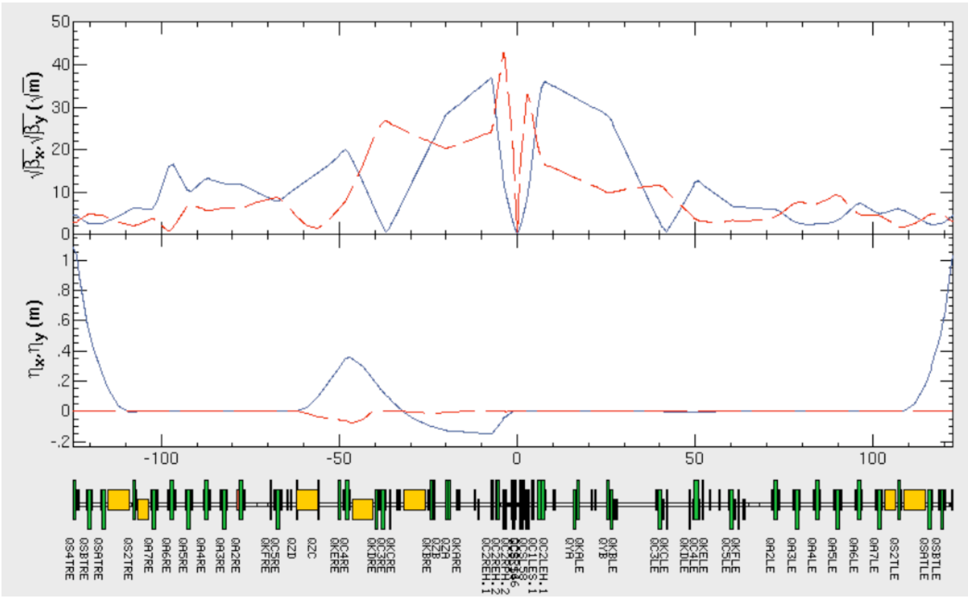
No interference between QC1 and end yoke.



IR optics

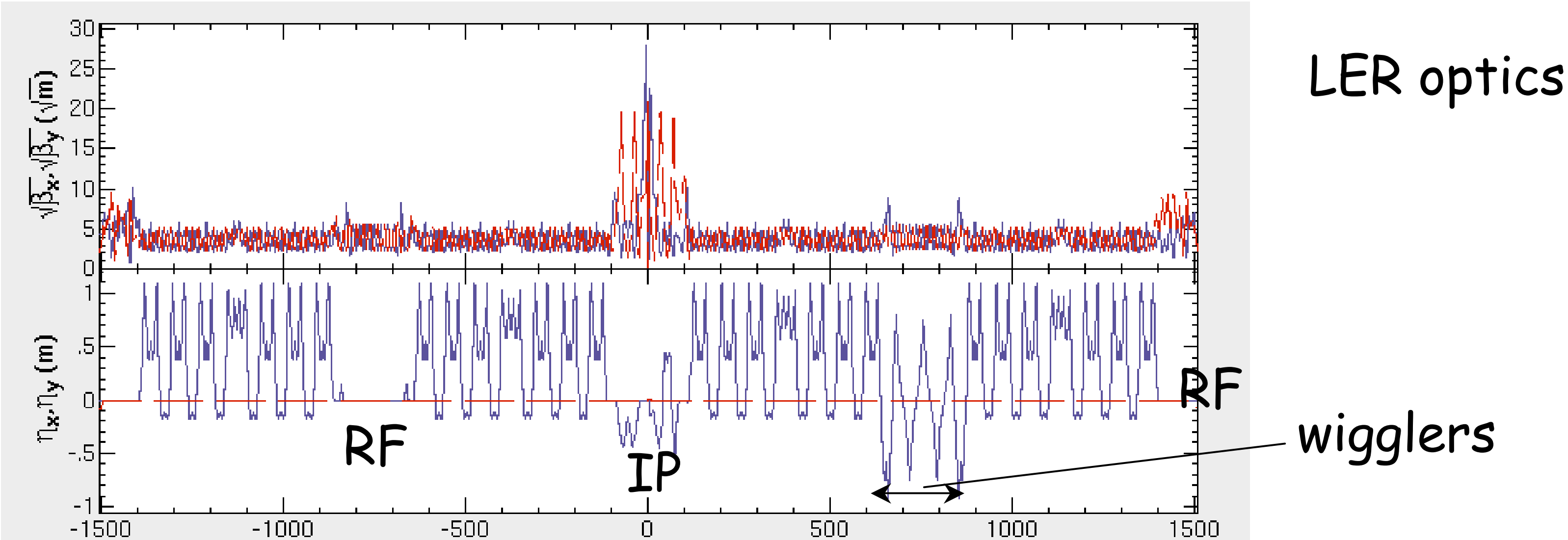


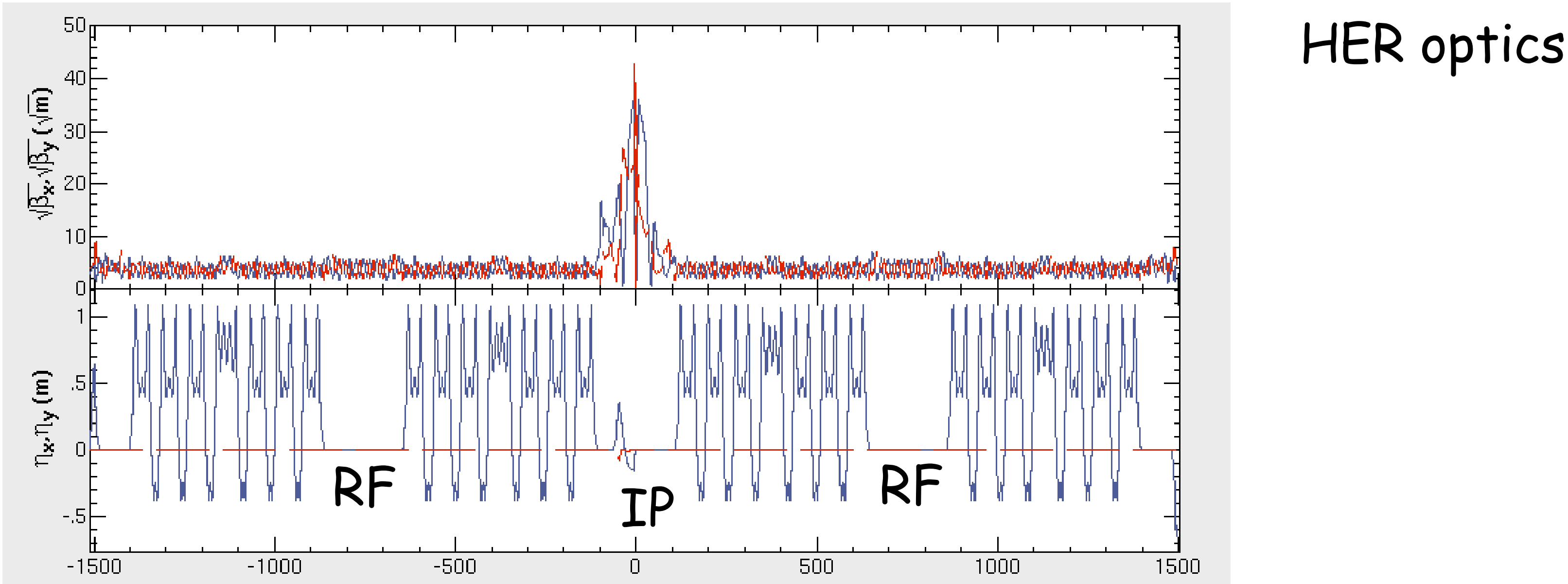
LER IR optics with local chromaticity correction



HER IR optics

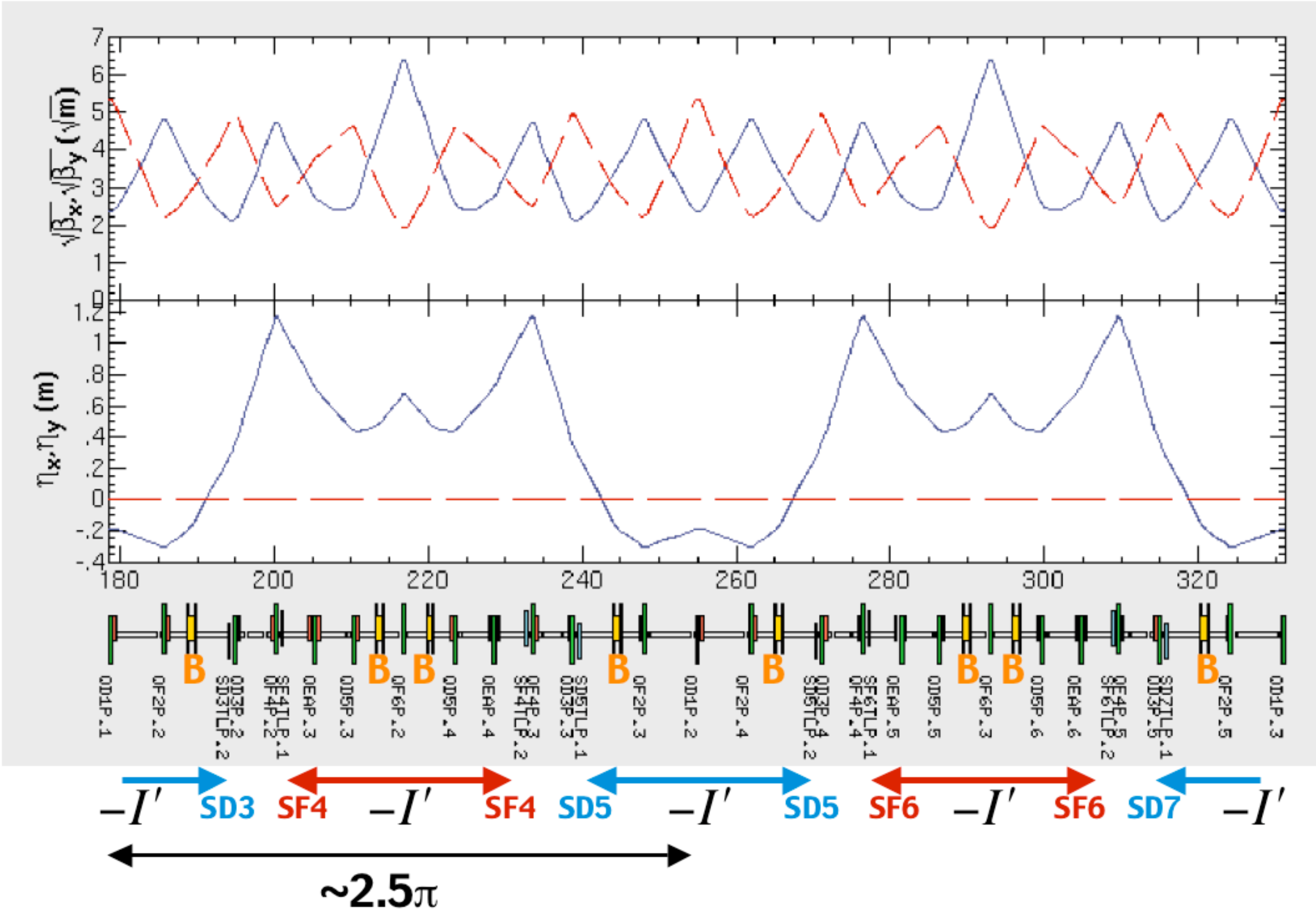
LER and HER optics (ring)





2.5π cell and non-interleaved chromaticity correction

LER arc section

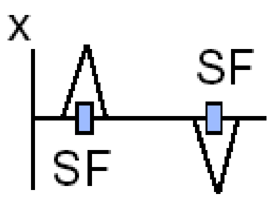
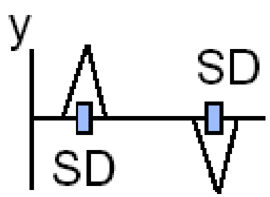
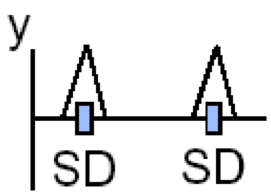


Two sextupole magnets in a pair are connected with -I' transformer.

Nonlinearities from sextupoles are cancelled. → Large dynamic aperture

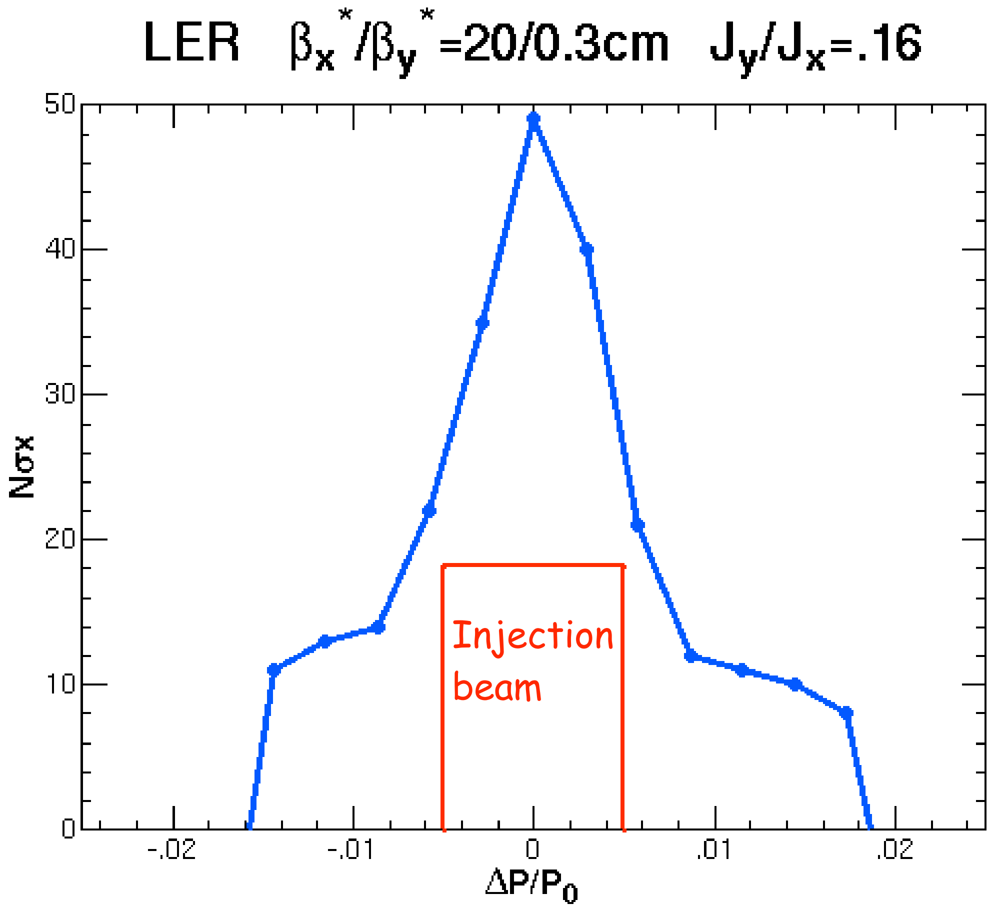
Optics correction

Local sextupole bumps are utilized to correct optics.
It works very well at KEKB.

optical variable	η_x	η_y	xy-coupling		β_x β_y
method	SF (-I trans)	SD (-I trans)	SD (-I trans)	Skew Q	QD/QF
	 Asym. local bumps in x	 Asym. local bumps in y	 Symm. local bumps in y	Fudge factors to K-value	Fudge factors to K-value
comment	w/o affecting xy-coupling and β-functions		w/o affecting vertical dispersion		Correction for each power supply

Sextupole movers(±2.5mm) are necessary instead of bump orbit.
Large SR may hit beam channel of ante-chamber due to bumps.
(SR channel : height ~ 7 mm)

Dynamic aperture



- Dynamic aperture in LER
- Machine errors are not included.
- Transverse aperture is acceptable.

Coupling	Lifetime
1%	51 min
2%	72 min
4%	102 min
6%	145 min

Summary

- Strategy of IR design
- Positron DR prior to IR upgrade
- Design of IR magnets
- Two options for QC1 :
  - superconducting / normal
- IR magnets is designed so that SR from QCS does not hit QC1 and QC2 as possible.
- Vacuum chamber in IR is under study.
- Optics for SuperKEKB is designed.
  - Dynamic aperture in LER ($\Delta p/p_0$ ~ 1.5 %)
  - Injection aperture can be kept.