Recent Progress of SuperKEKB Accelerators

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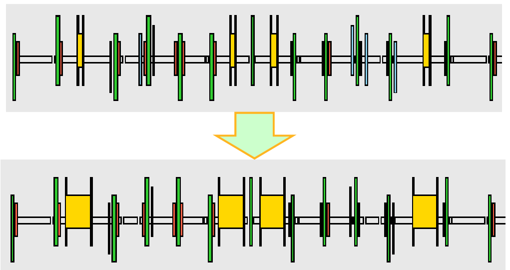
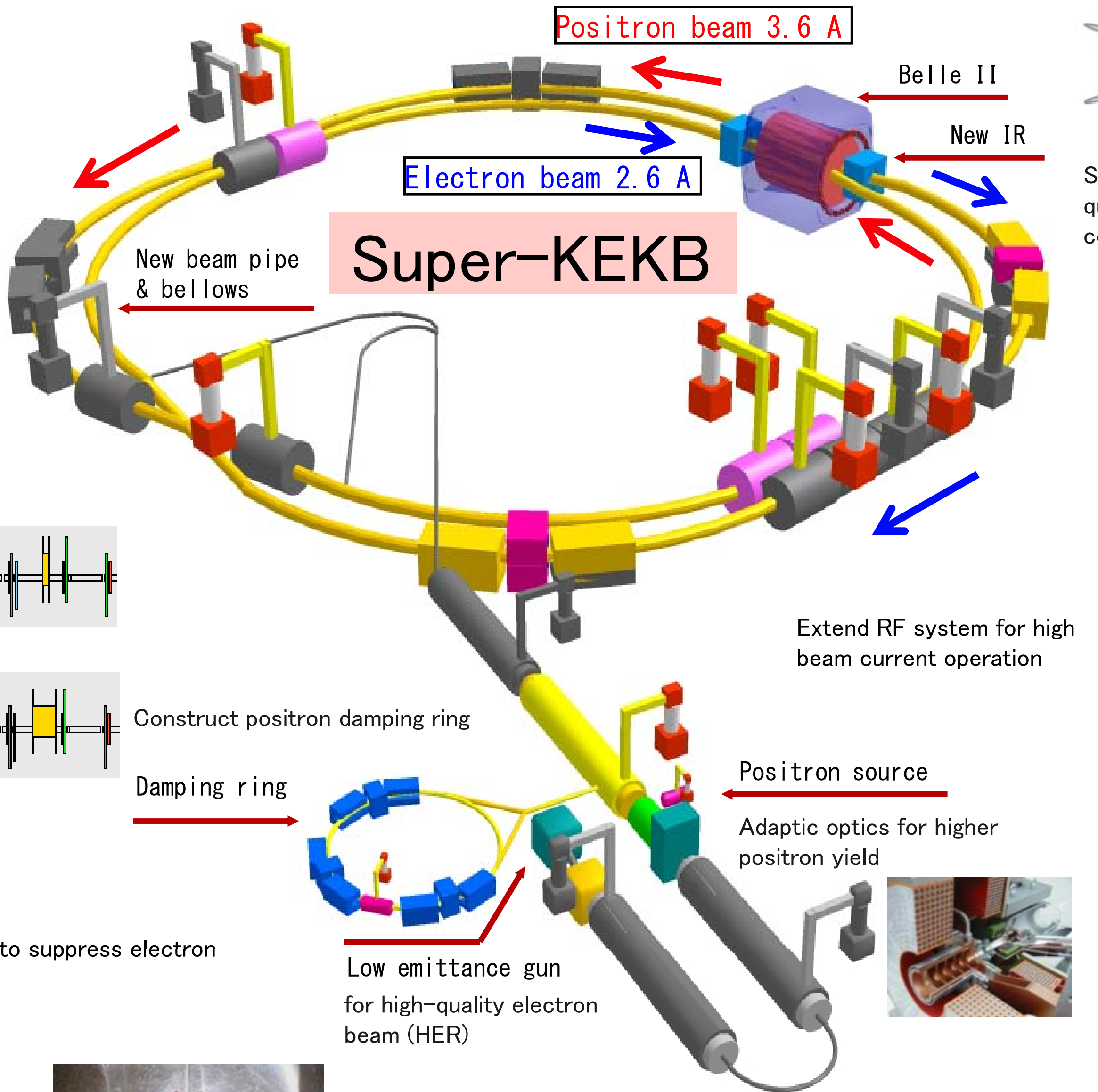
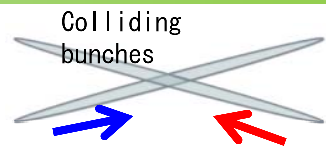
Replace LER dipoles with longer ones (0.82m->4.2m) to reduce emittance



Optimize beam optics for low emittance beam

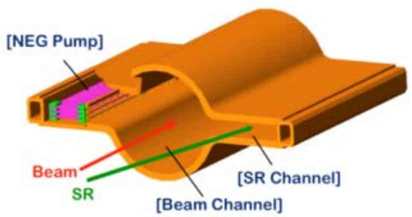


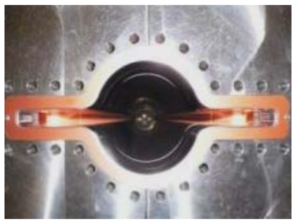


Superconducting quadrupoles to shrink colliding beam at IP

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

Antechamber with TiN coating to suppress electron cloud instability





40 times gain in luminosity
with nano-beam, double beam current

KEKB upgrade plan has been approved

- The MEXT, the Japanese Ministry that supervises KEK, has announced that it will appropriate a budget of 100 oku-yen (approx $117M) over the next three years starting this Japanese fiscal year (JFY2010) for the high performance upgrade program of KEKB. This is part of the measures taken under the new "Very Advanced Research Support Program" of the Japanese government.
- Council for Science and Technology in MEXT has announced that SuperKEKB project should be pushed forward with one of the highest priority.
- MEXT is requesting construction budget of SuperKEKB to Ministry of Finance for FY2011 (40 oku-yen).

Major items to upgrade

- LER
  - Energy 3.5 GeV -> 4 GeV
  - Replace ~110 dipole magnets in the arc section from L=0.89m to 4.2m to reduce emittance (18 nm -> ~3 nm).
  - Change the damping wiggler layout (shorten wiggler period).
  - Reduce vertical crossing scheme at Fuji point to reduce vertical emittance.
  - Replace most of the vacuum chambers with the new antechambers with TiN coating.

Major items to upgrade

- IR
  - Much larger crossing angle (22mrad ->83mrad)
  - New superconducting magnets around IP (HER and LER independent).
    - Might apply permanent quadrupole for LER QC2
  - Optimization of the compensation solenoid.
  - Fine tuning of higher-order components of superconducting magnets.
  - Two family local chromaticity correction scheme for both HER and LER.

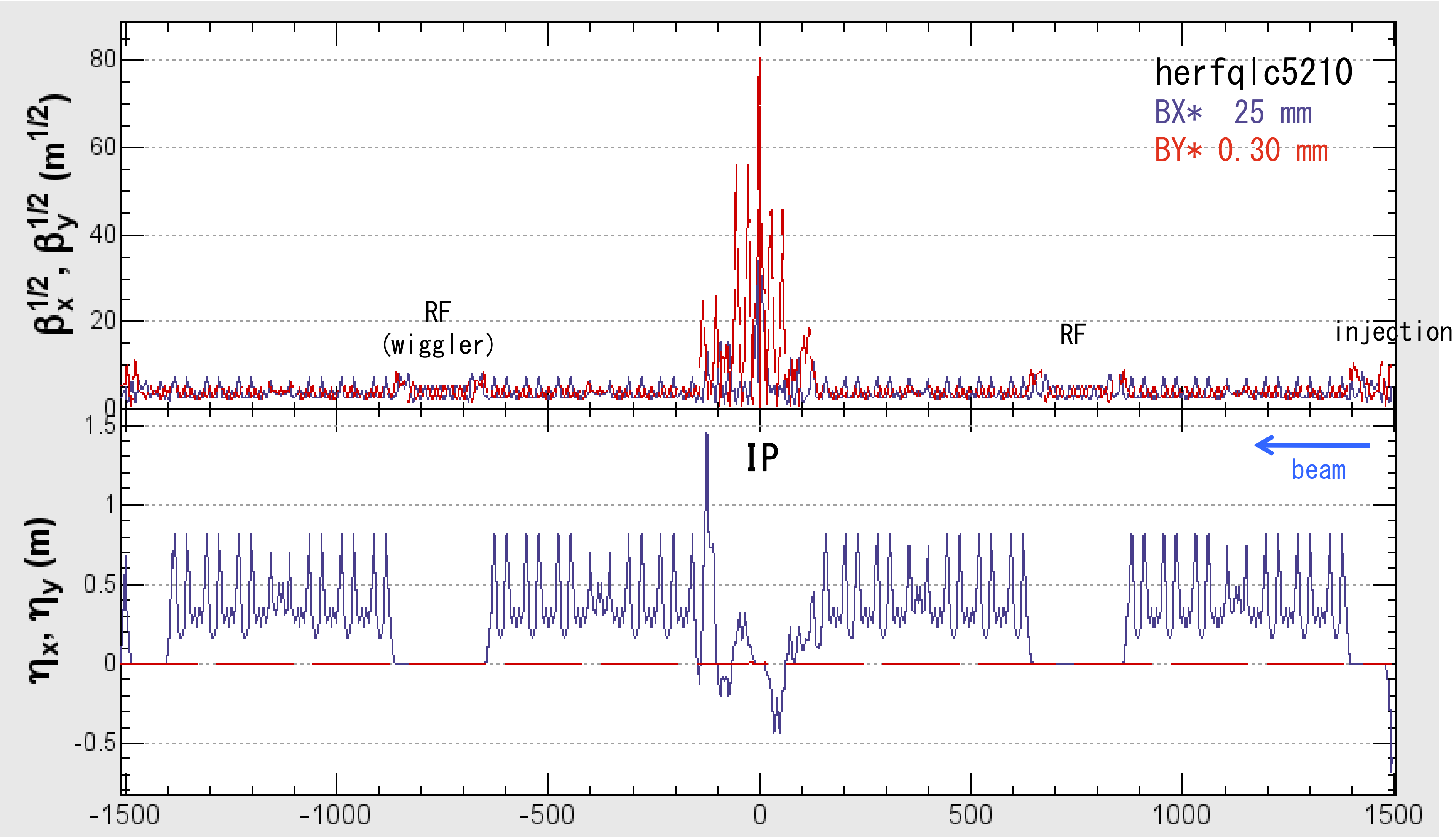
Major items to upgrade

- HER
  - Energy 8 GeV -> 7 GeV
  - Lower emittance(24nm -> 5nm)
  - Keep present placement of the most of arc magnets.
  - New antechamber , or keep present vacuum chamber (not fixed yet).
- Positron damping ring and new positron target.
  - 8nc/bunch, 2 bunch injection
- New RF gun for electrons with reduced emittance.

Machine parameters

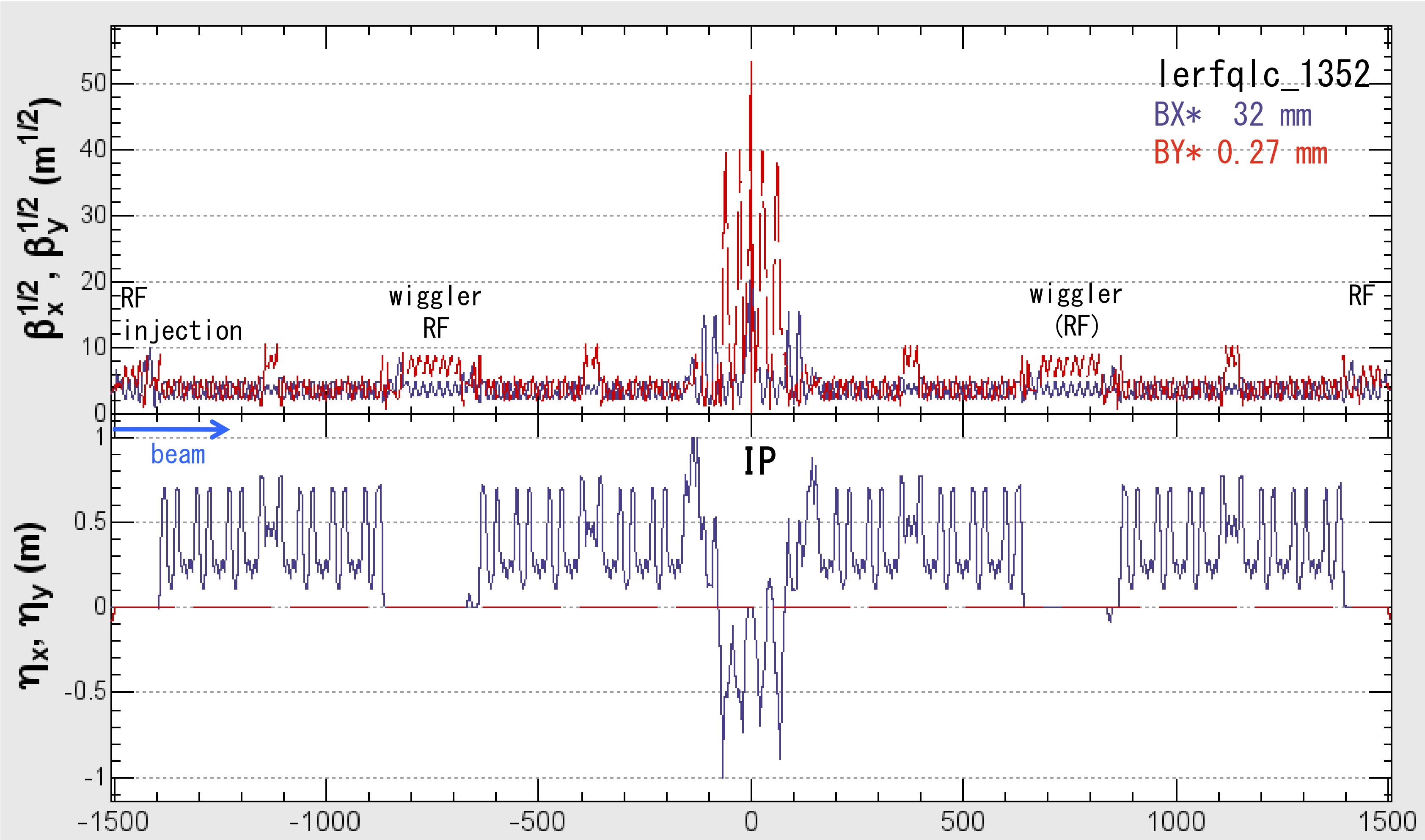
2010/Sept/8	LER	HER	HER	HER	unit
wiggler	Full	None	6/10	Full	
E	4.000	7.007	7.007	7.007	GeV
I	3.6	2.6	2.6	2.6	A
Number of bunches	2,500	2,500	2,500	2,500	
Bunch Current	1.44	1.04	1.04	1.04	mA
Circumference	3,016.3700	3,016.3700	3,016.3704	3,016.3707	m
$\varepsilon_x/\varepsilon_y$	3.2(1.9)/(2.8)	5.3(5.2)/(2.6)	4.6(4.5)/(2.2)	4.3(4.1)/(2.0)	nm/pm
β_x^*/β_y^*	32/0.27	25/0.30	25/0.30	25/0.30	mm
α_p	3.49×10^{-4}	4.55×10^{-4}	4.55×10^{-4}	4.54×10^{-4}	
σ_δ	$8.00(7.66)\times10^{-4}$	$5.85(5.78)\times10^{-4}$	$6.35(6.29)\times10^{-4}$	$6.59(6.54)\times10^{-4}$	
V_c	9.4	12.4	14.7	15.8	MV
σ_z	6.0(5.0)	5.0(4.9)	5(4.9)	5(4.9)	mm
ν_s	−0.0256	−0.0254	−0.0277	−0.0287	
ν_x/ν_y	44.53/43.57	45.53/43.57	45.53/43.57	45.53/43.57	
U_0	1.87	2.07	2.43	2.67	MeV
$\tau_{x,y}/\tau_s$	43.0/21.5	68.2/34.1	58.0/29.0	52.8/26.4	msec
	lerfqlc1351	herfqlc5210	herfqlc5214	herfqlc5215	

HER lattice



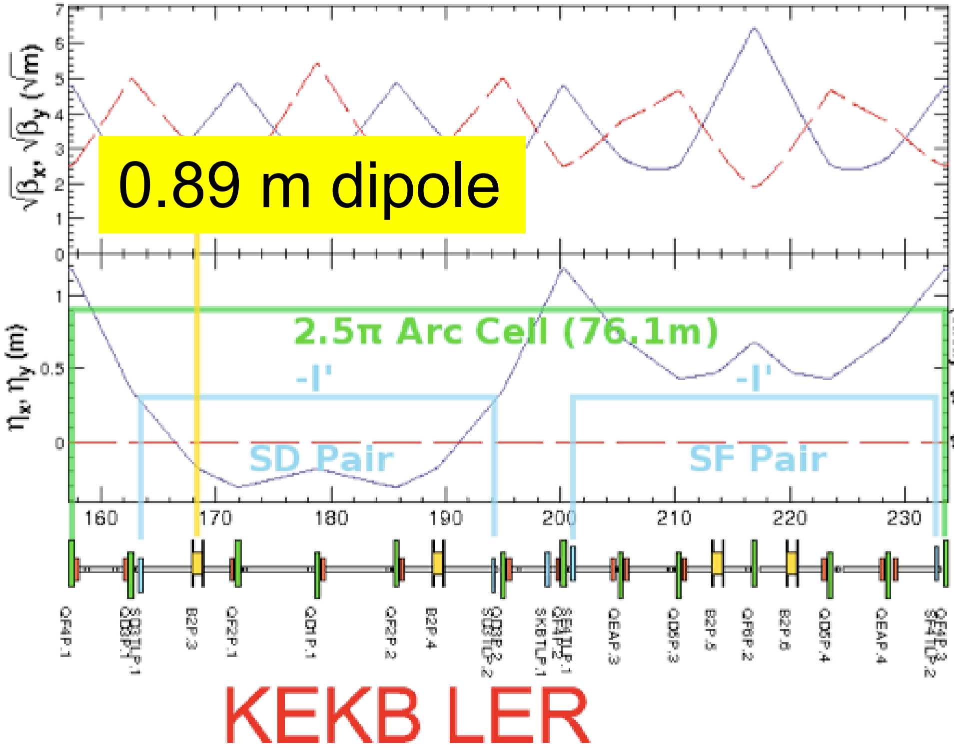
herfqlc5210
BX* 25 mm
BY* 0.30 mm
$\beta_x^{1/2}, \beta_y^{1/2}$ (m$^{1/2}$)
80
60
40
20
0
RF
(wiggler)
RF
injection
IP
beam
η_x, η_y (m)
1.5
1
0.5
0
-0.5
-1500
-1000
-500
0
500
1000
1500

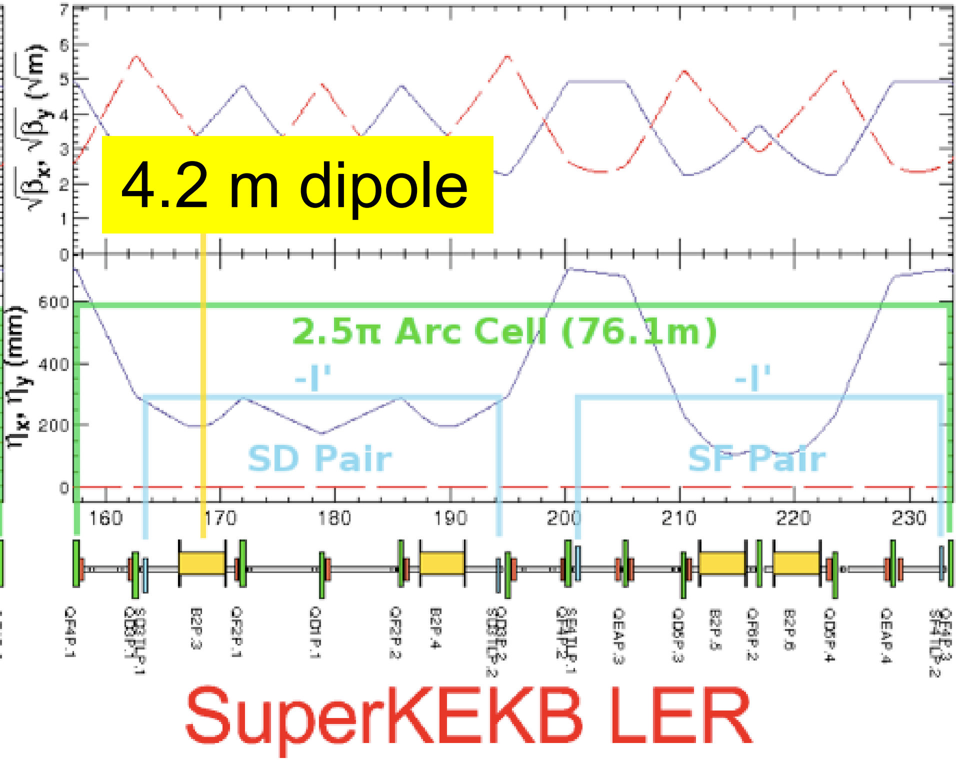
LER lattice



lerfqlc_1352
BX* 32 mm
BY* 0.27 mm
RF
injection
wiggler
RF
wiggler
(RF)
RF
beam
IP
$\beta_x^{1/2}, \beta_y^{1/2}$ ($m^{1/2}$)
η_x, η_y (m)
-1500
-1000
-500
0
500
1000
1500

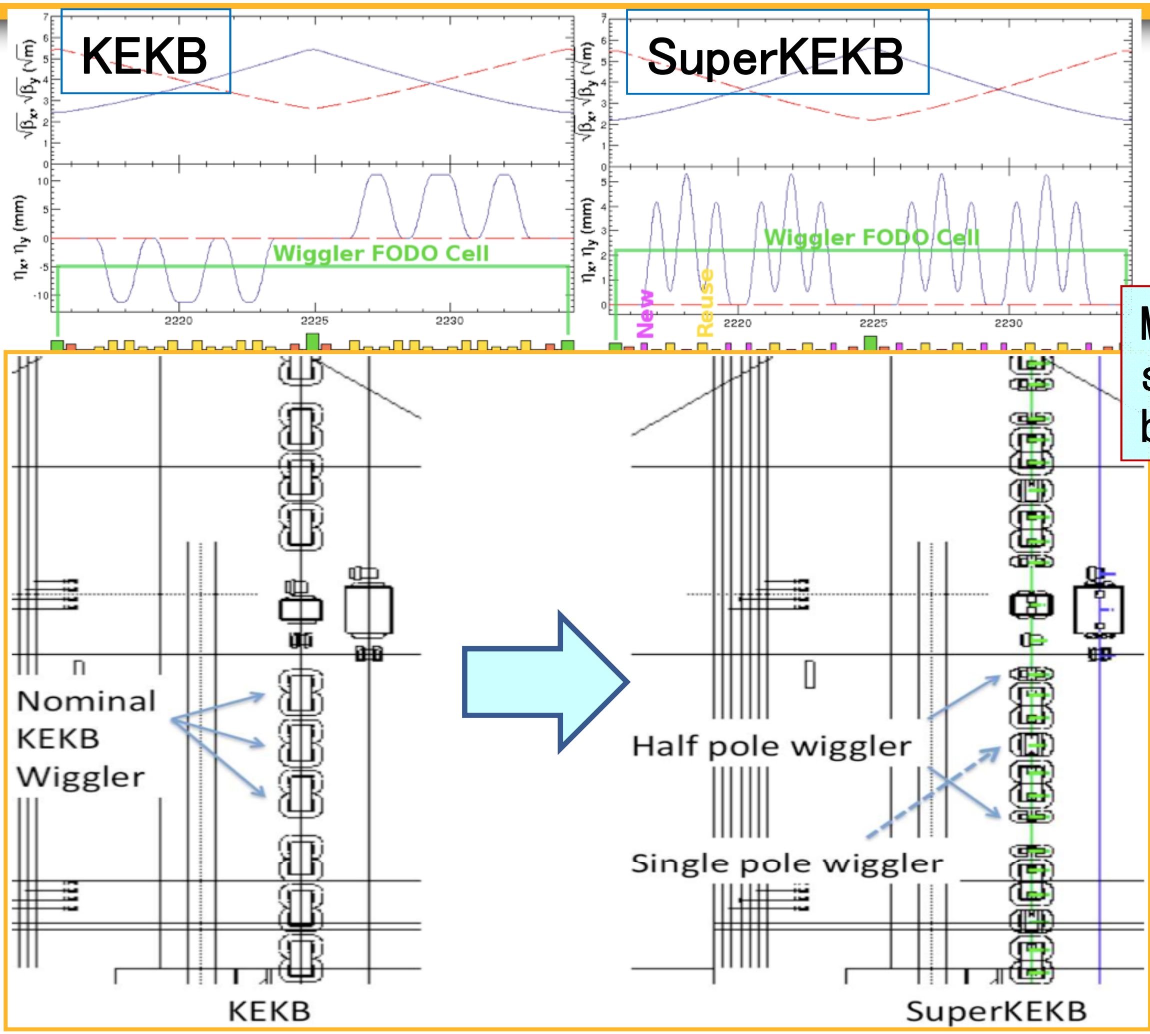
LER Low emittance lattice





Replace 0.89m dipoles in the arc section with new 4.2m dipoles.

LER wiggler section



Most of the Sextupoles, steering magnets will be replaced.

Double the wiggler period by adding new wiggler poles.

Collision parameter

Luminosity: **8.0049×10^{35} $cm^{-2}s^{-1}$**

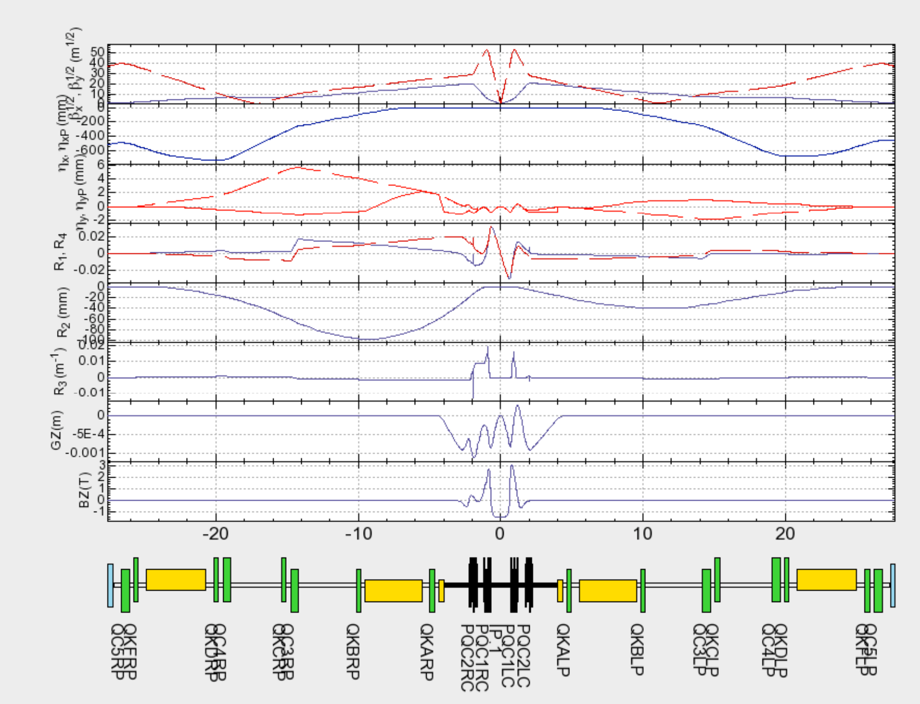
LER	Value	Min.	Max.	
ε_{xL}:	3.2000	2.8000	3.5	nm
β_{xL}:	32.0000	30.000	50	mm
$\varepsilon_{yL} / \varepsilon_{xL}$:	.2920	.2000	INF	%
β_{yL}:	.2700	.2700	.3	mm
ξ_{xL}:	.0028	.0000	INF	
ξ_{yL}:	.0880	.0000	.09	
I_L:	3.6000	A		
σ_{zL}:	6.0000	mm		
E_L:	4.0000	GeV		
σ_x:	10.119 μm	σ_y:	50.228 nm	
θ_{xh}:	41.5000	40.000	41.5	mrad

HER	Value	Min.	Max.	
ε_{xH}:	4.3700	1.5000	INF	nm
β_{xH}:	27.0000	20.000	INF	mm
$\varepsilon_{yH} / \varepsilon_{xH}$:	.2500	.1000	INF	%
β_{yH}:	.3560	.1000	INF	mm
ξ_{xH}:	.0013	.0000	INF	
ξ_{yH}:	.0900	.0000	.09	
I_H:	2.6000	A		
σ_{zH}:	5.0000	mm		
E_H:	7.0000	GeV		
σ_x:	10.862 μm	σ_y:	62.364 nm	
N_b:	2500.0000	2250.0	5000	

Working File: /mnt/nadata1a/users/koiso/.lum/OptLum100825H50X25L32

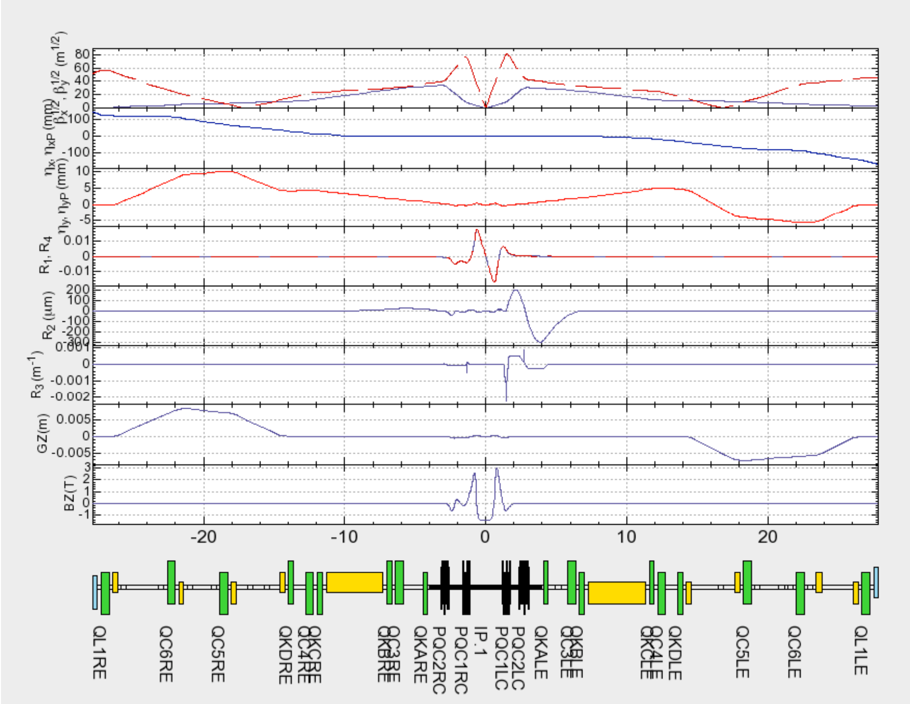
X-Y Coupling and Dispersion at IR

LER



lerfqlc1351

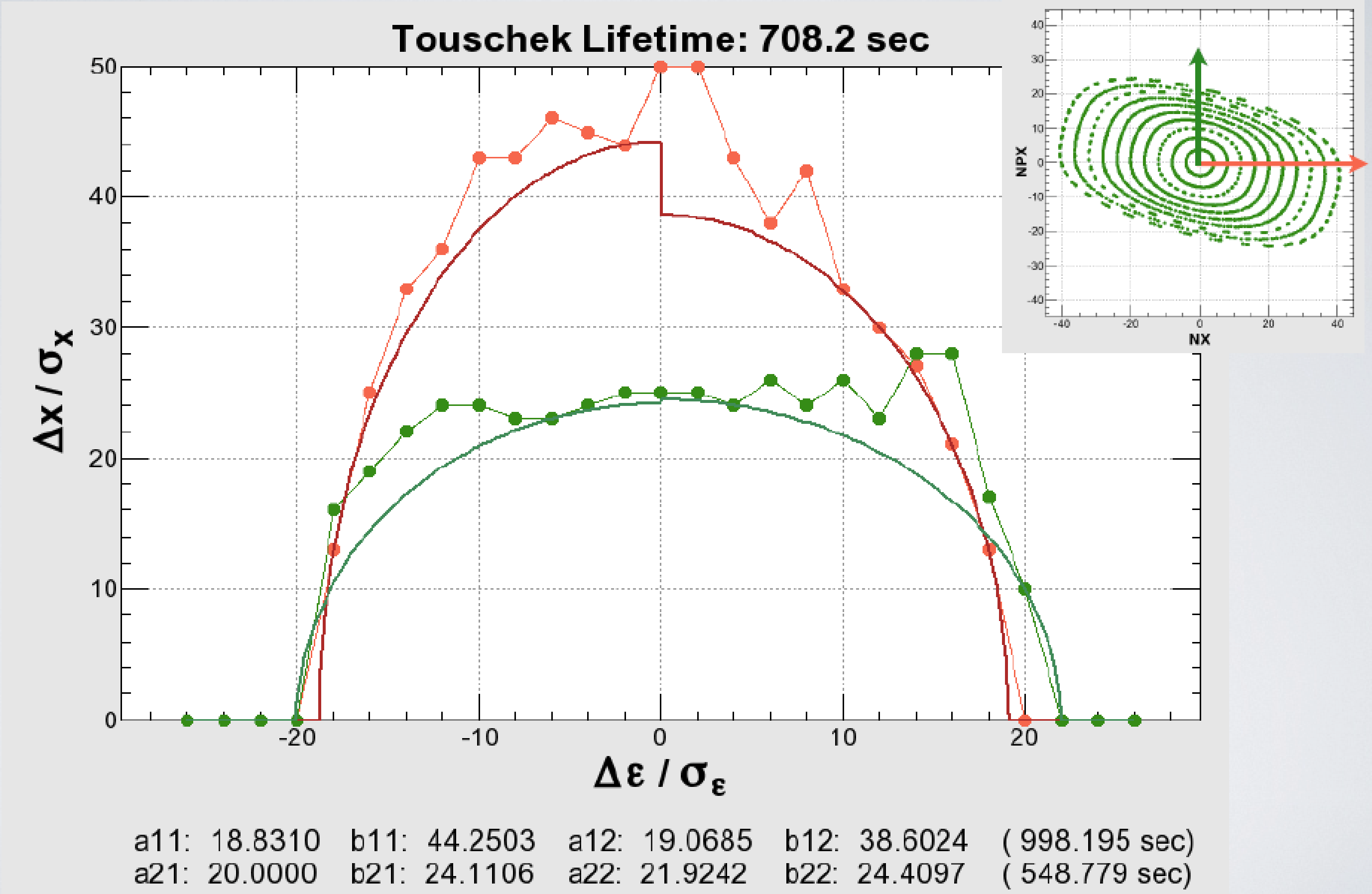
HER



herfqlc5210

- X-Y Couplings(r_1,r_2,r_3,r_4) and vertical dispersion induced by the solenoid field are corrected between two sextupoles to correct chromaticity locally.
- The correction is done by a rotation of final quadrupoles, skew quadrupoles and/or vertical bending magnets.

LER



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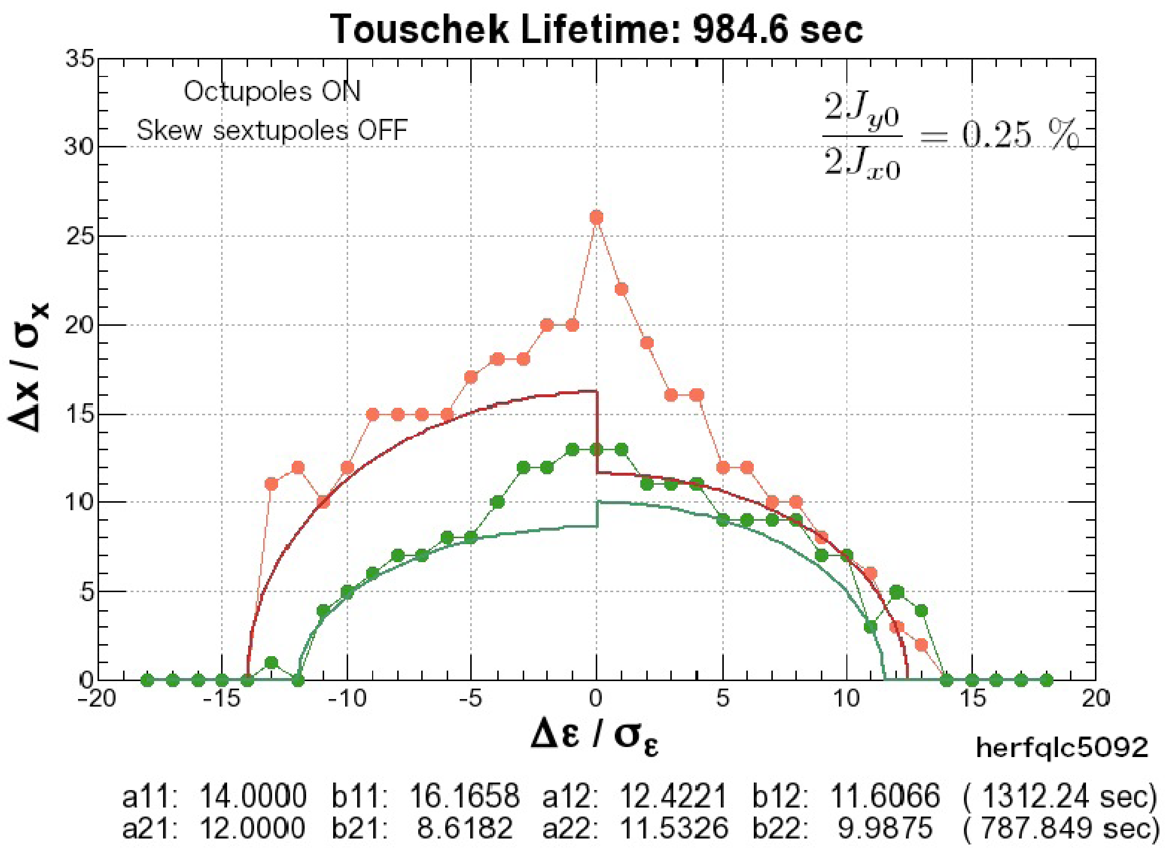
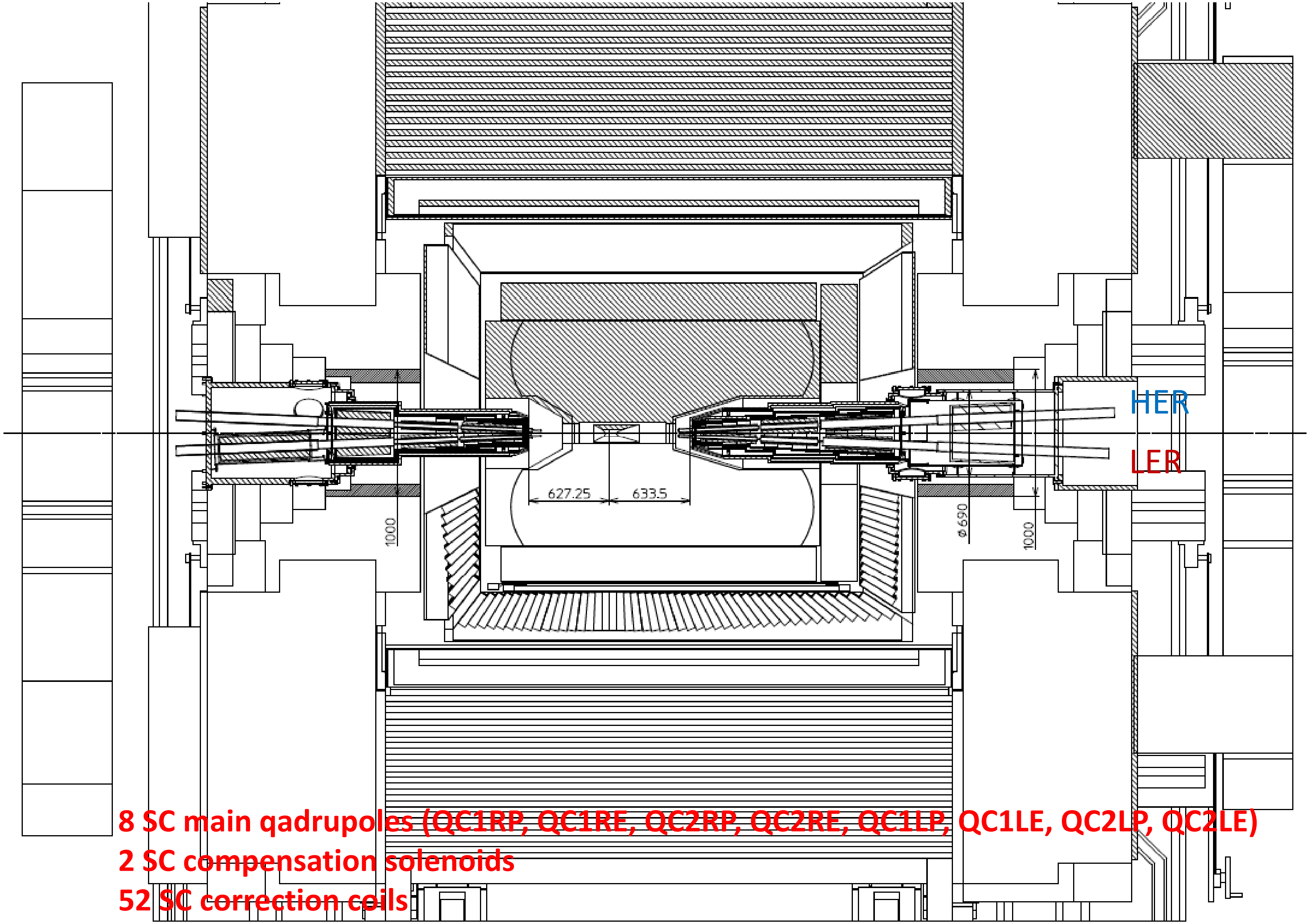
HER

Dynamic Aperture in HER

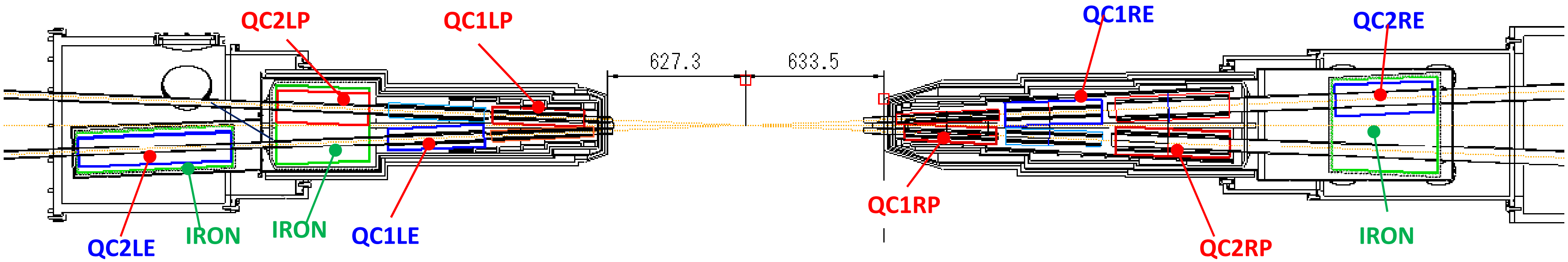


Configuration of IR magnet system



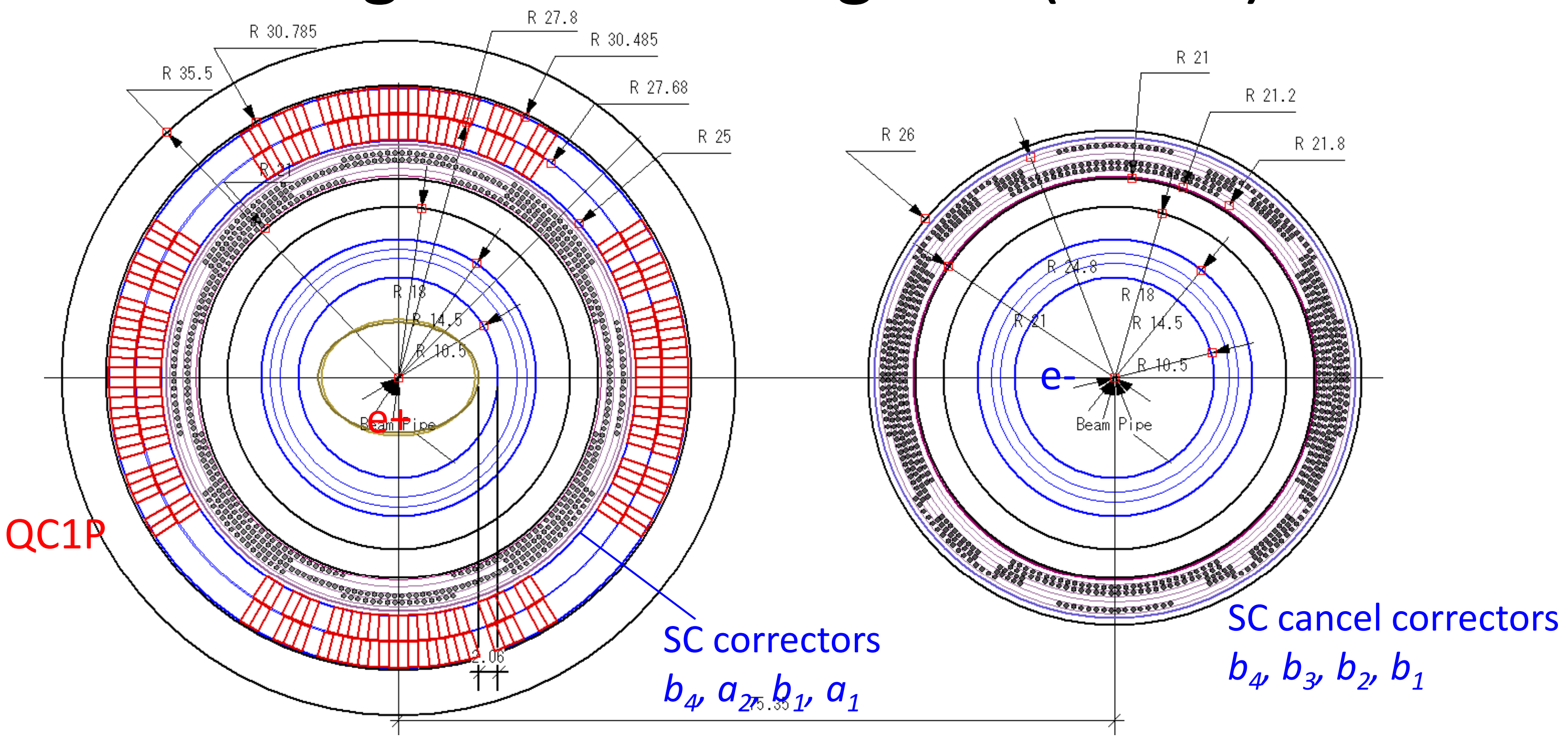
8 SC main qadrupoles (QC1RP, QC1RE, QC2RP, QC2RE, QC1LP, QC1LE, QC2LP, QC2LE)
2 SC compensation solenoids
52 SC correction coils

IR magnets



	Integral field gradient, (T/m)・m	Position from IP, mm	Magnet type
QC2RE	12.91	2925.0	S.C.
QC2RP	10.92 [31.21T/m*0.350m]	1936.1	S.C.
QC1RE	26.22 [72.91*0.360]	1390	S.C.
QC1RP	22.43 [75.61*0.297]	922	S.C.
QC1LP	22.91 [62.00*0.370]	-922	S.C.
QC1LE	26.03 [72.38*0.360]	-1390	S.C.
QC2LP	10.96	-1977.1	S.C.
QC2LE	14.13	-2900.0	S.C.

Design of IR SC magnets (QC1P)



Magnet design (QC1RP and QC1LP)

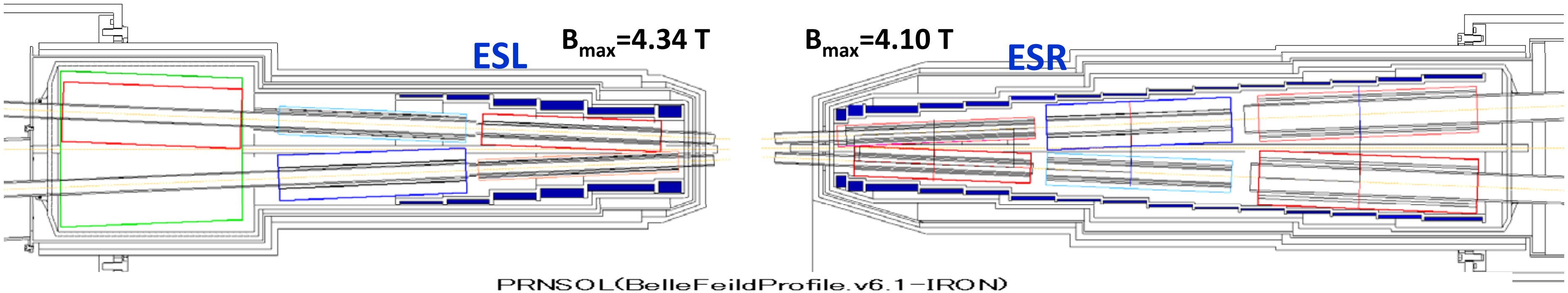
- Same design of the cross section for QC1RP and QC1LP
- 2 layer coils [double pancake type]
- Designed SC cable [under development]
  - Cable size : 2.5 mm in height, and 0.93 mm in width
  - SC strand cable : ϕ 0.5 mm, 10 wires in the cable
- SC correctors inside of the magnet bore
  - b_4, a_2, b_1, a_1 from the inside
  - Single layer coil
- Beam pipe : warm tube, inner radius=10.5 mm

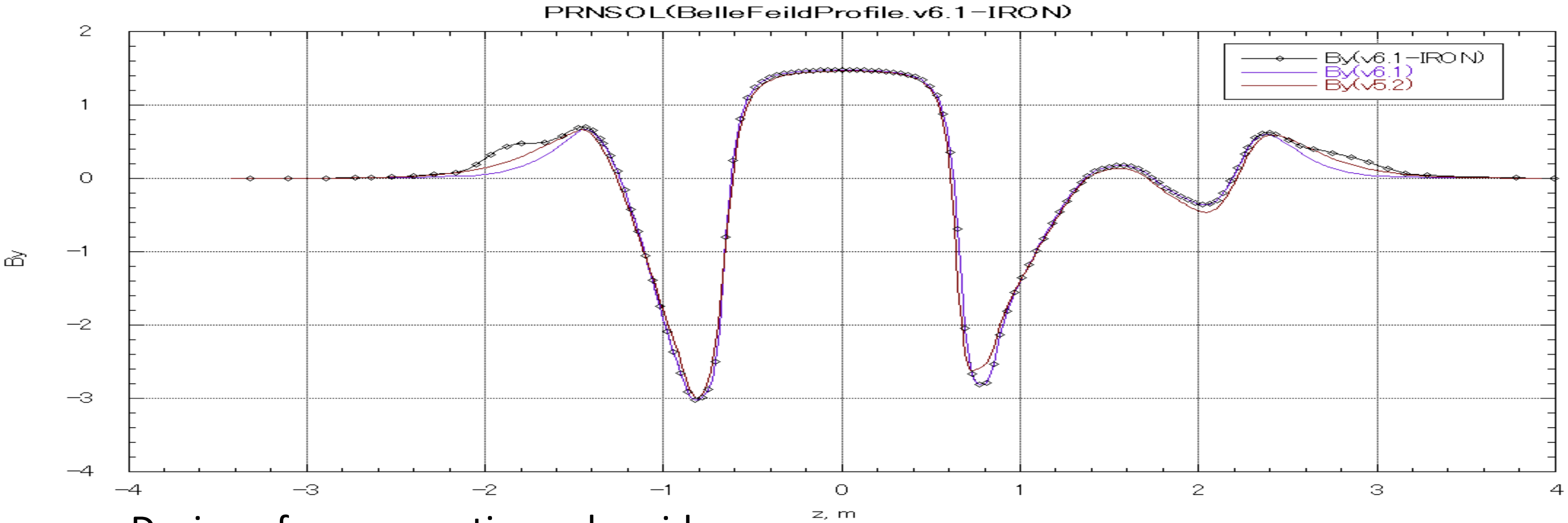
SC cancel correctors against the leak field from QC1P

- b_3, b_2, b_1 from the inside

Beam pipe : warm tube , inner radius=10.5 mm

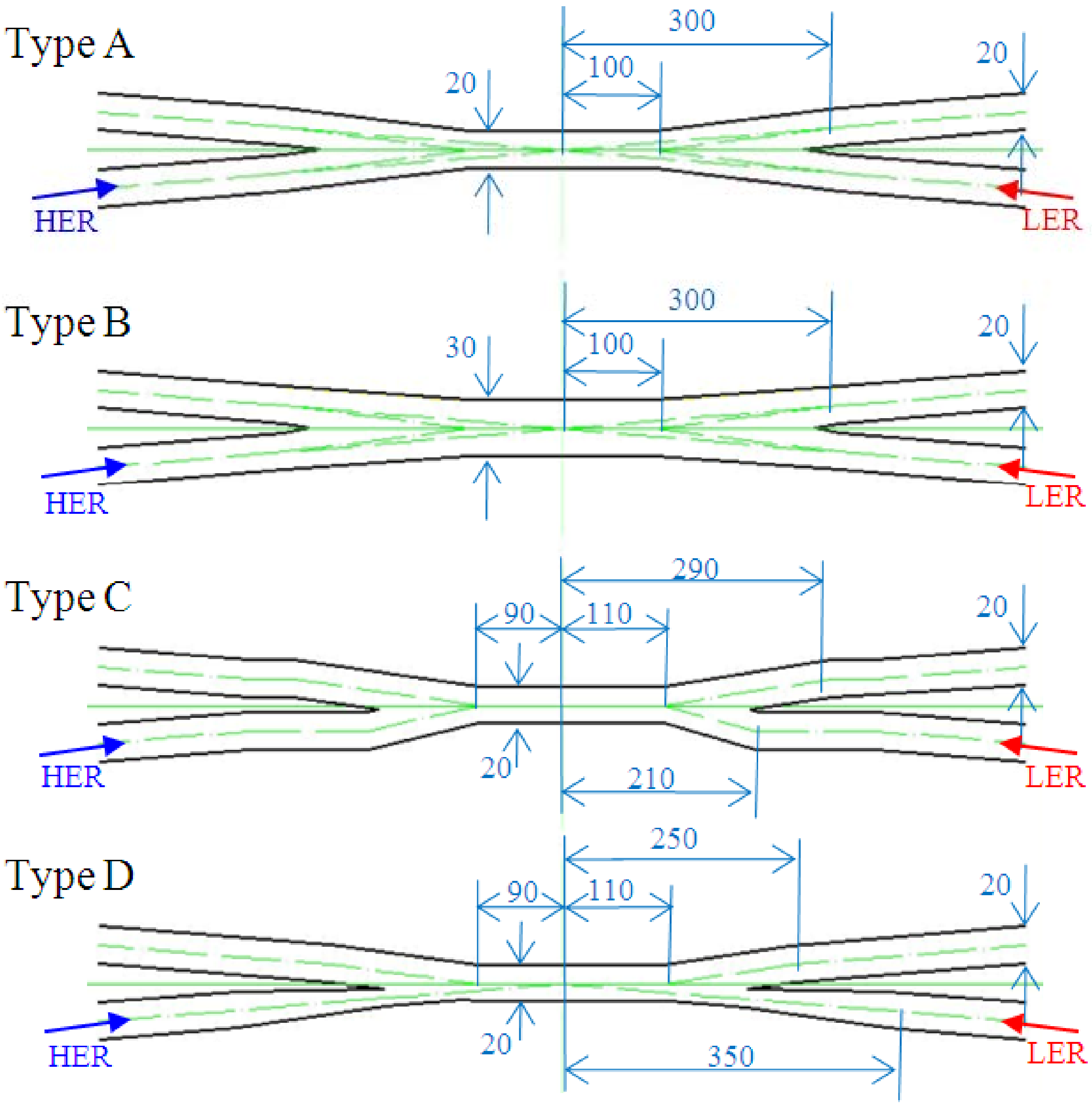
Compensation solenoids



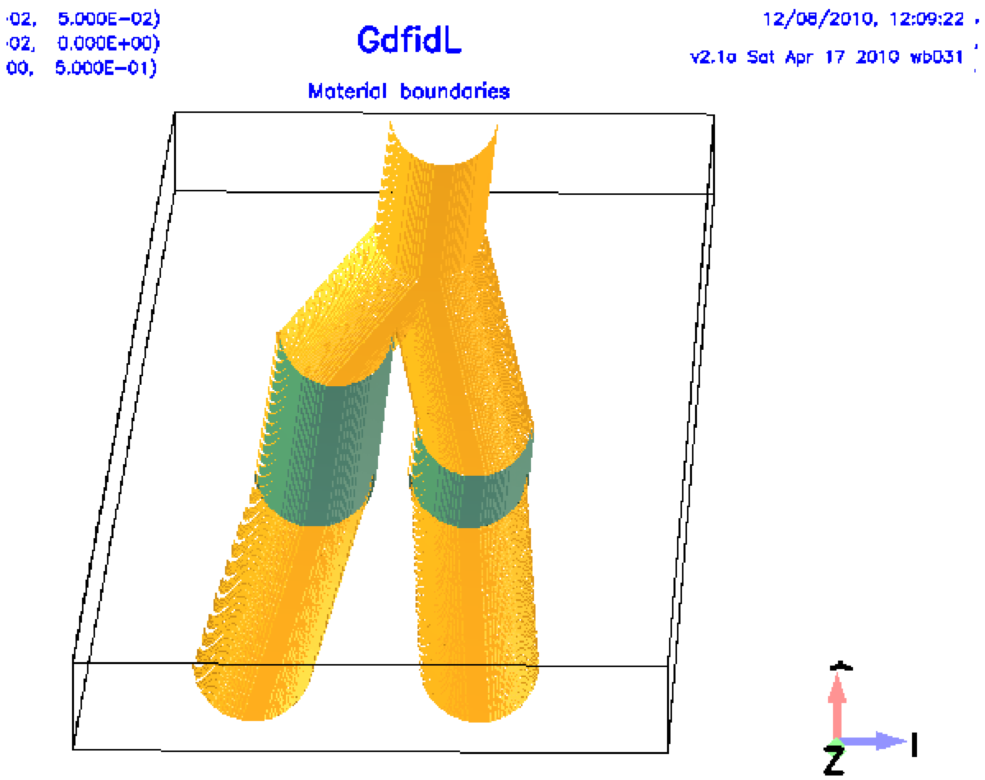


- Design of compensation solenoids
  - The solenoids are designed to be segmented into small coil pieces.
  - The coil pieces have decreased turns gradually along the distance from IP.
  - The electro-magnetic forces on the ESR and ESL are 29 kN and -18 kN, respectively.
- The field changes of the solenoid field are managed to be a half of the previous design.
- Fringe field influence on beam emittance is negligible by the beam simulation.

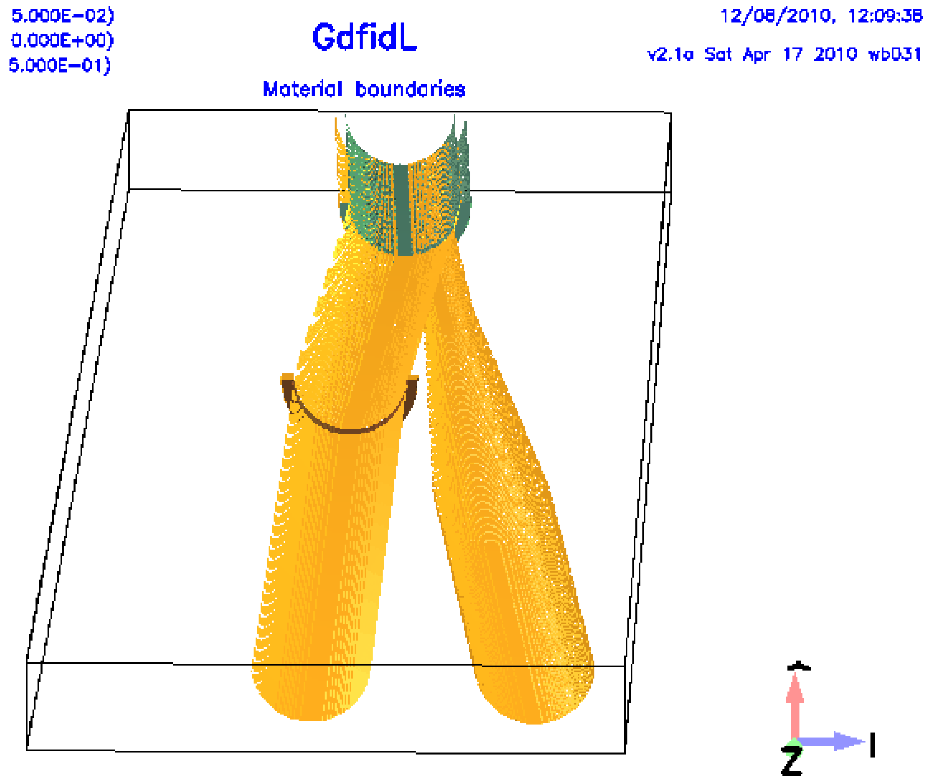
New IP chamber design



GdfidL model (cut model)



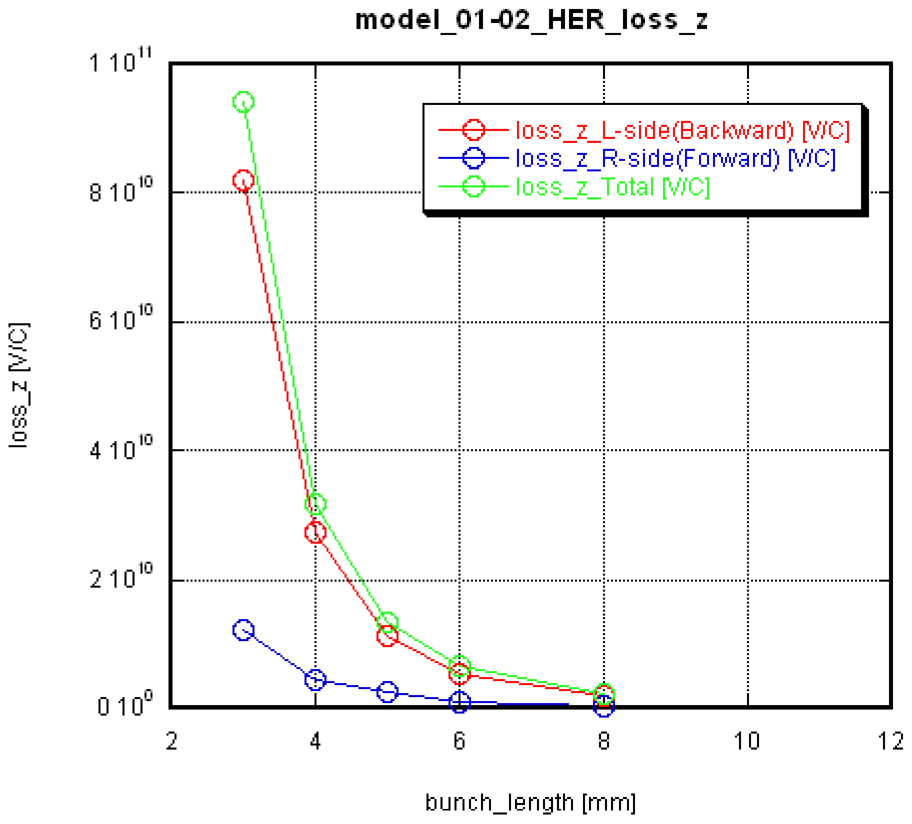
Type C



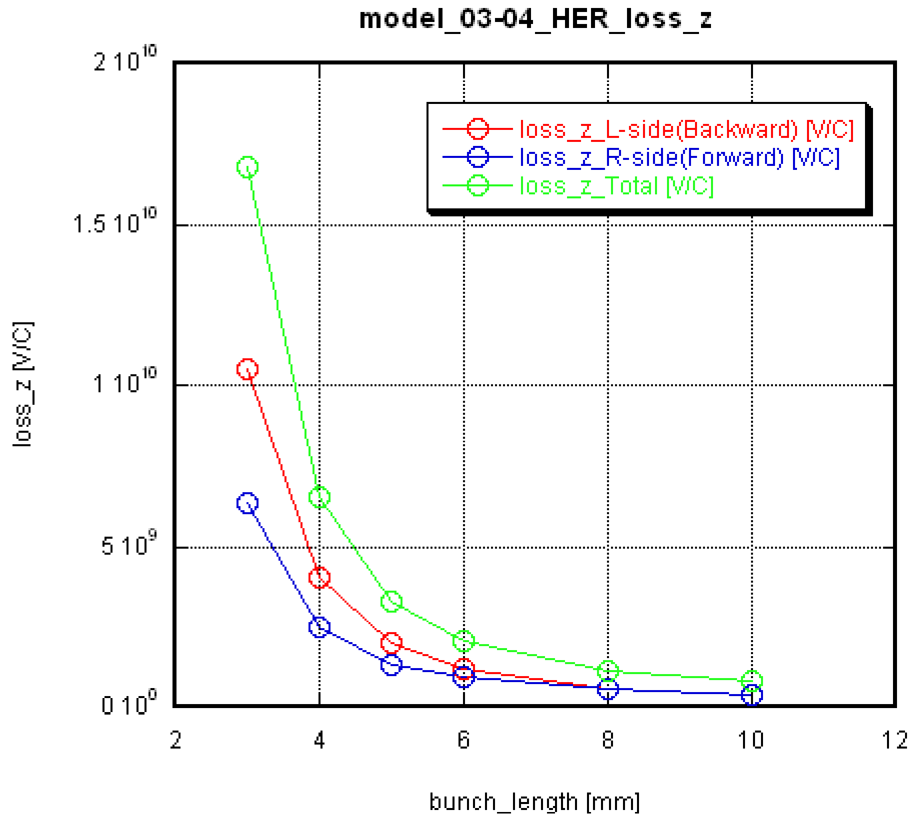
Type D

Loss_z : (x,y) = (0,0)

Type C_HER

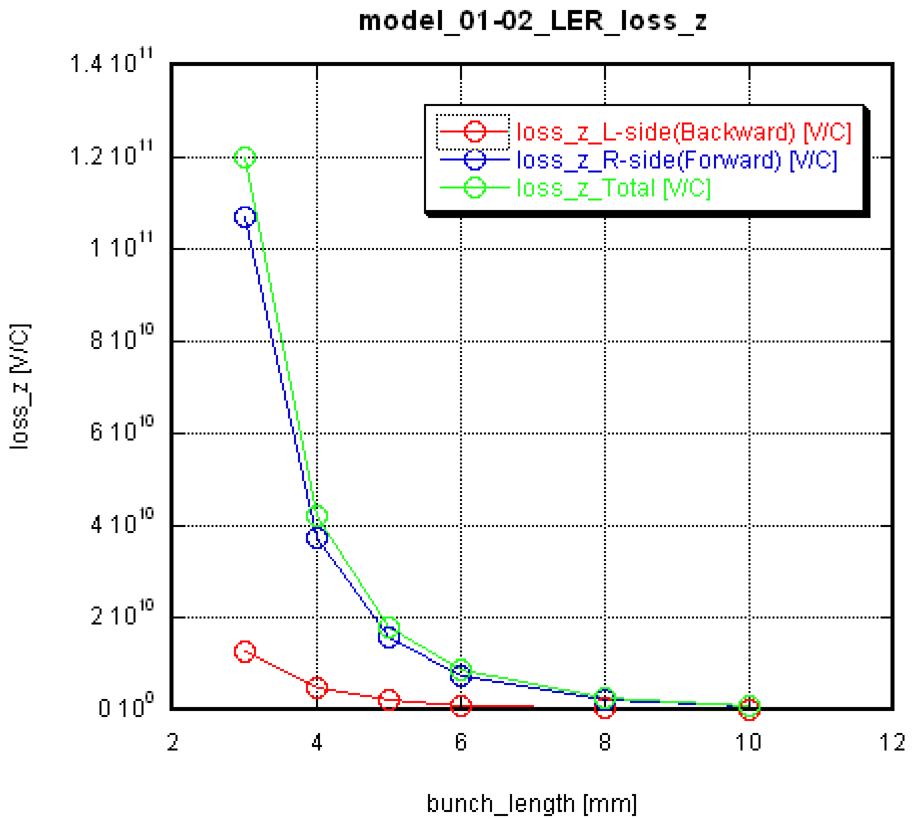


Type D_HER

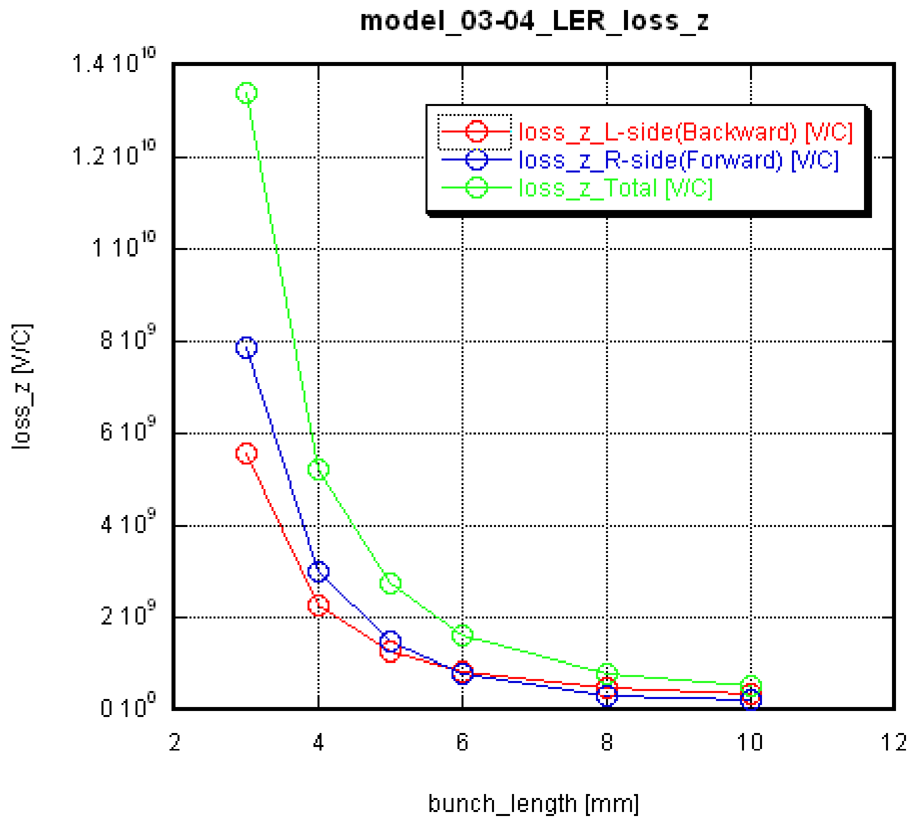


Loss_z : (x,y) = (0,0)

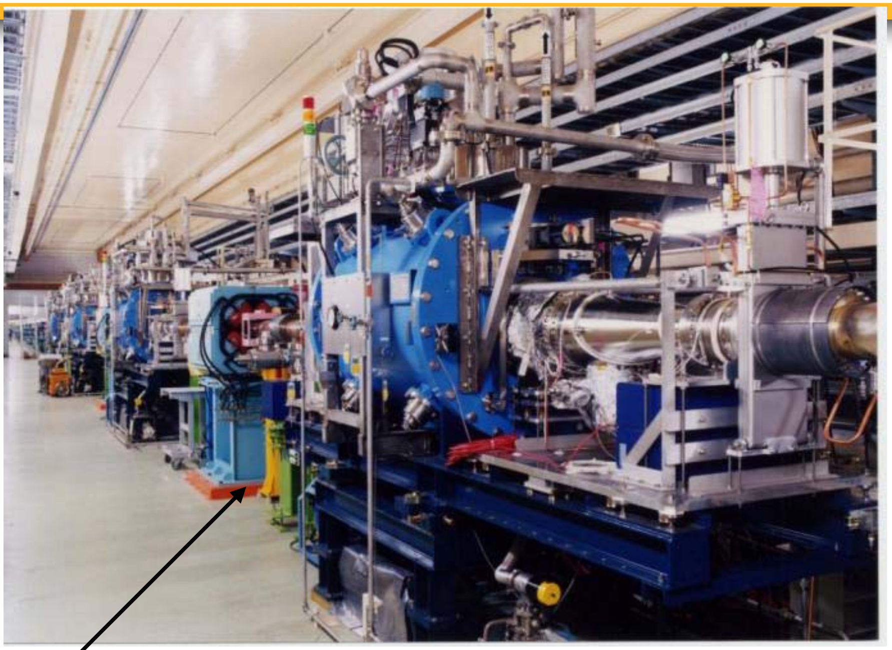
Type C_LER



Type D_LER



RF systems (in the tunnel)



KEKB Superconducting cavity

KEKB-ARES Nomalconducting cavity

- We will continuously use those cavities with small change, such as change of coupling.

RF systems (grand level)

- Add 7 (or 9) RF stations for higher beam loading from 25 stations to 32 (or 34) stations.
- Introduce digital low level RF system for much fine tuning..

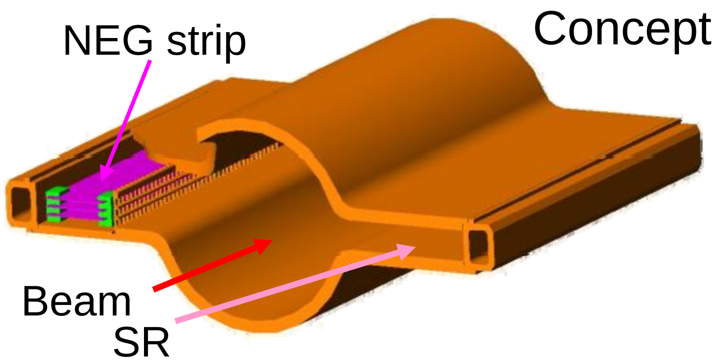
High power RF system

1.2MW CW klystron

Design of main components_1

- **Beam pipes:** beam pipes with ante-chambers
  - Low beam impedance
    - ∵ Pump ports and SR masks locate in an antechamber.
  - Reduction of SR power density is not a main purpose now.
  - The cross section should fit to the existing magnets.
  - **LER:**
    - An effective countermeasure against the electron cloud.
    - Aluminum alloy is now available for arc section.
    - Copper is required for wiggler sections due to high SR power.
  - **HER:**
    - Copper is required due to high SR power.

- **Pump (NEG) is installed into one of the ante-chamber** (inside of the ring)
  - Distributed pump system for effective pumping. *S* ~ 80 l/s/m.
  - Inserted from end flanges.

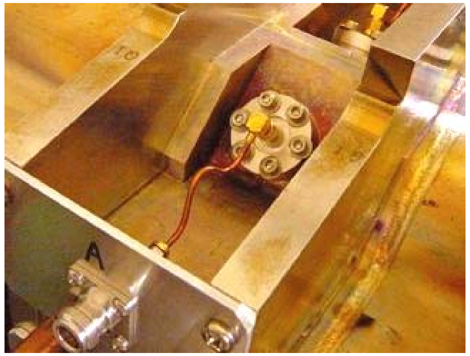


Design of main components_2

- **R&Ds of beam pipes_1**
  - Copper beam pipes with antechambers have been installed into the LER, and tested with beams.
  - Cold drawing method for copper pipe was established.

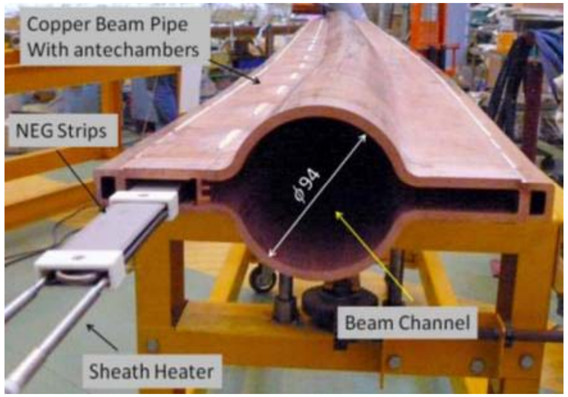
Straight duct

BPM



Wiggler section

Bent duct

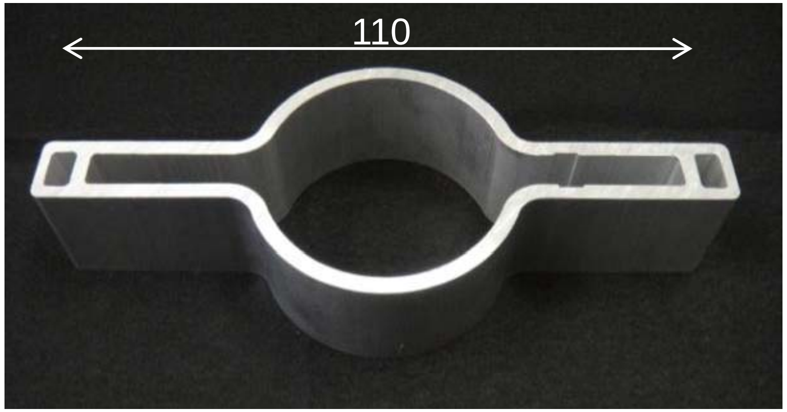


Arc section

Design of main components_3

- **R&Ds of beam pipes_2**
  - Tests of the extrusion of aluminum-alloy beam pipes are under going for LER.

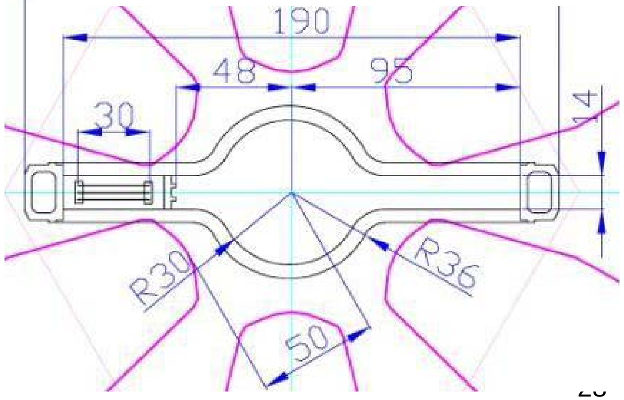
Aluminum-alloy duct



Aluminum-alloy duct

  - The design of **HER beam pipe** has not yet fixed.
    - Fit to existing magnets.
    - If the half-aperture is ~90 mm the SR power is the same level as the present HER.

Example of cross section of HER beam duct



Design of main components_4

- **LER: More powerful countermeasures against the electron cloud effect is required.**

Sections	L [m]	L [%]	Countermeasure	Material
Total	3016	100		
Drift space (arc)	1629 m	54	TiN coating + Solenoid	Al or Cu
Steering mag.	316 m	10	TiN coating + Solenoid	Al or Cu
Bending mag.	519 m	17	TiN coating + Grooved surface	Al
Wiggler mag.	154 m	5	Clearing Electrode	Cu
Q & SX mag.	254 m	9	TiN coating	Al or Cu
RF section	124 m	4	(TiN coating +) Solenoid	Cu
IR section	20 m	0.7	(TiN coating +) Solenoid	Cu

- With these countermeasures, the average electron density of 1E11 e^-/m^3 will be obtained.

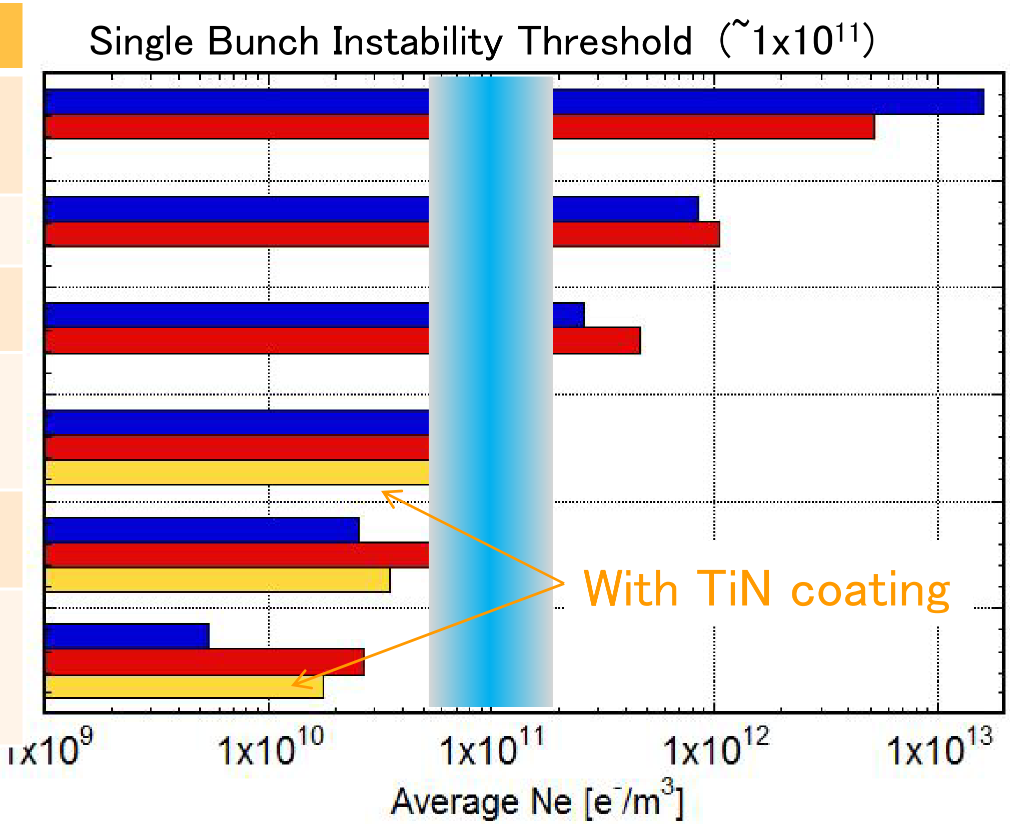
Cloud density simulation / experiment

Blue：CLOUDLAND simulation

– δ_{max}=1.2, Effect of antechamber has been estimated by setting the photoelectron yield to 1/10 (0.01). Effect of clearing electrode and the groove has been estimated by the experimental result.

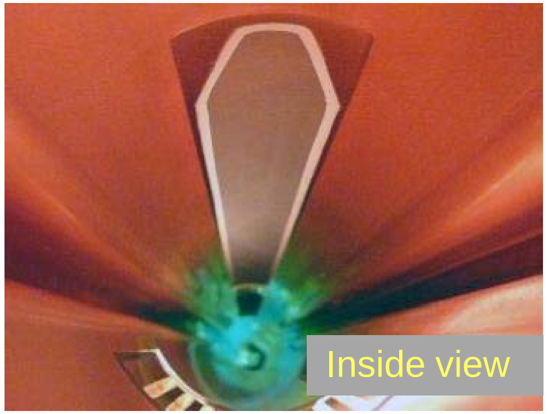
- **Red: Experimental result using KEKB LER**
- **Yellow: with TiN coating**

Condition	ne [m^{-3}]
Circular Cu chamber [KEKB beam pipe]	5.2E12
Antechamber (1/4)	1.1E11
Solenoid at Drift (1/50)	4.7e11
Solenoid at Drift (1/50) +Cu Antechamber (1/4)	9.4E10 5.7e10
+Electrode in Wiggler (1/100)	5.84e10
+Electrode in Wiggler (1/100) +Groove in B (1/10)	2.7E10 1.7e10

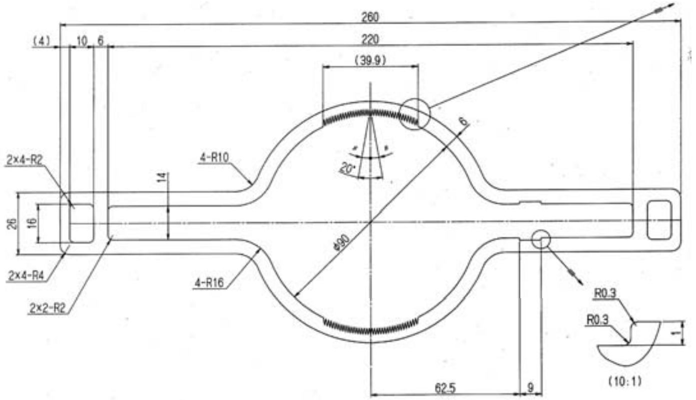


Design of main components_5

- **Some R&Ds for EC mitigation**
- Clearing electrode for wiggler section.
  - Manufacturing has already started.



- Grooved surface for bending magnets section
  - Extrusion test of aluminum beam pipe is undergoing.

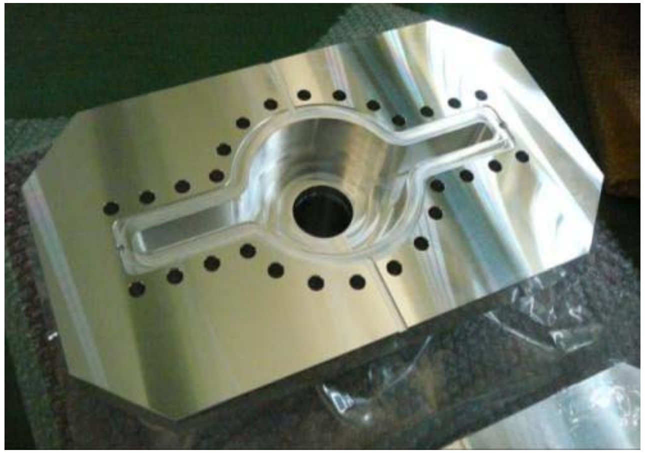


Design of main components_6

- **Flange :** MO-type Flanges
  - Thermally strong, sure RF bridge, applicable to ante-chamber scheme, low beam impedance
  - In addition to SS flanges, **copper alloy** and **aluminum-alloy** flanges has been developed.
    - Easy welding to pipes, reduction in heating by joule loss
  - Several flanges have been installed into the ring and tested.

Cu-alloy flange (CrZrCu)

Al-alloy flange (A2219, A2024)



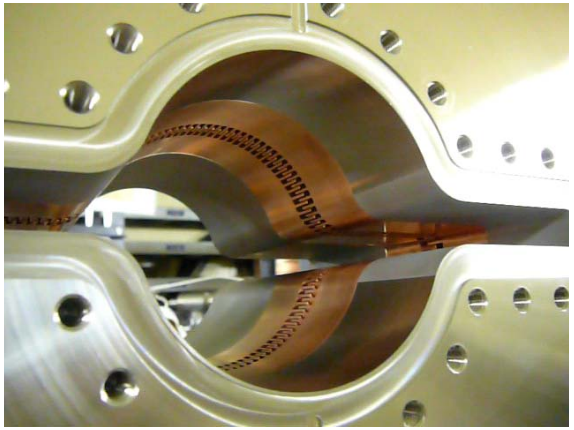
Design of main components_7

- **Bellows and gate valves** with comb-type RF-shield
  - Sure RF shielding, thermally strong
  - Applicable to ante-chamber scheme
  - Finger-type for some cases, if flexibility is required.
- Trial modes has been installed into the ring and tested.
  - Reduction in the temperature of bellows has been demonstrated.
- Aluminum RF shield is under study for aluminum bellows chambers.

Gate valve

Bellows chamber (by BINP)

RF-shield (gate valve)



SuperKEKB Injector Linac Parameters

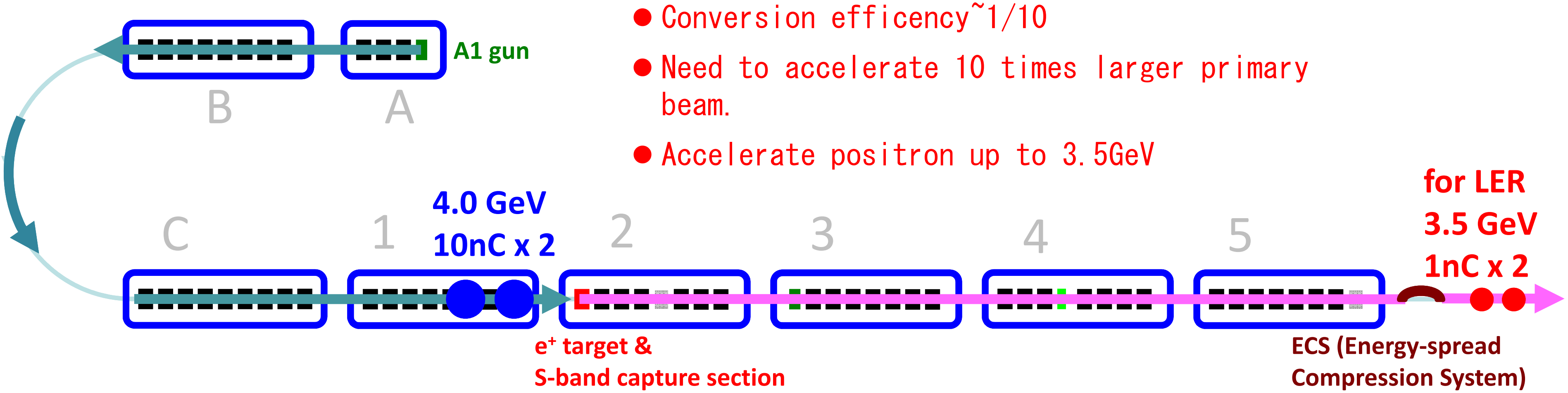
	KEKB (e+/e-) achieved	SuperKEKB (e+/e-) required
beam energy	3.5 GeV / 8.0 GeV	4.0 GeV / 7.0 GeV
stored current	1600 mA / 1200 mA	3600 mA / 2620 mA
beam lifetime	150 min / 200 min	10 min / 10 min
bunch charge	primary e^- e^+ e^- 10 -> 1.0 nC / 1.0 nC	primary e^- e^+ e^- 10 -> 4.0 nC / 5.0 nC
# of bunches	2 / 2	2 / 2
beam emittance $(\gamma\varepsilon)_{[1\sigma]}$	2100 μm / 300 μm	43 μm / 20 μm
energy spread σ_E/E	0.125 % / 0.05 %	0.46 % / 0.08 %
bunch length σ_z	2.6 mm / 1.3 mm	6.05* mm / 1.3 mm

*(assuming bunch compression after DR)

Positron Linac

KEKB e$^+$

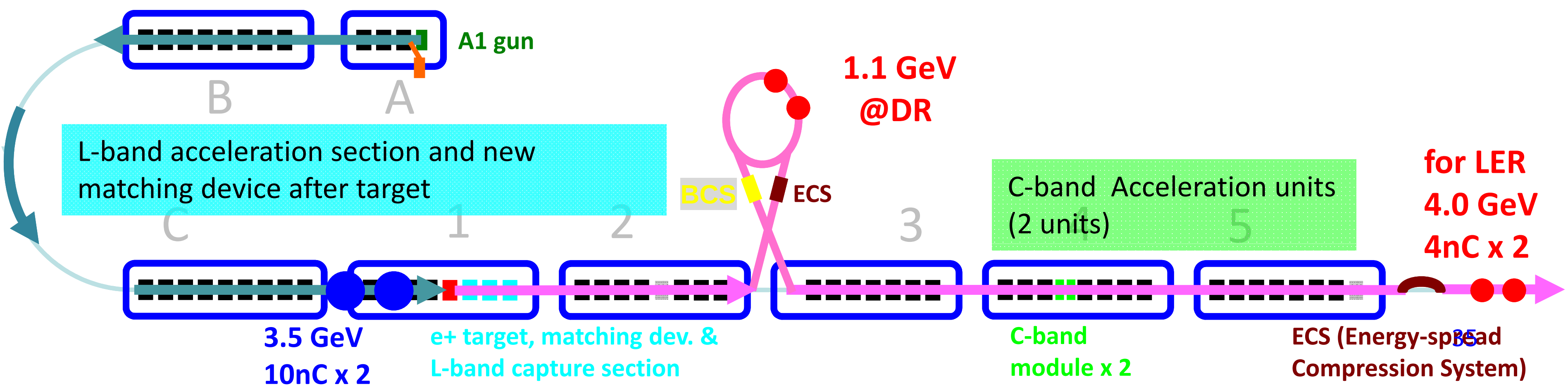
- Accelerate e− (primary) beam to 4GeV, inject positron target.
- Conversion efficency~1/10
- Need to accelerate 10 times larger primary beam.
- Accelerate positron up to 3.5GeV



SuperKEKB e$^+$

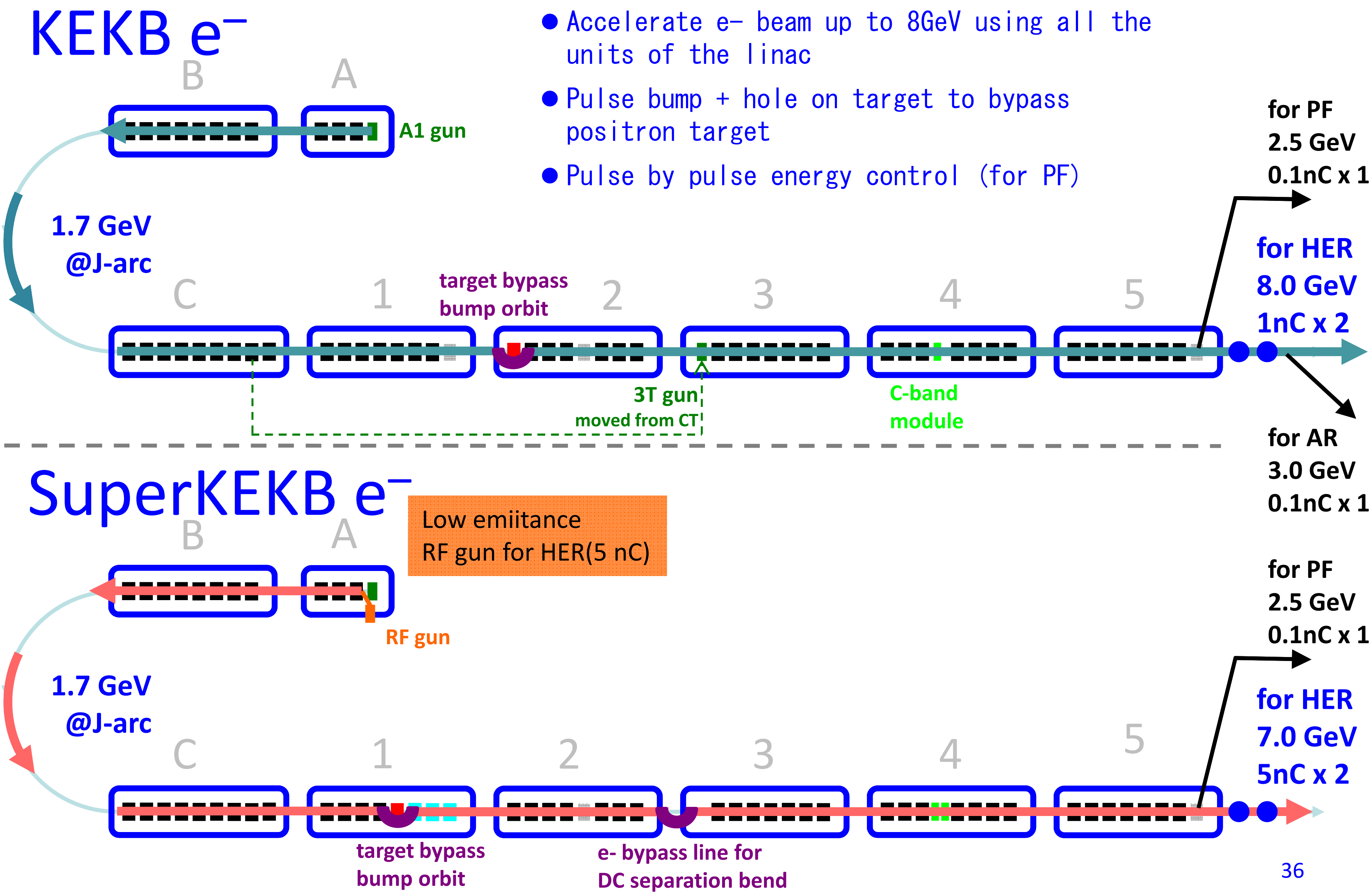
Primary electron beam (10nC)

Positron damping ring to reduce emittance



Electron linac

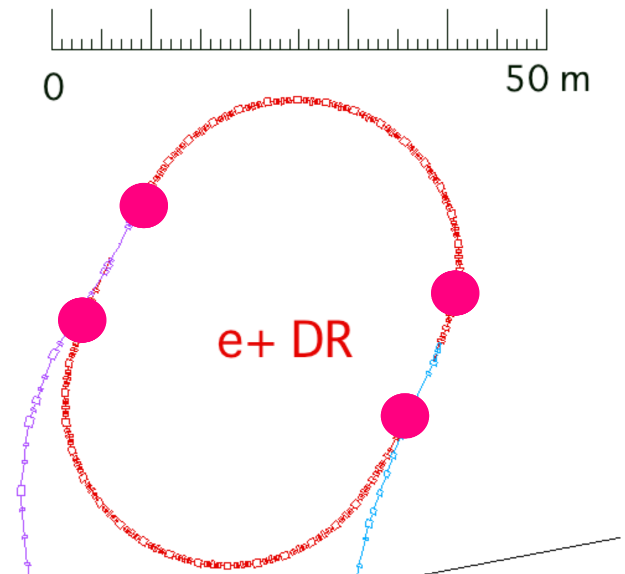
- Accelerate e− beam up to 8GeV using all the units of the linac
- Pulse bump + hole on target to bypass positron target
- Pulse by pulse energy control (for PF)

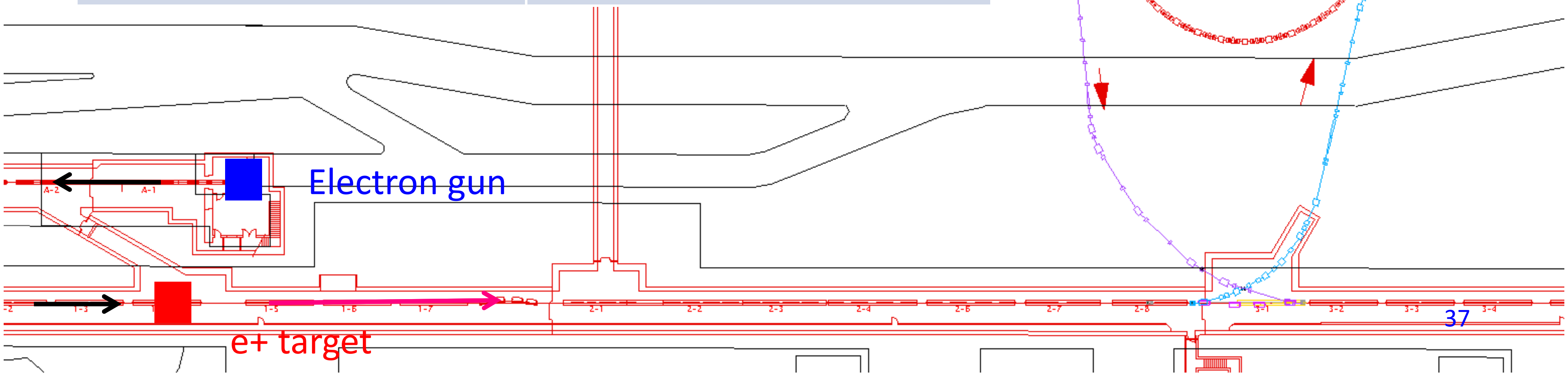


Damping Ring Layout

Damping ring is necessary to inject the positron beam
to SuperKEKB LER (due to smaller physical and dynamic aperture)

parameters	value
Beam energy	1.1GeV
# of bunches	4
Bunch charge	4 nC (max.8 nC)
# of bunch trains	2
max. stored current	35 mA (max.70 mA)
Emittance (injected)	1700 nm (normalized)
Emittance (extracted)	42.5 nm (normalized)

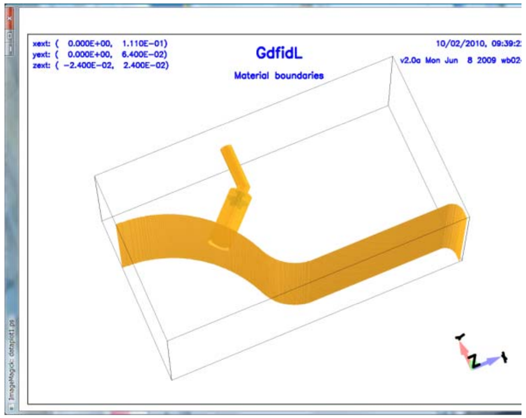


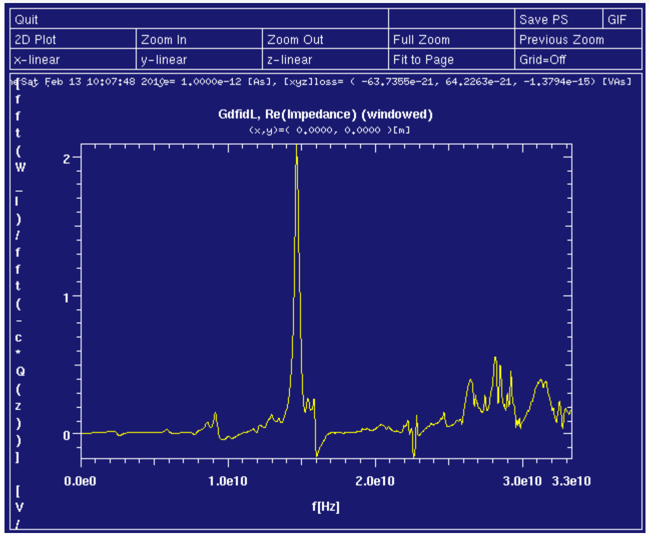


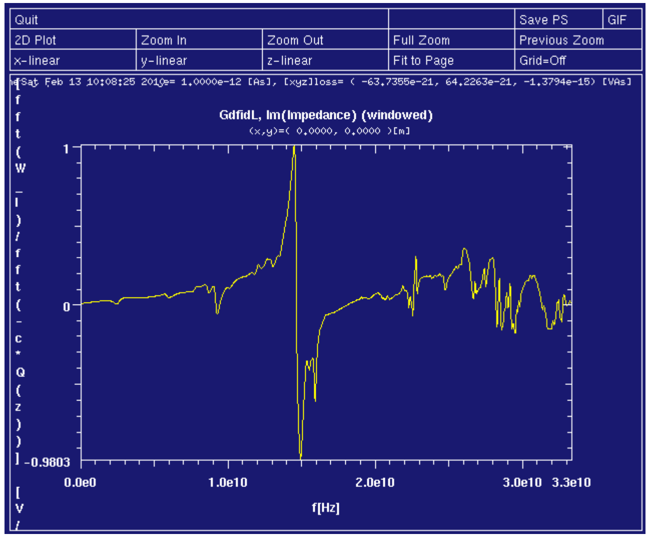
Beam instrumentation

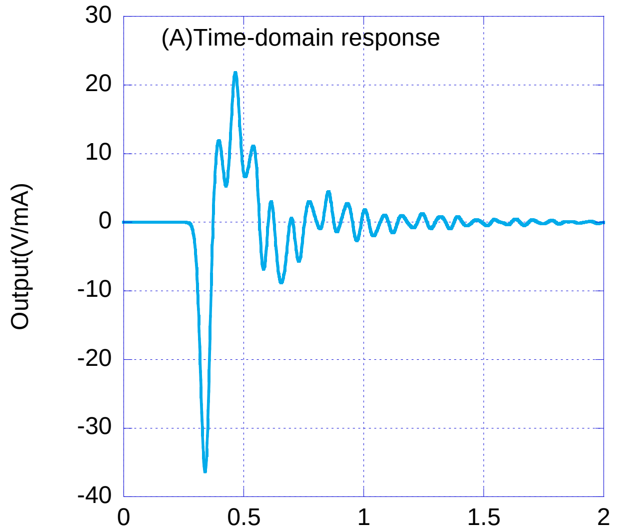
- **New BPM chamber with flange-connection BPM heads.**
- **New 508MHz narrowband detectors(VXI)**
- **Medium-band position detectors for fast orbit feedback**
  - Especially around IP and local chromaticity correction region
  - Orbit function (phase advance, XY coupling) measurement using pilot bunch during collision.
- **X-ray bunch-by-bunch beam size monitor**
  - CesrTA (KEK, Cornell Univ., Hawaii Univ.)

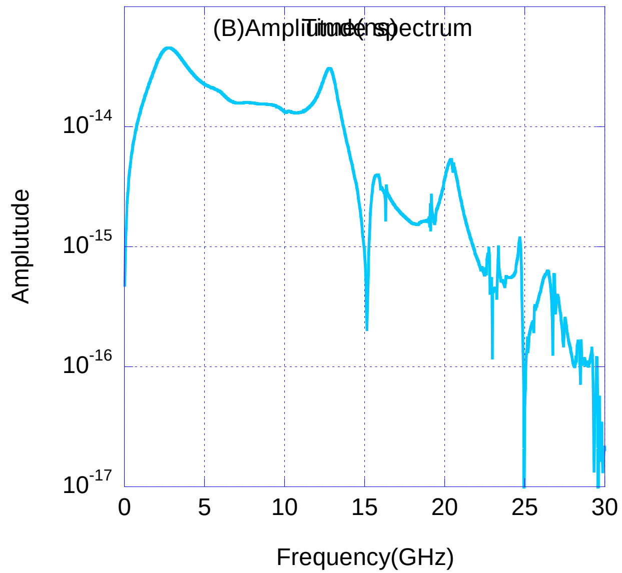
Impedance/button output simulation



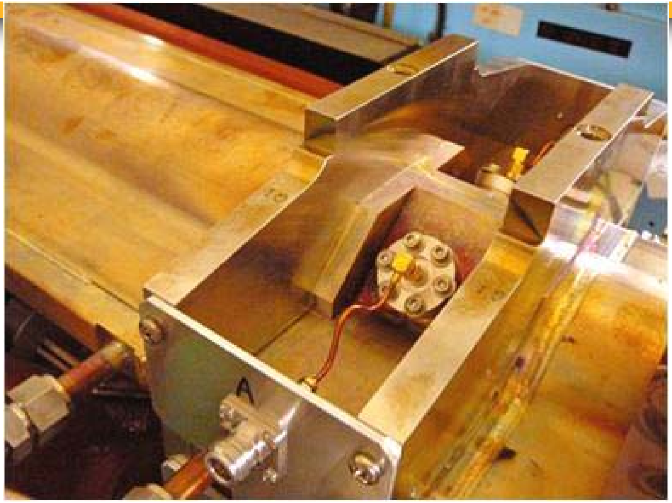


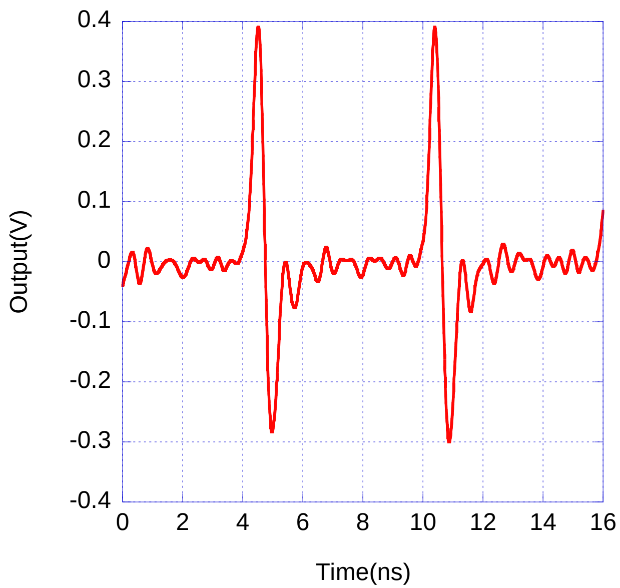




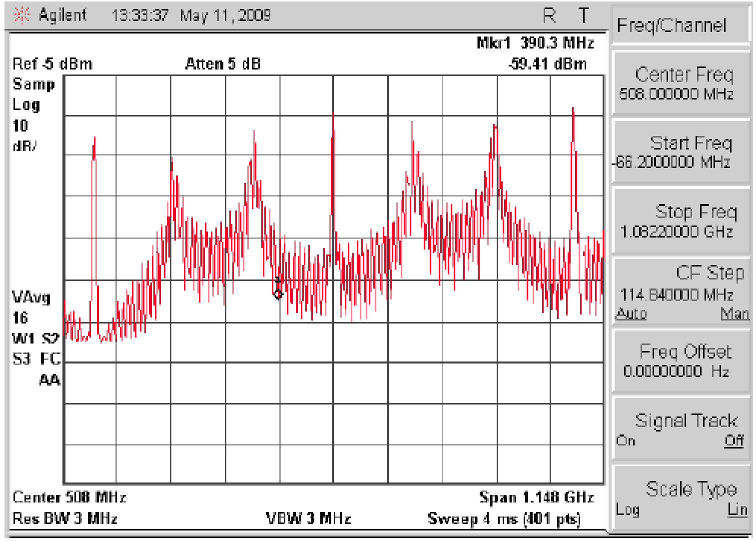


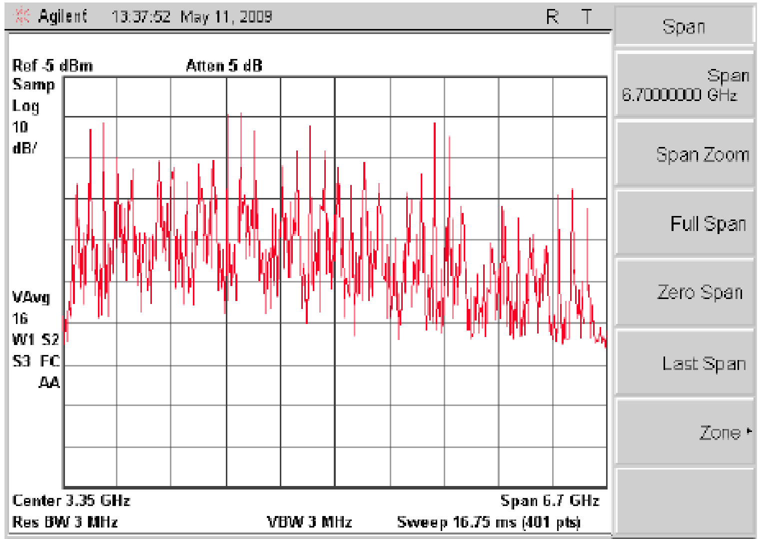
Beam signal



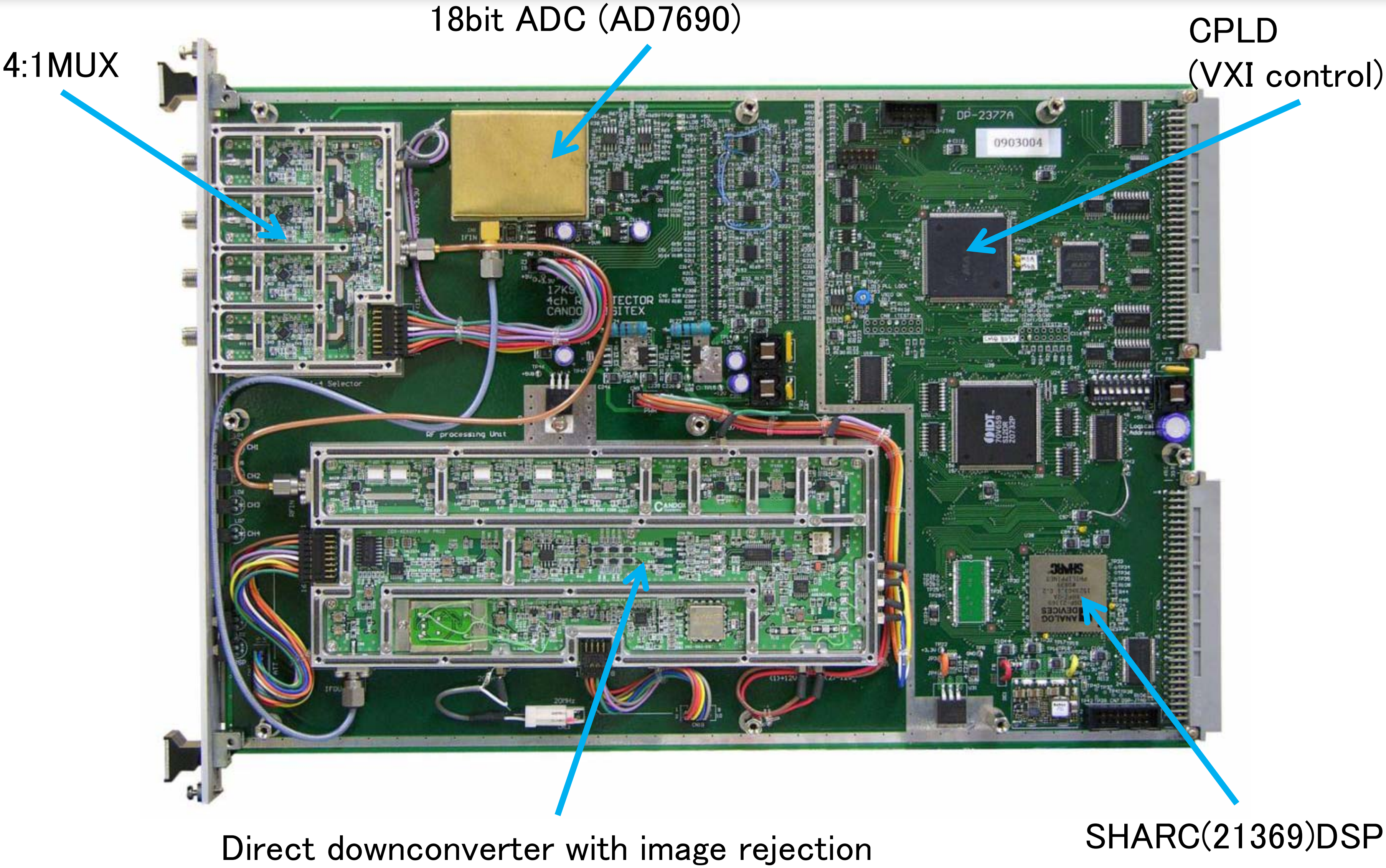


Temperature rise ~3deg @ 1.6A





Digitex 17K94A 509MHz detector

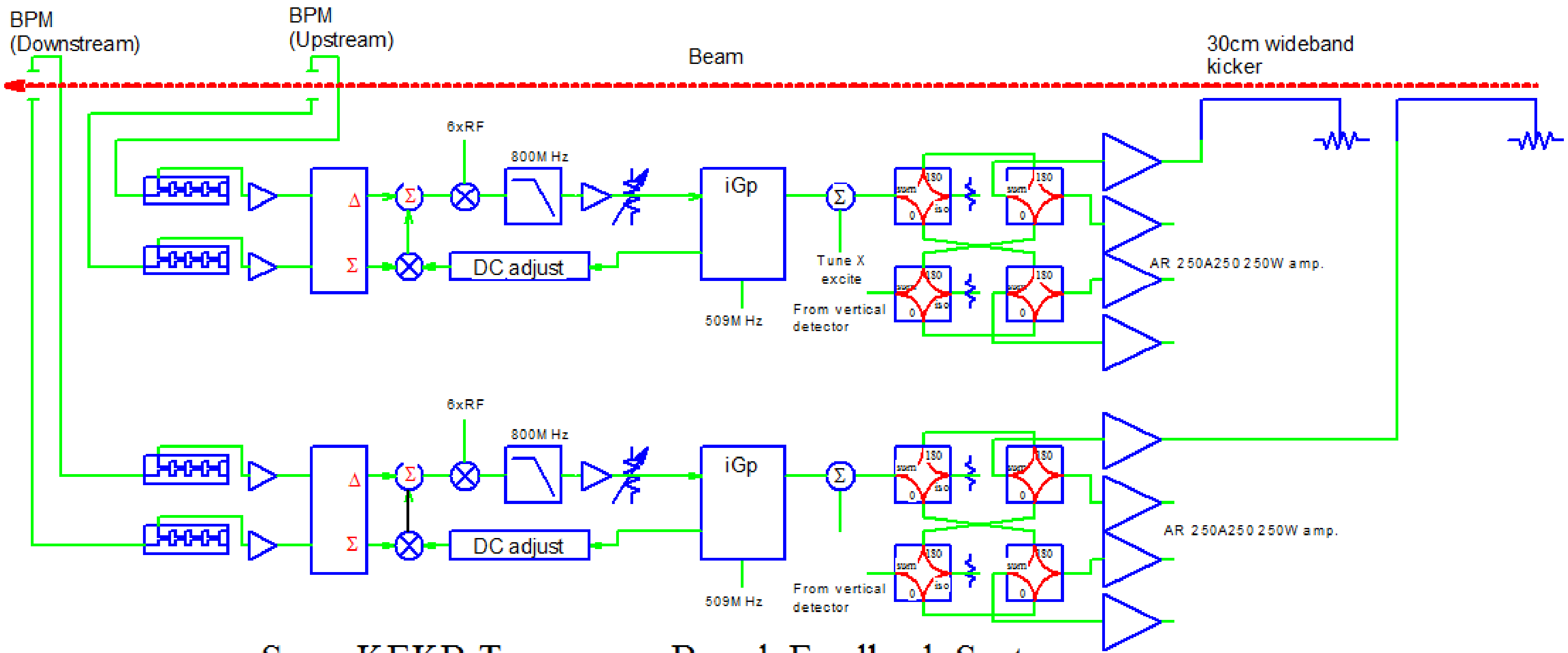


SuperKEKB BxB feedback

- We need to
  - prepare longitudinal feedback systems on both rings.
  - improve the performance of the transverse feedback systems
  - design and prepare much durable vacuum components such as BPM electrode or feedback kickers to stand higher beam current..

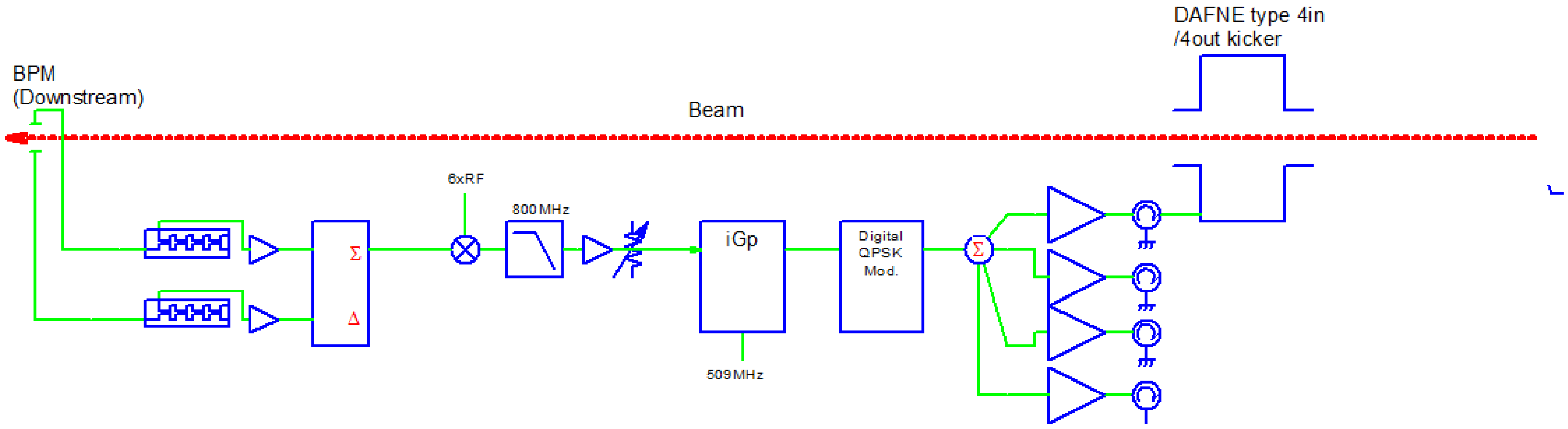
- Use general purpose feedback signal processing system– iGp or iGp12
- Development of BPM electrode with improved time response using glass-type seal
- Development of better bunch detection circuit

SuperKEKB Transverse FB plan



SuperKEKB Transverse Bunch Feedback System

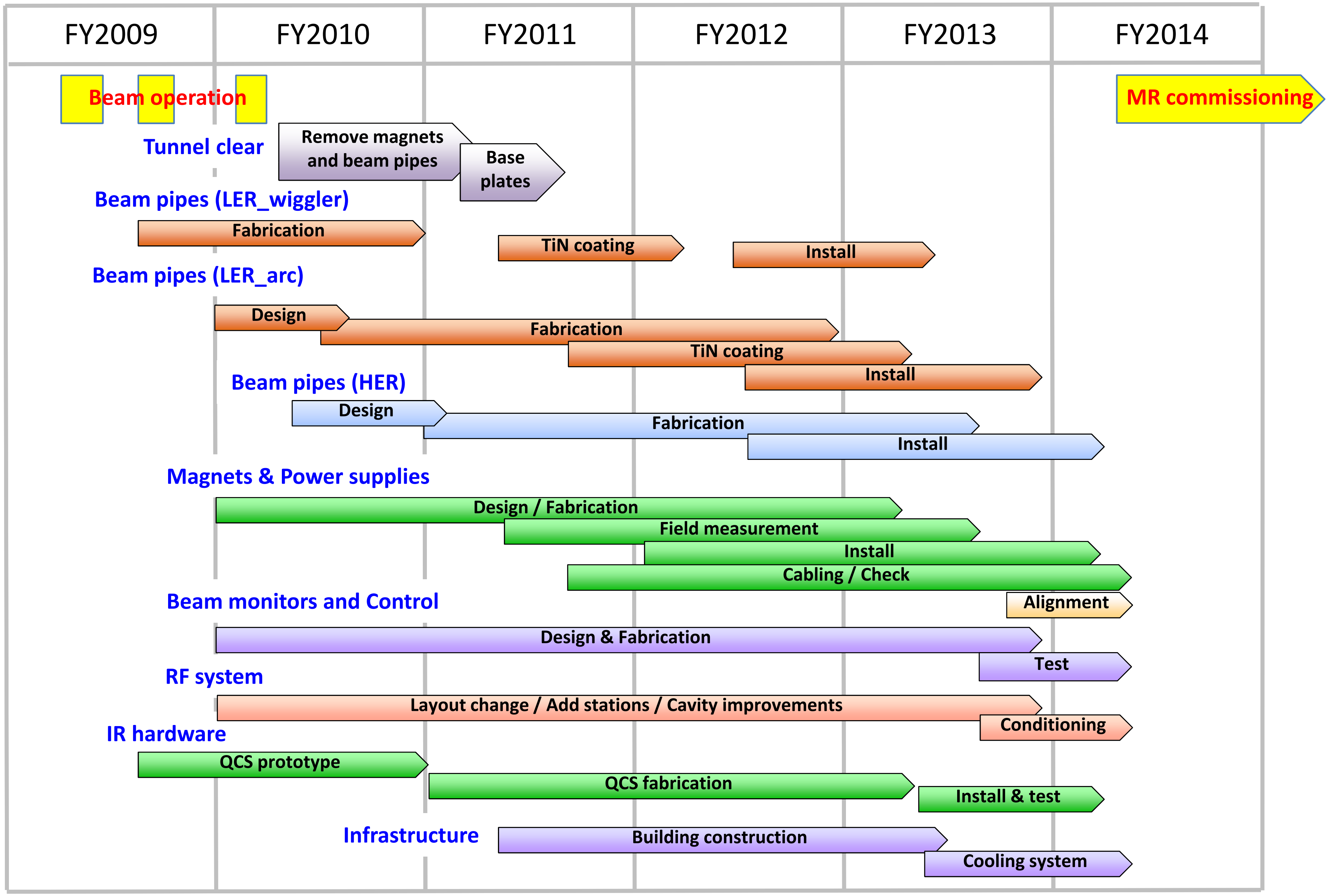
SuperKEKB Longitudinal FB plan



SuperKEKB Longitudinal Bunch Feedback System

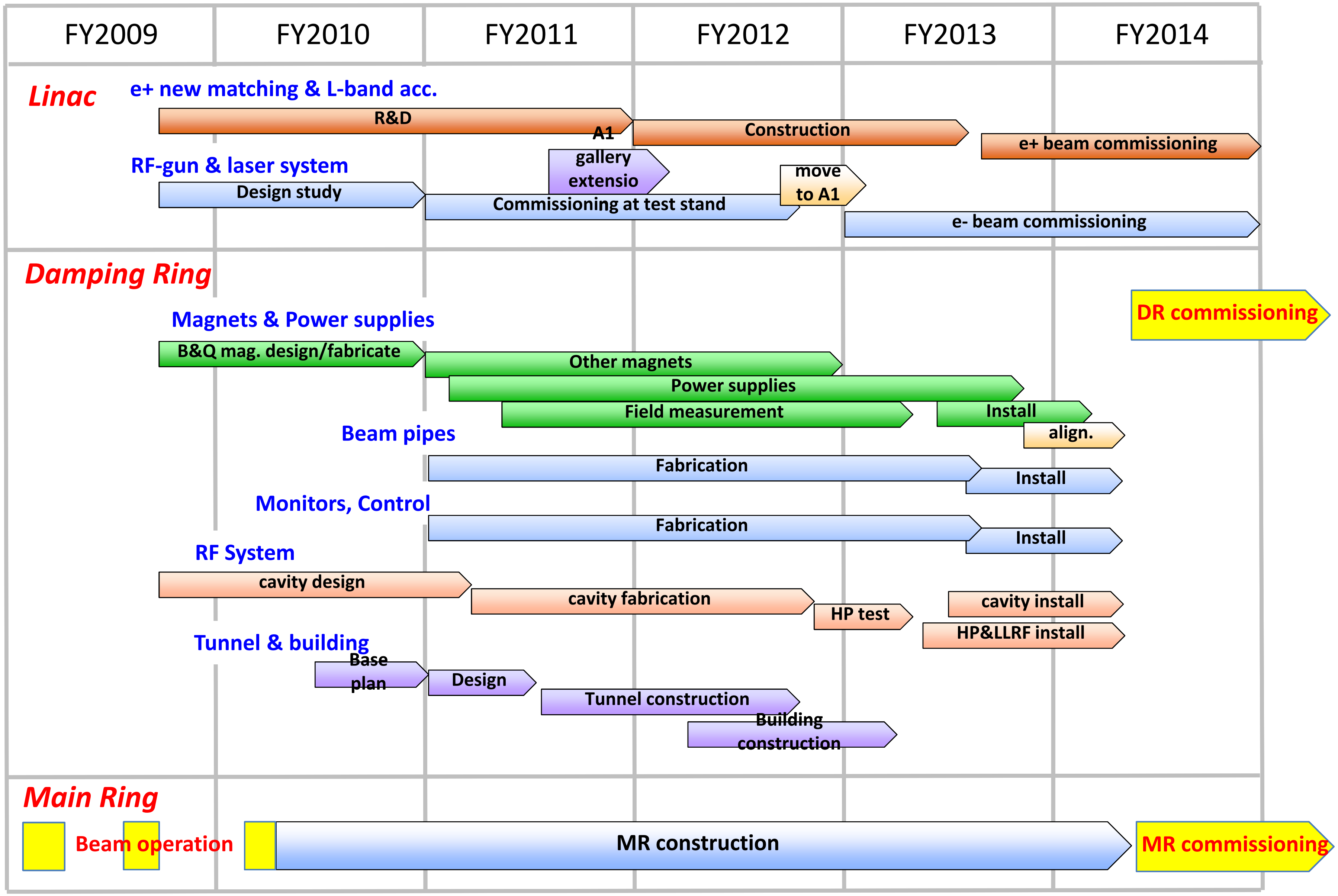
SuperKEKB Main Ring schedule

Jul. 30, 2010

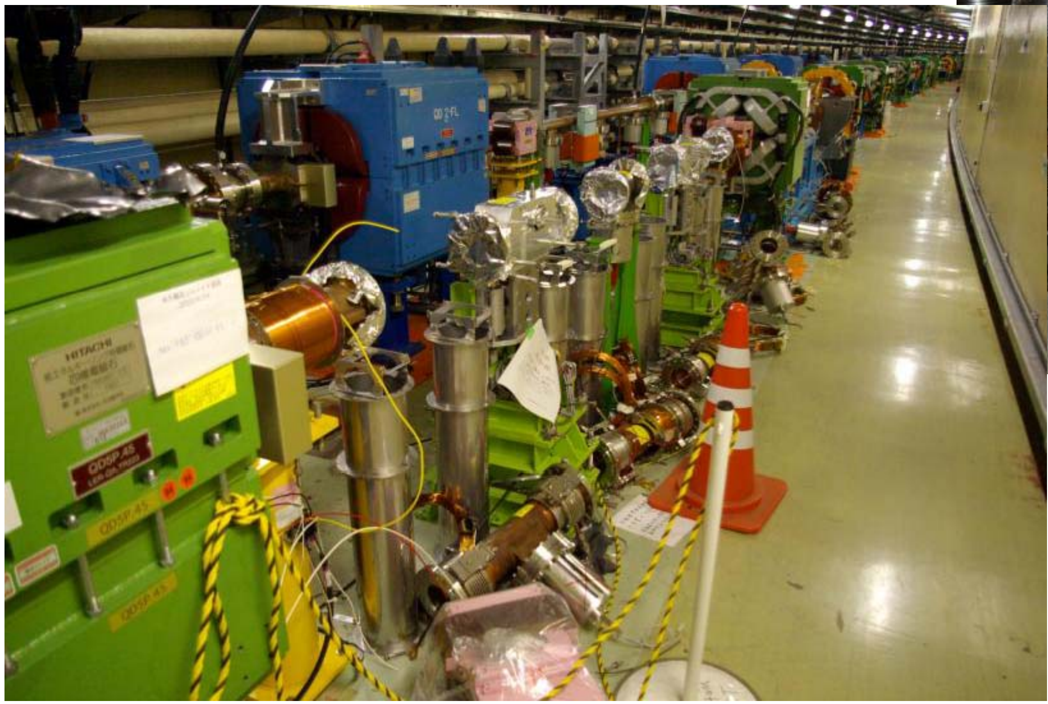


Injector upgrade and DR construction schedule

Jul. 30, 2010



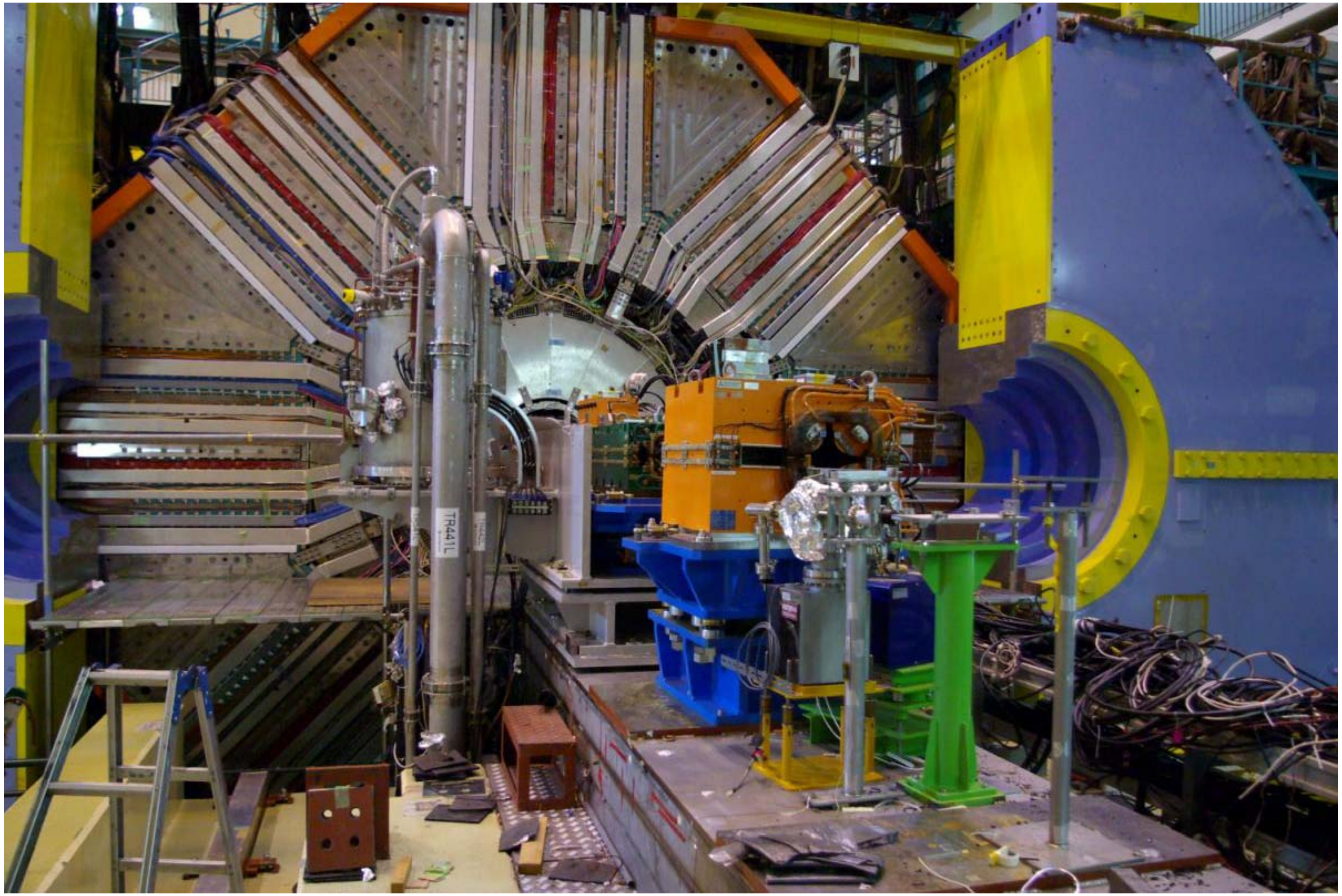
Starting removing LER vacuum chambers



Most of the LER bending magnets will be removed (and discarded) within this fiscal year.

Open Quads, removing LER vacuum chambers

Belle will be rolled-out in Oct.



Summary

- **KEKB upgrade (to SuperKEKB) has been approved.**
- **Design work is still in progress**
  - Found optics parameters with large enough dynamic aperture in both HER and LER.
  - Hardware design around IP including installing/removal method are settling.

↓

- **We have now reliable parameter set for L=8E35cm^{-2}s^{-1}**
- **Construction of new components for SuperKEKB have been started.**
  - LER wiggler chambers will be delivered within this year.
  - Most of magnets of the positron damping ring will be delivered by Mar/2011.
  - Bid for LER vacuum chambers (totally ~2km) and LER bending magnets and other components will be made soon.
- **Removal work (LER vacuum chamber, magnets, IR) has been started**