SuperKEKB Design Status

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SuperB Workshop
Perugia

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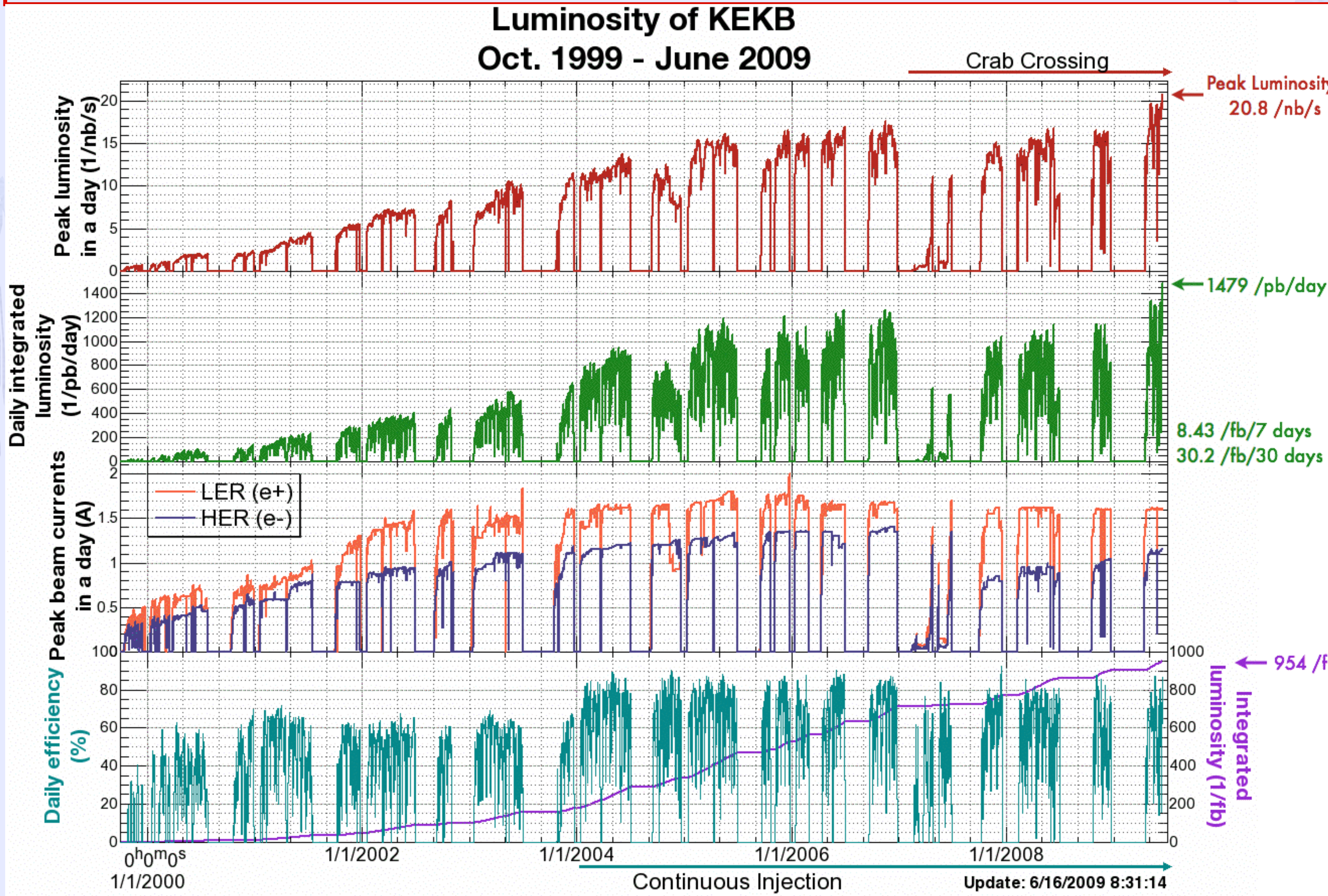
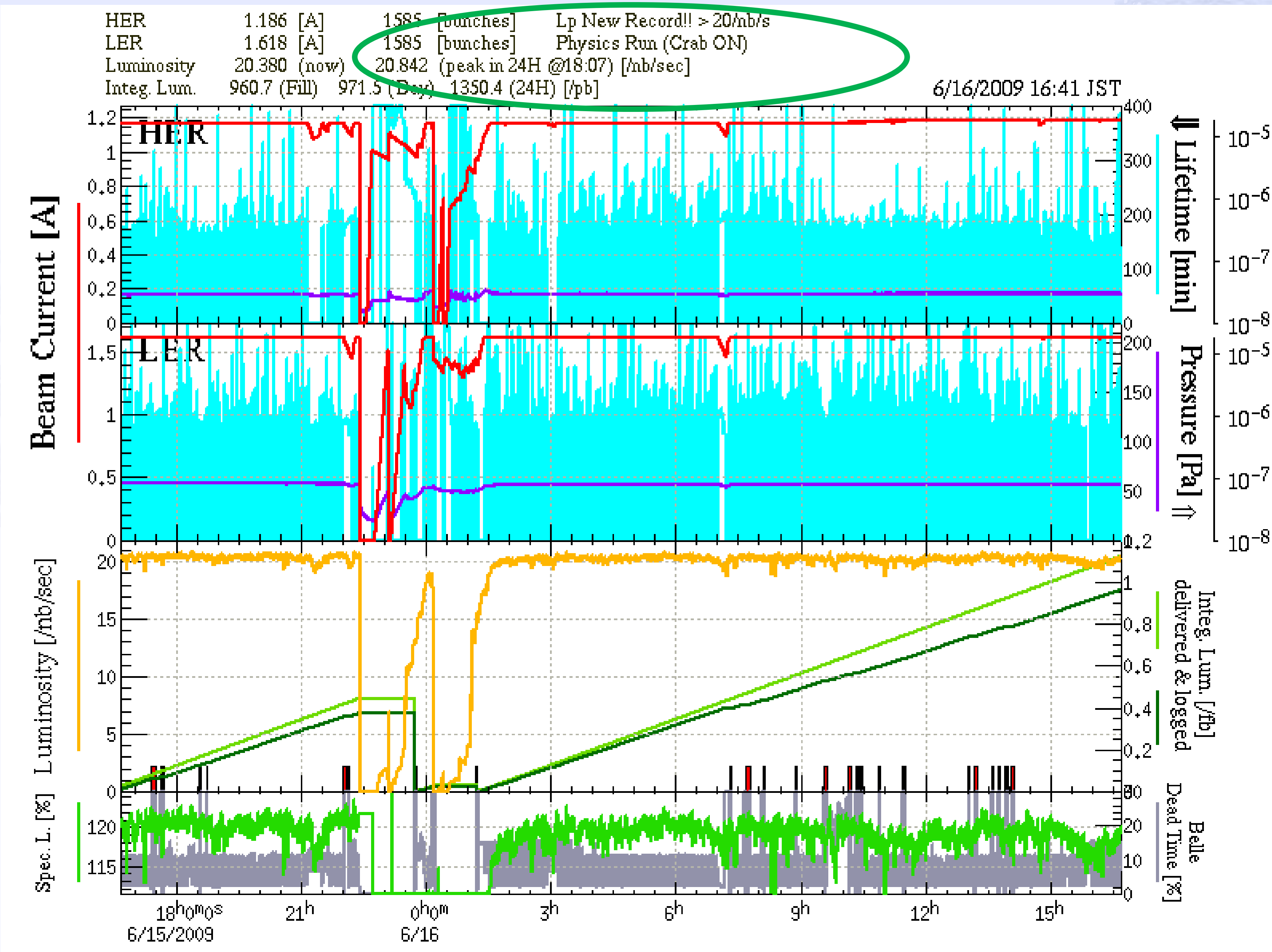
1. Introduction

Luminosity goal

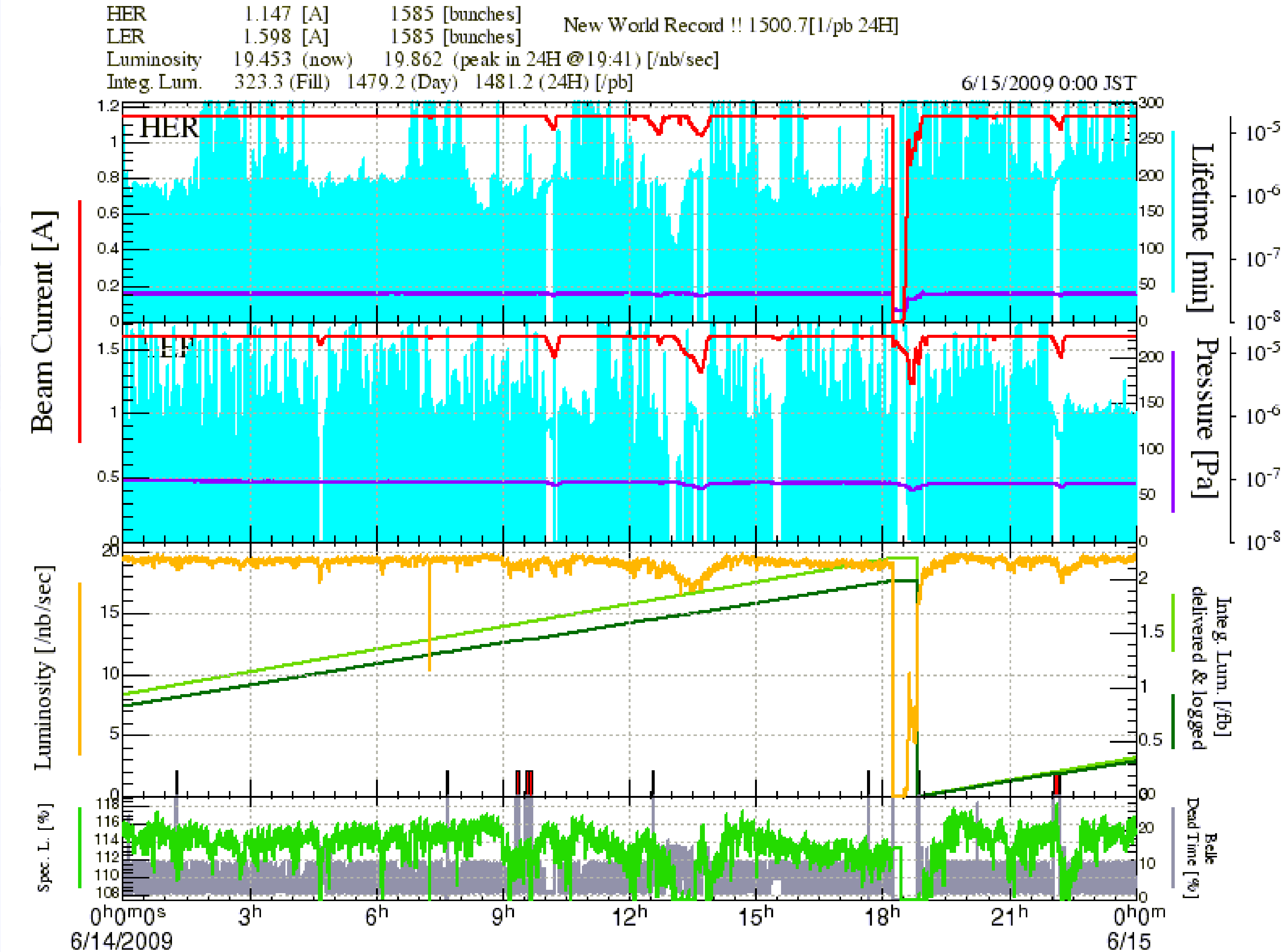
A new peak luminosity record made with Crab Crossing: $2.08 \times 10^{34} cm^{-2} s^{-1}$

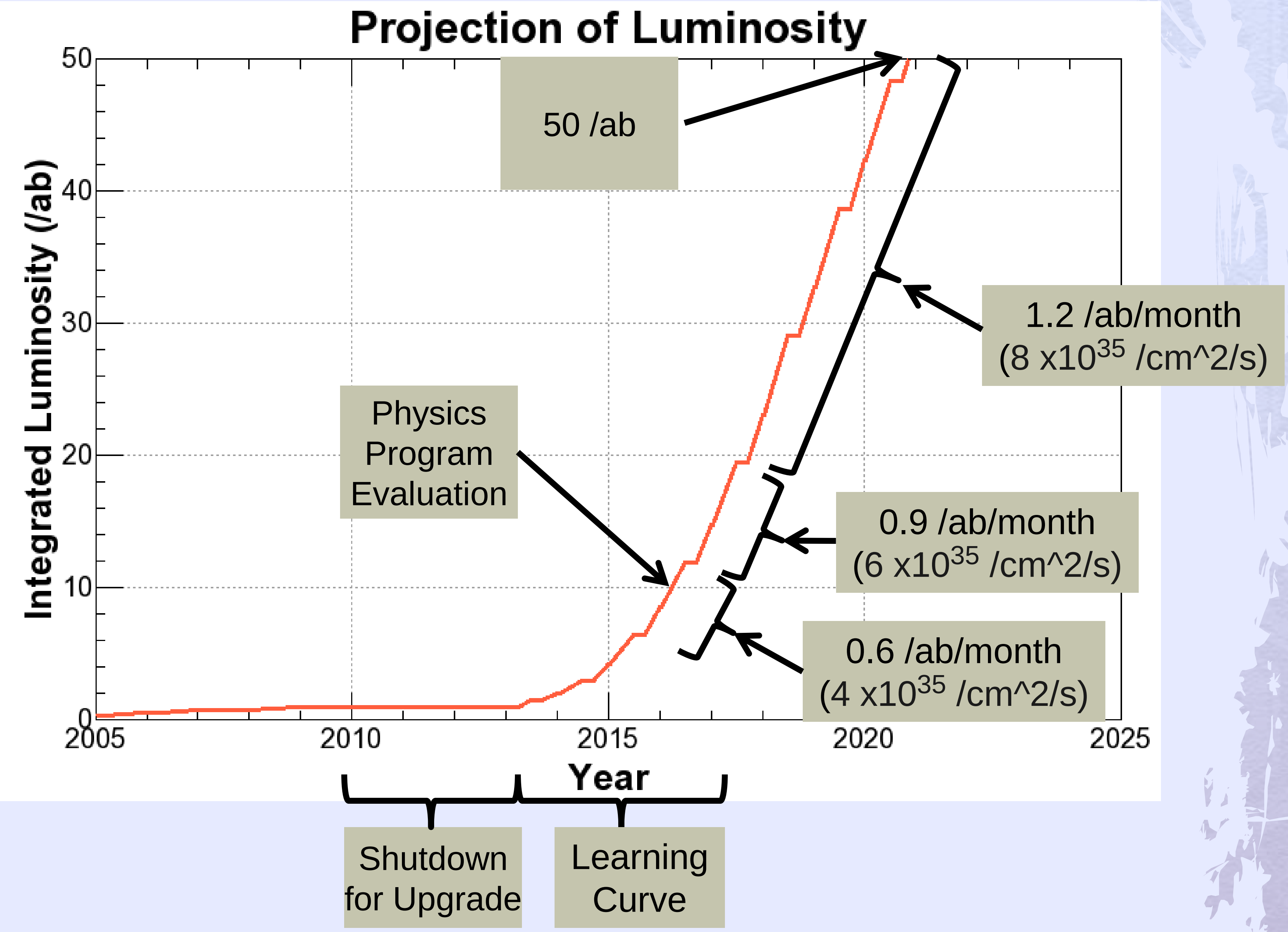




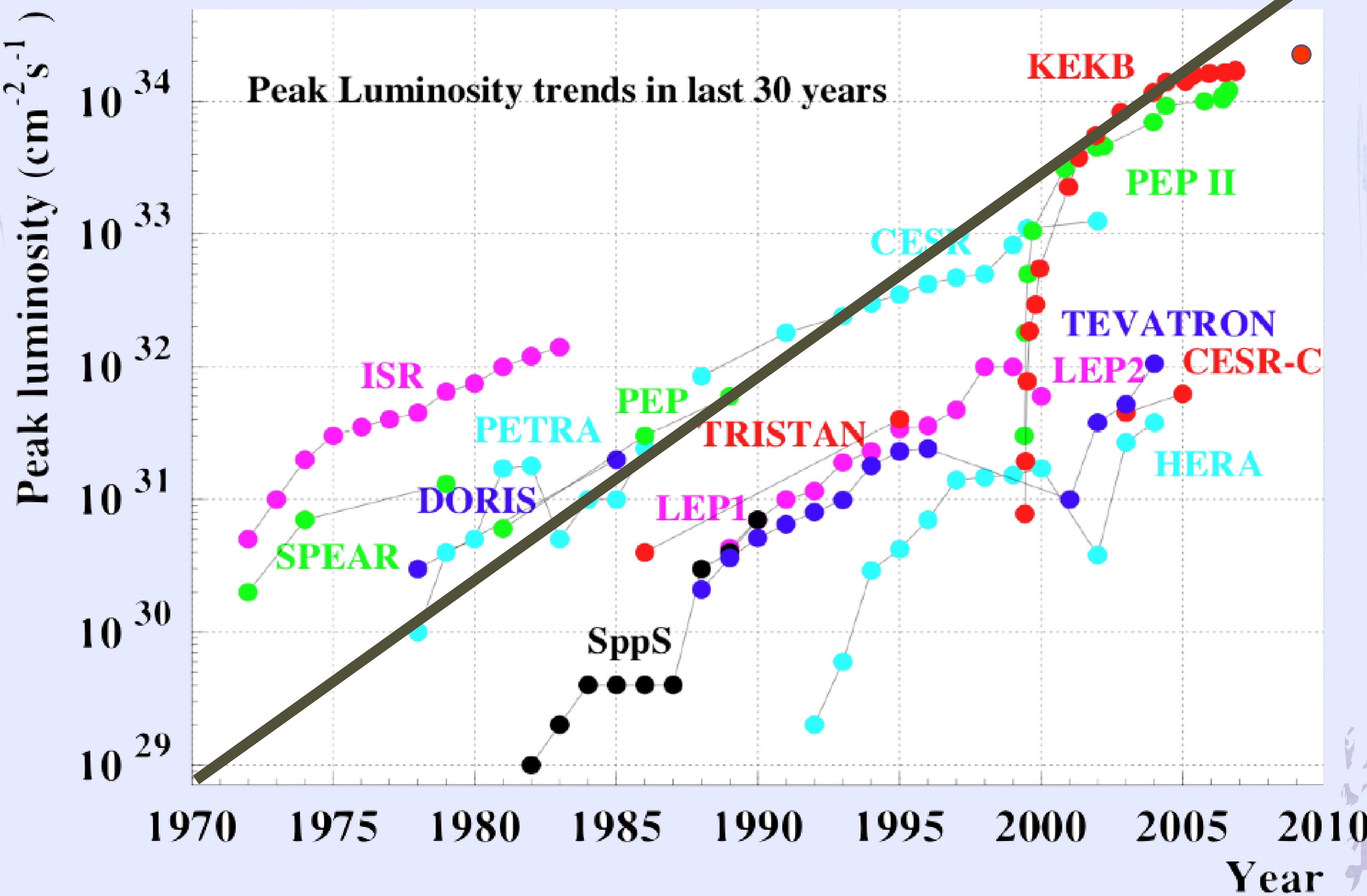
HER 1.186 [A] 1585 [bunches] Lp New Record!! > 20/nb/s
LER 1.618 [A] 1585 [bunches] Physics Run (Crab ON)
Luminosity 20.380 (now) 20.842 (peak in 24H @18:07) [/nb/sec]
Integ. Lum. 960.7 (Fill) 971.5 (Day) 1350.4 (24H) [/pb]
6/16/2009 16:41 JST
HER
LER
Beam Current [A]
Lifetime [min]
Pressure [Pa]
Luminosity [/nb/sec]
Integ. Lum. [/fb]
delivered & logged
Spec. L. [%]
Belle
Dead Time [%]
18h0m0s
6/15/2009
21h
0h0m
6/16
3h
6h
9h
12h
15h

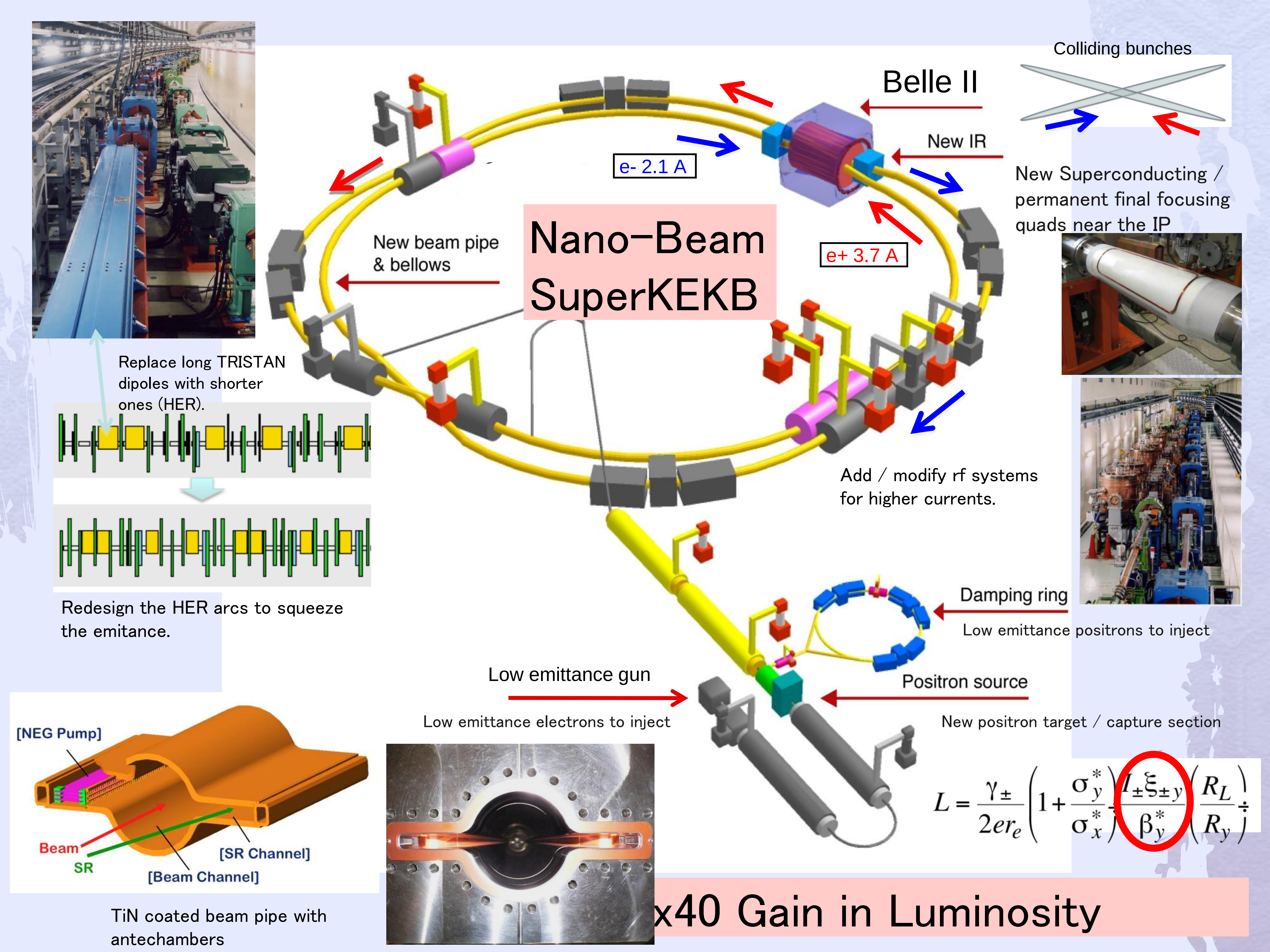
Best Day: 1.48 fb^{-1}/day, 1.50 fb^{-1}/24h




Projection of Luminosity
Integrated Luminosity (/ab)
Year
0
10
20
30
40
50
2005
2010
2015
2020
2025
50 /ab
1.2 /ab/month
(8 x10^35 /cm^2/s)
0.9 /ab/month
(6 x10^35 /cm^2/s)
0.6 /ab/month
(4 x10^35 /cm^2/s)
Physics Program Evaluation
Shutdown for Upgrade
Learning Curve

Target: 8 × 10^{35} $cm^{-2}s^{-1}$
= 40 x World Record (KEKB)





Nano-Beam SuperKEKB
Belle II
Colliding bunches
New IR
New Superconducting / permanent final focusing quads near the IP
e- 2.1 A
e+ 3.7 A
New beam pipe & bellows
Replace long TRISTAN dipoles with shorter ones (HER).
Redesign the HER arcs to squeeze the emitance.
Add / modify rf systems for higher currents.
Damping ring
Low emittance positrons to inject
Low emittance gun
Low emittance electrons to inject
Positron source
New positron target / capture section
[NEG Pump]
Beam
SR
[SR Channel]
[Beam Channel]
TiN coated beam pipe with antechambers
$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$
x40 Gain in Luminosity

Strategies for Increasing Luminosity

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

Lorentz factor

Beam current

Beam-beam parameter

Lumi. reduction factor (crossing angle)& Tune shift reduction factor (hour glass effect) 0.8 ~ 1 (short bunch)

Classical electron radius

Beam size ratio@IP 1 ~ 2 % (flat beam)

Vertical beta function@IP

High-Current Option

(1) Smaller β_y^*

(2) Increase beam currents

(3) Increase ξ_y

Nano-Beam Option

2. Strategy

Luminosity

High-Current Option

Nano-Beam Option

Two Options

- High-Current Option
  - Variation on original LoI design.
  - Extension of current KEKB design, with much higher beam currents (9.4 A LER, 4.1 A HER), and crab crossing.
- Nano-Beam Scheme
  - Variation on proposal by P. Raimondi *et al.* for Italian Super B Factory.
  - Primarily reduced beam size at the IP.
  - Lower beam-beam parameter required
    - Close to current KEKB
  - Beam currents close to KEKB design currents => 25% lower running costs

Strategy: High-Current Option

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

- Lorentz factor
- Beam current
- Beam-beam parameter
- Classical electron radius
- Beam size ratio@IP 1 ~ 2 % (flat beam)
- Vertical beta function@IP
- Lumi. reduction factor (crossing angle)& Tune shift reduction factor (hour glass effect) 0.8 ~ 1 (short bunch)

(1) Smaller β_y^*

•6.5(LER)/5.9(HER) mm→3.0/6.0 mm

(2)Increase beam currents

•1.7 A (LER) / 1.4 A (HER) → 9.4 A (LER) / 4.1 A (HER)

(3) Increase ξ_y

•0.1(LER)/0.06(HER) → ~0.3 or more

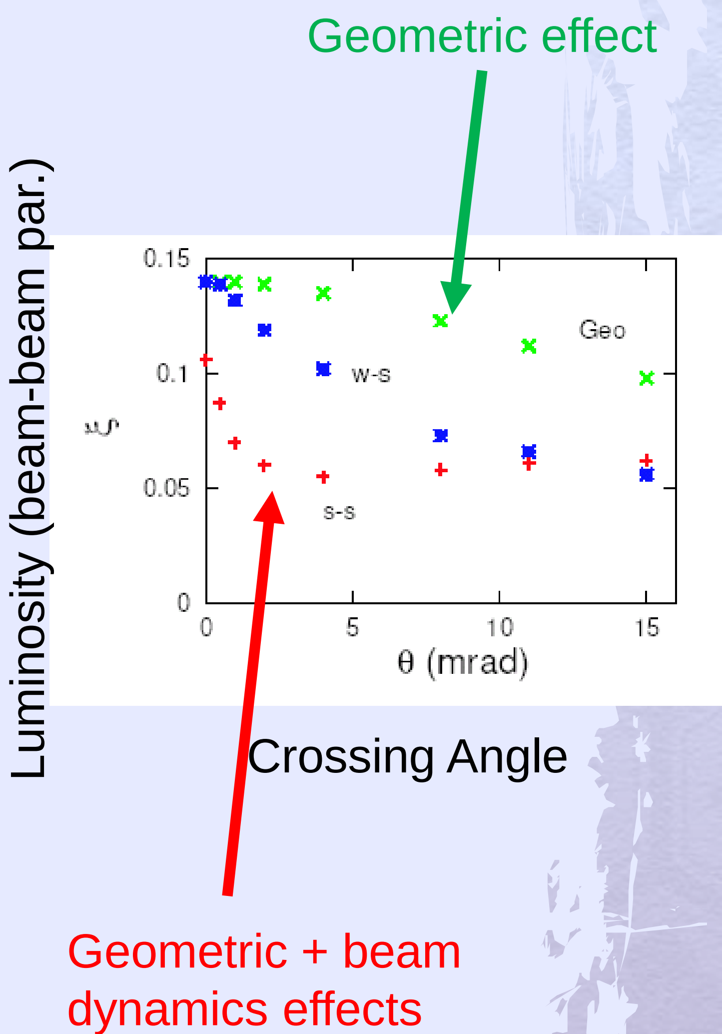
Evolution of design in original Letter of Intent (LoI) for SuperKEKB (2004)

Beam-Beam Limit

- Historically, the beam-beam limit is the term applied to the experimental observation that as the bunch currents increase, at some point the luminosity stops increasing as I^2 and merely increases as I.
  - At SPEAR, set in at a beam-beam tune shift ξ=0.03
    - M. Month, IEEE Vol. NS-22, Num. 3, p. 1376 (1975).
  - In the 1980s, ξ="almost universally 0.05."
    - K. Hirata, PRL **58** 1, p. 25 (1987).
  - CESR reached 0.07, LEP 0.083 (without saturation)
  - KEKB ~0.1
    - Without crab crossing: LER ξ y=0.108, HER ξ y=0.058
    - With crab crossing: LER ξ y=0.101, HER ξ y=0.096
- Associated with beam size blow-up and lifetime drop.
  - Modelling methods include induced resonances and bunch-shape distortions due to non-linear focusing effects.

Beam-beam limit

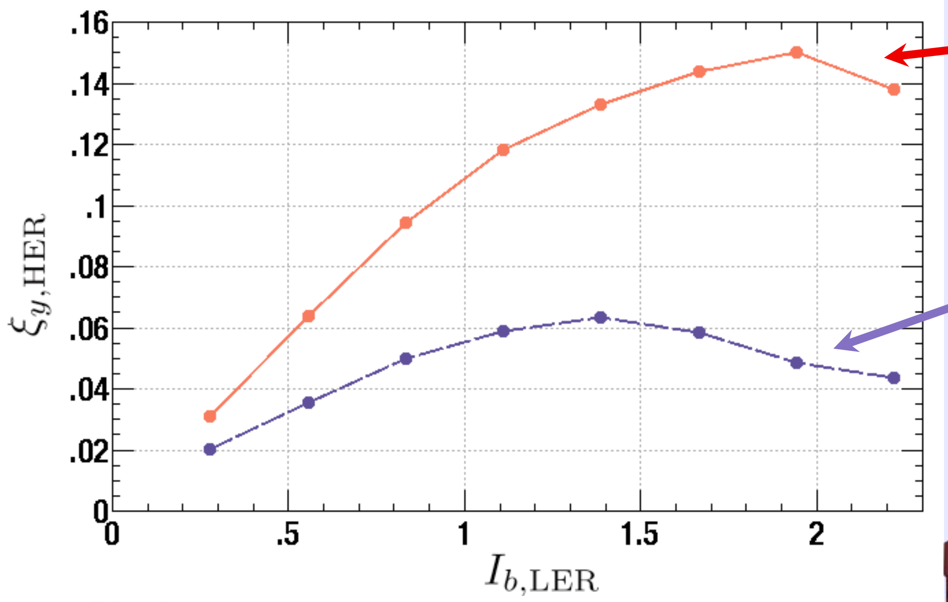
- Beam-beam parameter up to 0.059 has been achieved with a finite crossing angle at KEKB.
- Beam-beam simulations say:
  - A head-on collision greatly improves the luminosity, for two reasons:
    - Geometrical cross-section improvement
    - Improved beam dynamics (reduce non-Gaussian tails)
  - Crab crossing scheme (finite crossing angle but with crab cavity) effectively creates a head-on collision.
- The crab crossing scheme is being tested now.



Crab Crossing @ KEKB

●Simulation: Crab Crossing can boost the beam-beam parameter above 0.15

K. Ohmi

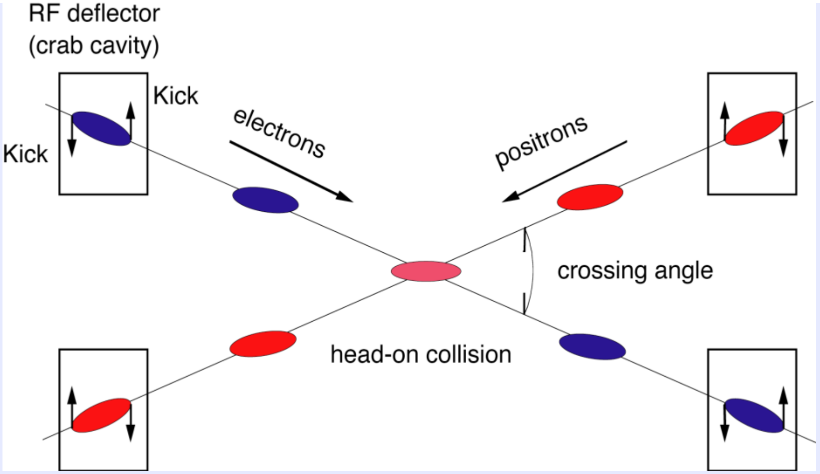


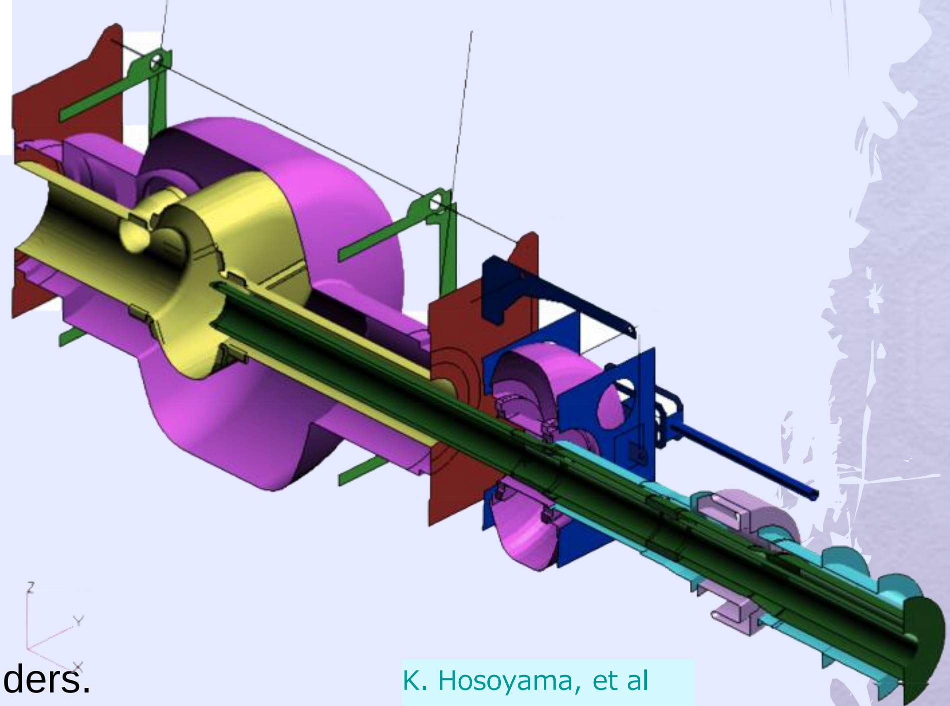
Head-on (crab)

(Strong-strong simulation)

Crossing angle 22 mrad

●Crab cavities were successfully produced and beam study started in Feb. 2007.

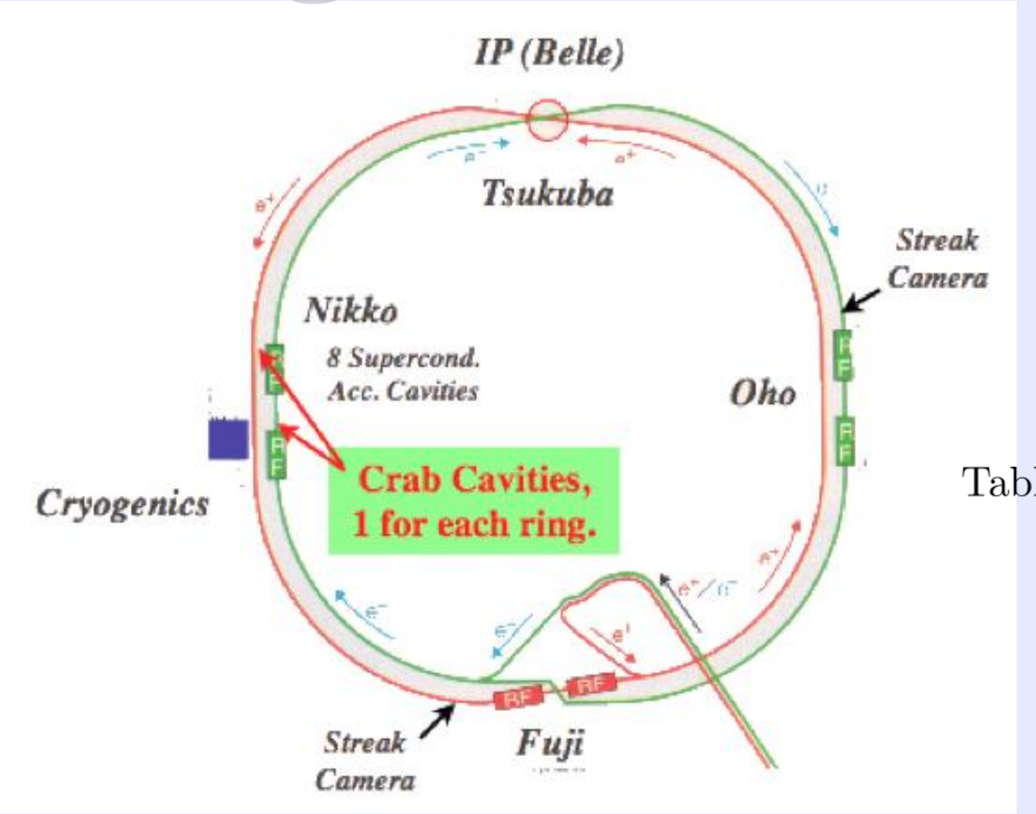




First proposed by R. B. Palmer in 1988 for linear colliders.

K. Hosoyama, et al

Single Crab Cavity Scheme



- Beam tilts all around the ring.
- z-dependent horizontal closed orbit.
- tilt at the IP:

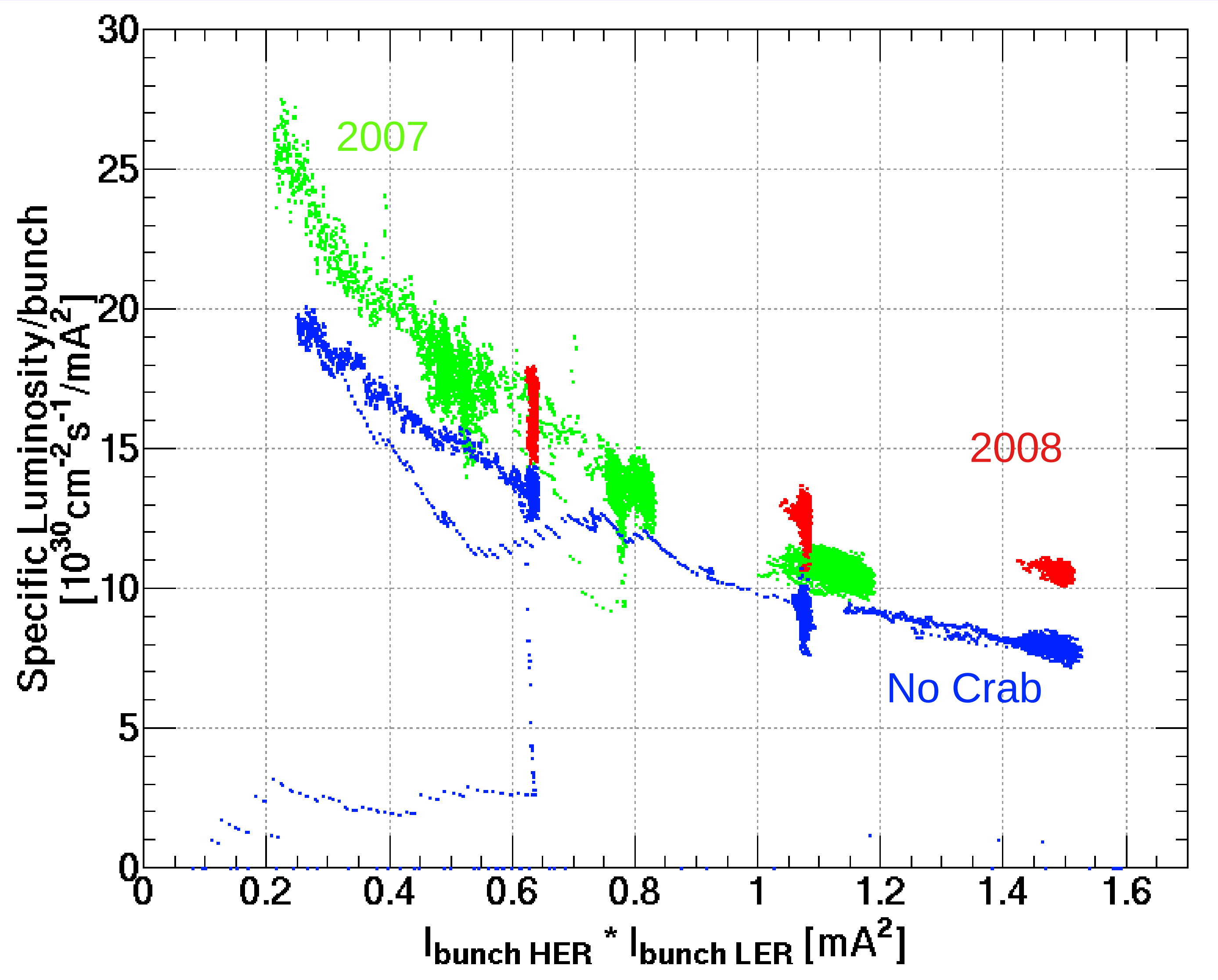
$$\frac{\theta_x}{2} = \frac{\sqrt{\beta_x^C \beta_x^*}\cos(\psi_x^C - \mu_x/2)}{2\sin(\mu_x/2)} \frac{V_C \omega_{\mathrm{rf}}}{Ec}$$

Table 1: Typical parameters for the crab crossing.

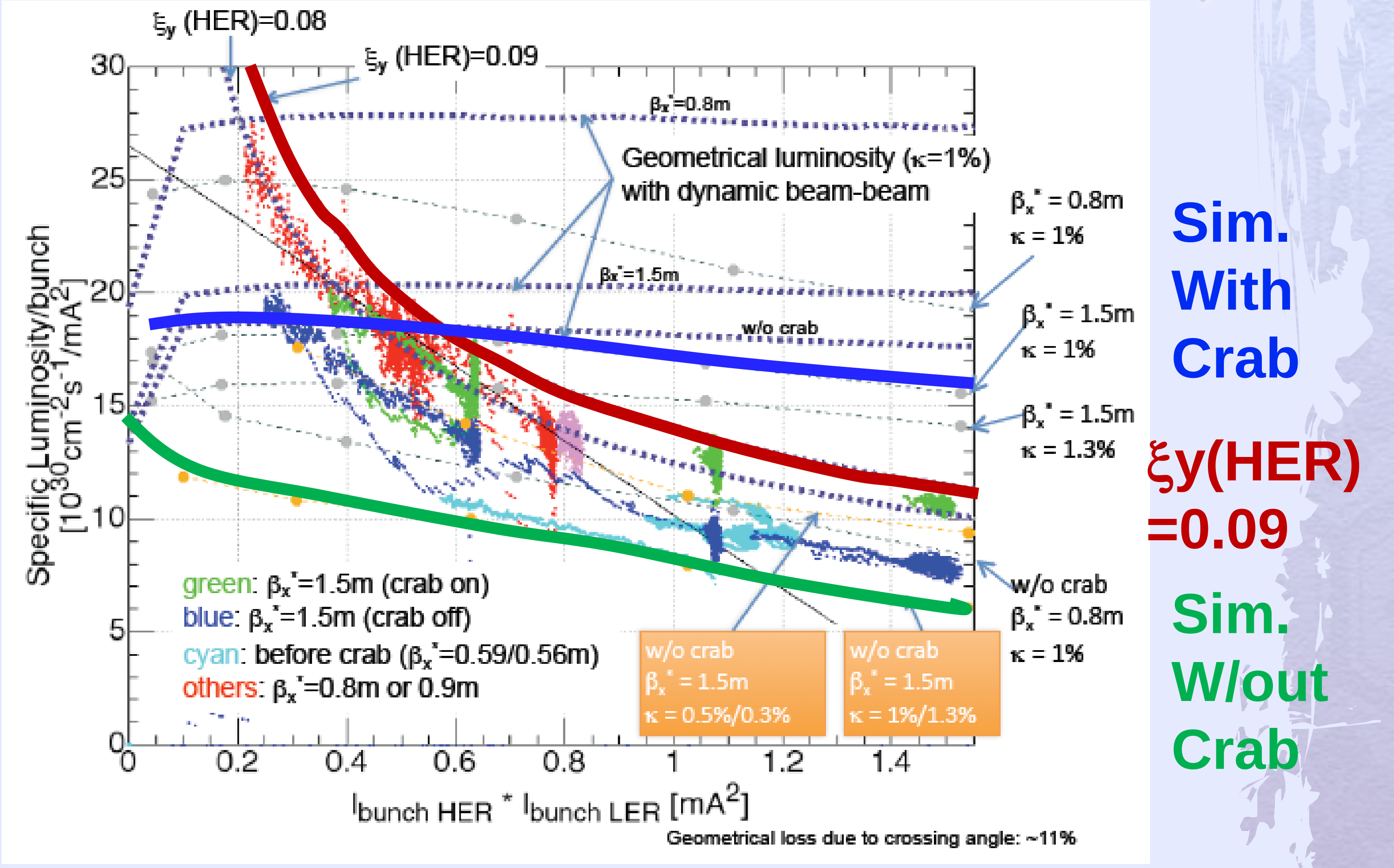
Ring	LER	HER	
θ_x	22		mrad
β_x^*	80	80	cm
β_x^C	73	162	m
$\mu_x/2\pi$	0.505	0.511	
$\psi_x^C/2\pi$	~ 0.25	~ 0.25	
V_C	0.95	1.45	V
$\omega_{\mathrm{rf}}/2\pi$	509		MHz

- 1 crab cavity per ring.
- Saves the cost of the cavity and cryogenics.
- Avoids synchrotron radiation hitting the cavity.

Specific Luminosity with & without Crab Crossing

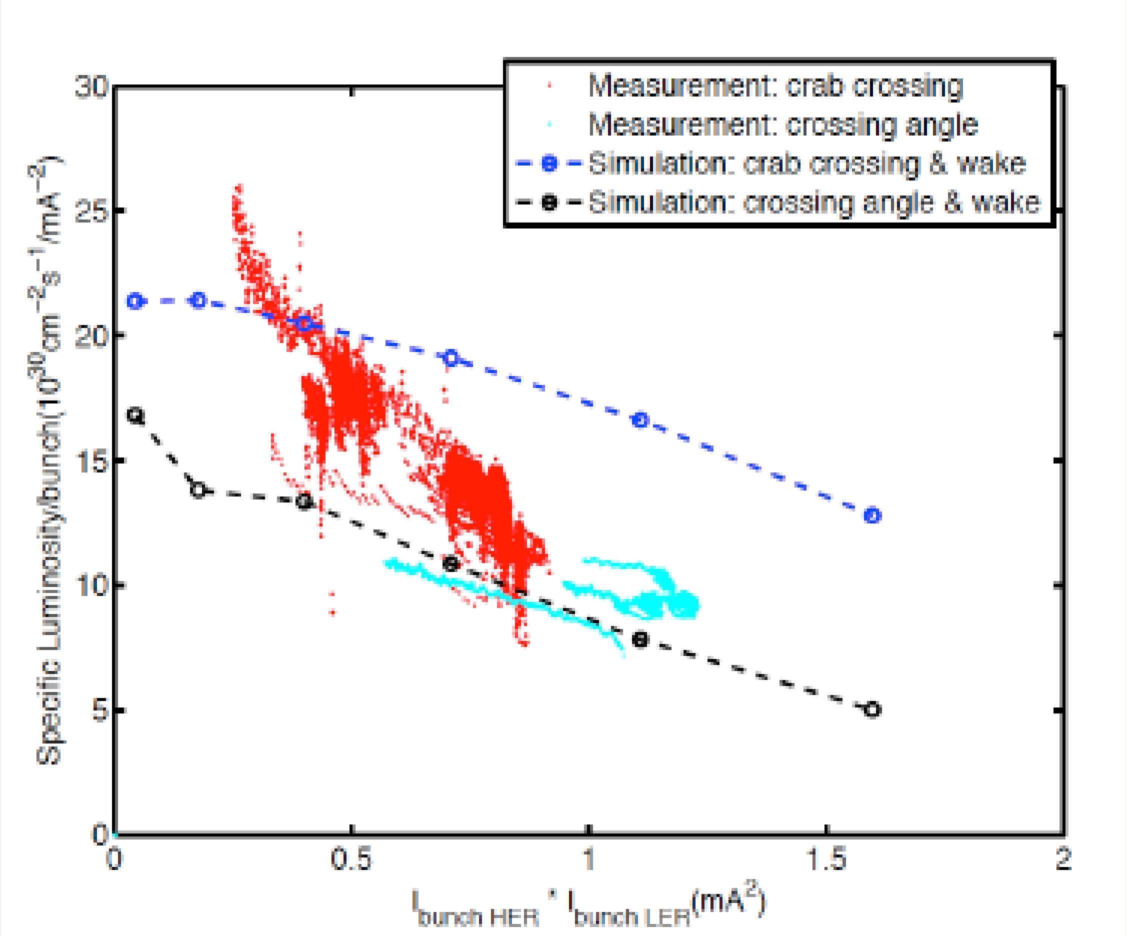


Specific Luminosity with & without crab crossing (Data + K. Ohmi Simulations)



Funakoshi, KEKB Review (2009)

Specific Luminosity with & without crab crossing (Data + Y. Cai Simulations)



Funakoshi, KEKB Review (2009)

Discrepancies between simulation and data

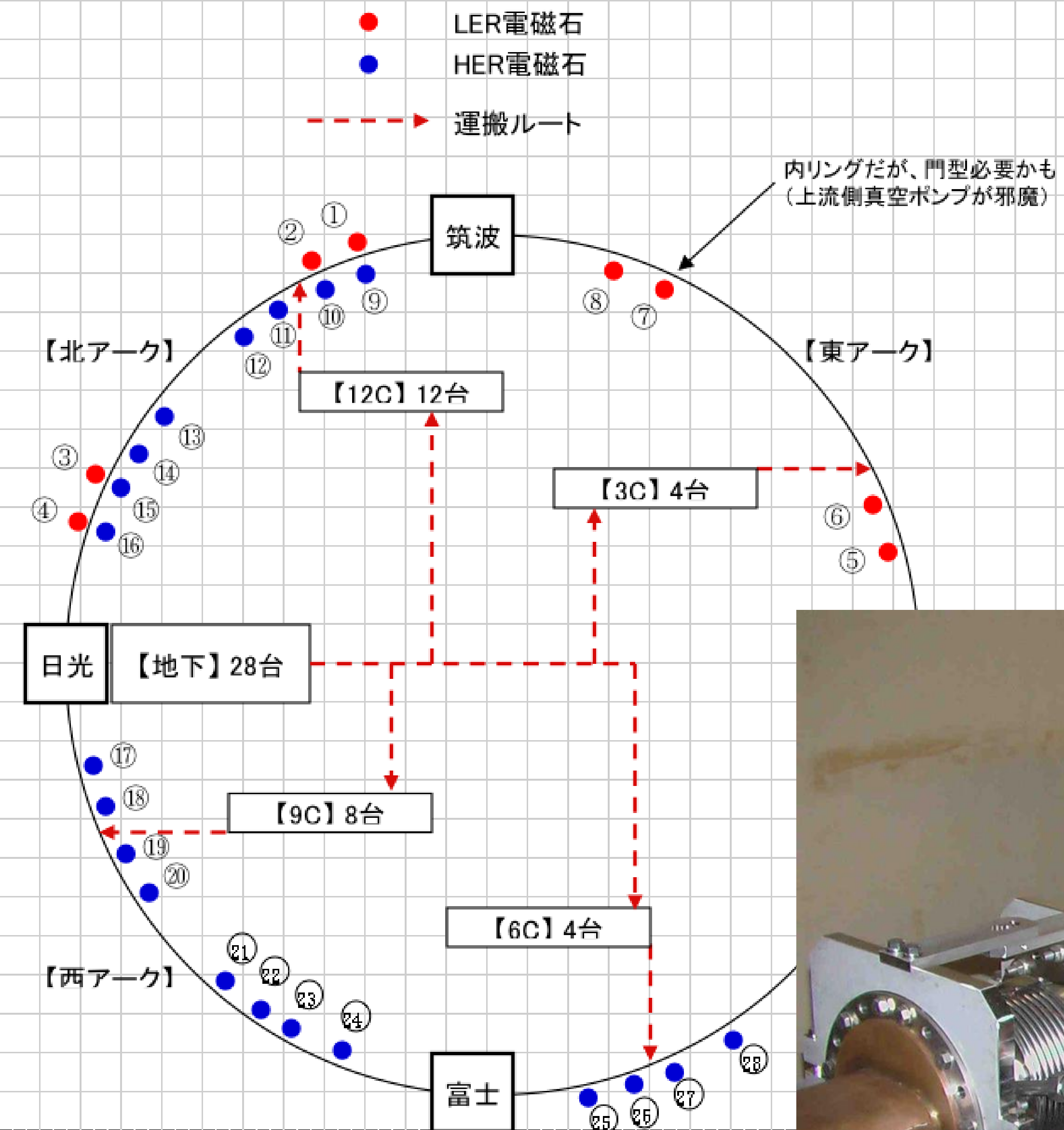
Many possibilities studied. Among them:

- Crab angle errors (horizontal, vertical)
  - Studied extensively, no errors found
- Aperture restrictions near HER crab cavity
  - Fixed with orbit bump, but did not improve luminosity.
- Tuning methods for finding needle in haystack
  - Possibly still room for improvement

- Coupling is corrected for on-momentum particles by “optics correction” but not for off-momentum particles.
  - Coupling dependence on momentum might be playing some role at higher bunch current.
  - Potential source for the steep slope??

Recent Developments: Skew Sextupoles

- During Winter 2009 shutdown, skew sextupoles for optics tuning were installed around the ring.
- Have successfully demonstrated correction of chromatic coupling effects with them in Spring 2009 run:
  - Measurements of R Chromaticity show very effective correction (Ohmi, Ohnishi, et al.)
  - Peak luminosity increased to 2.08 /nb/s
    - Yesterday!
    - New world record
    - Double the KEKB design



28 skew sextupoles (20 in HER & 8 in LER) manufactured and installed during Winter 2009 shutdown.

Coherent Synchrotron Radiation

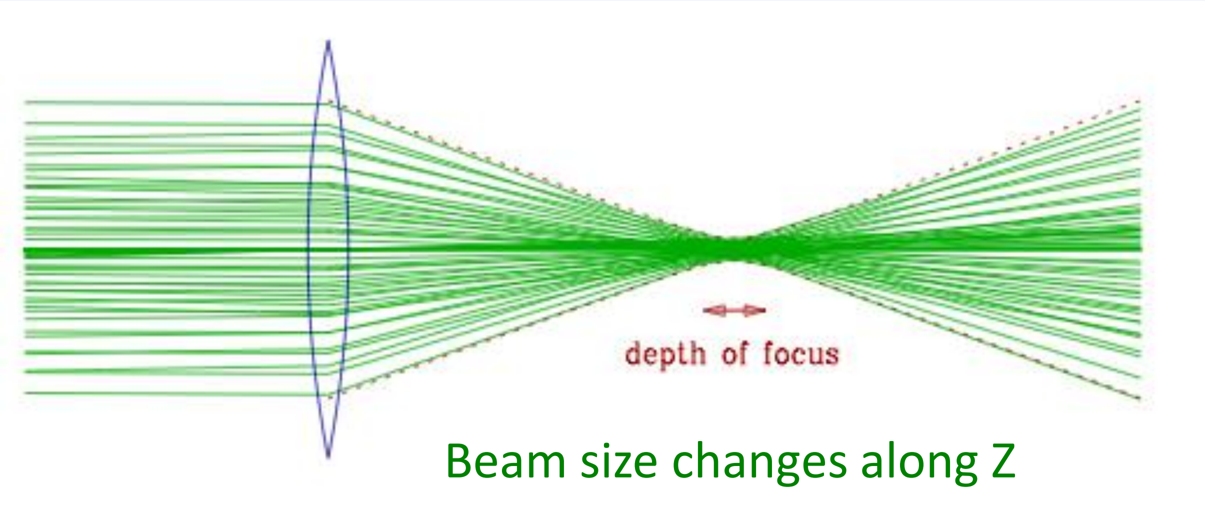
- Coherent Synchrotron Radiation (CSR) results from SR from tail of bunch hitting head of bunch in a bend, resulting in increased energy spread and bunch lengthening.
- Recent simulations show practical beam pipe modifications are ineffective in mitigating this effect.
- With a negative compaction factor, the bunch lengths at full current can be brought down to ~5 μm (LER) and ~3 μm (HER), at best.
- ➔Serious impact on High-Current Option

		zero bunch current	design bunch current	
LER	sigz	5	6	mm
	sige	7.1	8.0	10^{-4}
LER neg. alpha	sigz	4.5	5.3	mm
	sige	7.1	8.5	10^{-4}
HER	sigz	3	3.6	mm
	sige	6.8	7.0	10^{-4}
HER neg. alpha	sigz	3	3.1	mm
	sige	6.8	7.7	10^{-4}

K. OIDE

Impact of CSR on High-Current Option

Head-on collision/crab crossing requires $\sigma_z <\sim \beta_y^*$ to minimize hourglass effect.



Bunch lengthened by CSR:

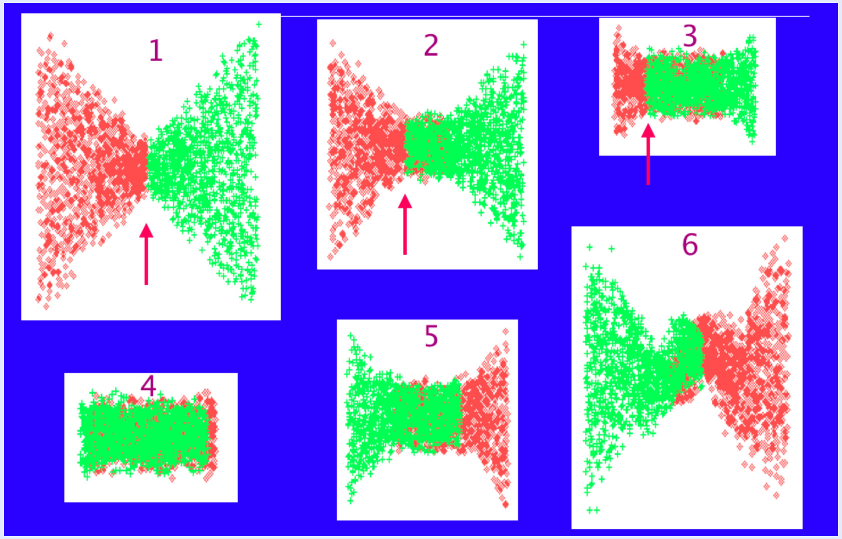
LER bunch σ_z=5mm (not 3mm) when β_y^*=3mm⇨$\sigma_z > \beta_y^*$

→Hourglass effect is not negligible.

⇨A possible cure is to use travelling focus

Travelling focus

•Known technique for linear collider (Balakin, et al.)
•Move vertical waist backward longitudinally
  •Match highest-density part of opposing bunch



N. Walker

•Needs:
  •Pair of sextupole magnets at both sides of the crab cavity; and
  •Two crab cavities each ring.

•Current simulation results by Ohmi suggest that travelling focus, in combination with horizontal tunes pushed closer to the half-integer and smaller βx, can partially recover luminosity lost to CSR, to ~5x10^-35 cm^-2s^-1, though very high beam-beam parameters are needed.

Strategy: Nano-Beam Option

Lorentz factor

Beam current

Beam-beam parameter

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

Classical electron radius

Beam size ratio@IP
1 ~ 2 % (flat beam)

Vertical beta function@IP

Lumi. reduction factor (crossing angle)&
Tune shift reduction factor (hour glass effect)
0.8 ~ 1
(short bunch)

(1) Smaller β_y^*

- 6.5(LER)/5.9(HER) mm→3.0/3.0 mm

(2)Increase beam currents

- 1.7 A (LER) / 1.4 A (HER) → 2.96 A (LER) / 1.5 A (HER)
    - Close to original KEKB design

~~(3) Increase ξ_y~~

- 0.1(LER)/0.06(HER) → 0.09/0.09

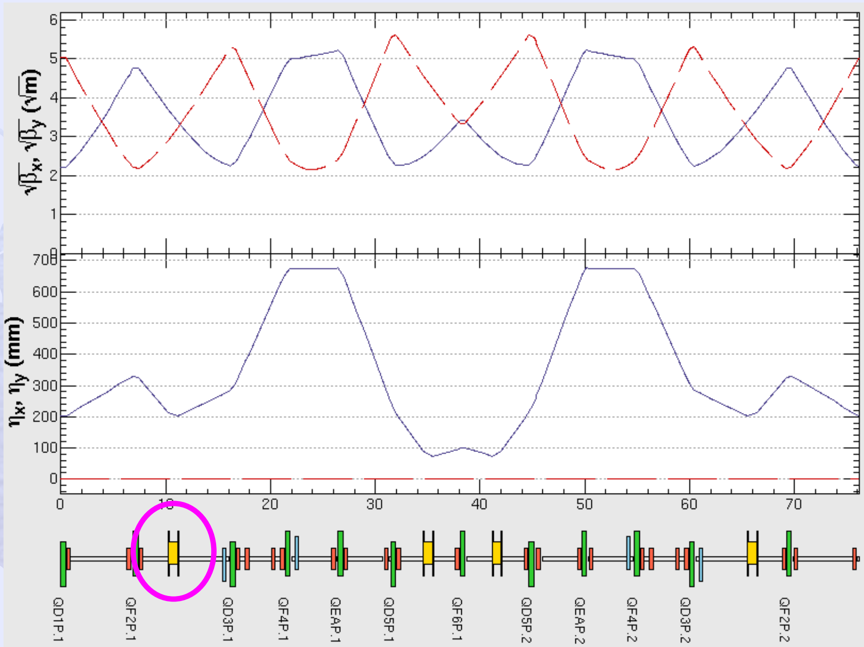
Proposed by P. Raimondi et al., along with Crab Waist, for use at Italian Super B Factory

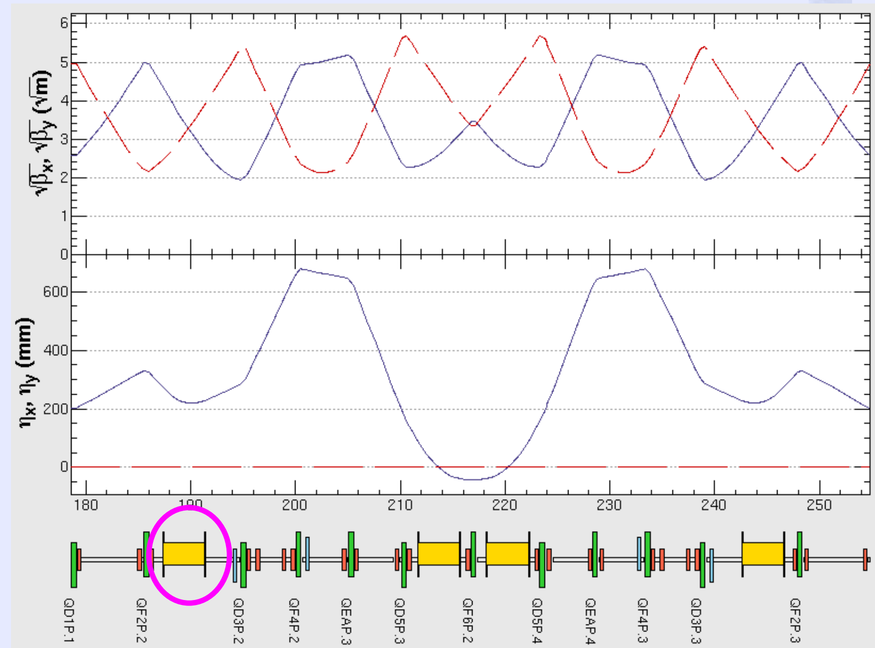
Nano-beam Lattice

LER arc cell

KEKB

SuperKEKB (Preliminary)





L bend = 0.9 m

L bend = 3.7 m

ε_x = 6.8 nm

ε_x =2.8 nm

- LER: Lower average energy of SR emitted in high dispersion regions (bends).
  - The arc cell lattice of the KEKB LER (left) can be modified to the low-emittance version (right), by weakening the magnetic field of the dipoles.
- No need for changing other components, beam pipes, geometry.
- HER: Lower dispersion in bends. (No room to lengthen bends.)
  - Arc cells shortened and increased in number 1.7 times.

H. Koiso

Design Options Preliminary

Comparison of parameters

	KEKB Design	KEKB Achieved (): with crab	SuperKEKB High-Current Option	SuperKEKB Nano-Beam Scheme
β_y^* (mm)(LER/HER)	10/10	6.5/5.9 (5.9/5.9)	3/6	0.24/0.37
ε_x (nm)	18/18	18(15)/24	24/18	2.8/2.0
κ(%)	1	0.8-1	1/0.5	1.0/0.7
σ_y(μm)	1.9	1.1	0.85/0.73	0.084/0.072
ξ_y	0.052	0.108/0.056 (0.101/0.096)	0.3/0.51	0.09/0.09
σ_z (mm)	4	~ 7	5(LER)/3(HER)	5
I_{beam} (A)	2.6/1.1	1.8/1.45 (1.62/1.15)	9.4/4.1	3.6/2.1
$N_{bunches}$	5000	~1500	5000	2119
Luminosity (10^{34} cm^{-2} s^{-1})	1	1.76 (2.08)	53	80

High Current Option includes crab crossing and travelling focus.

3. What we need

Components for higher currents,
smaller beam sizes

What we need
for (1) higher beam currents

a. Vacuum components (pipes/bellows…)
b. Modification of the monitors (BPMs,SRMs…)
c. Longitudinal bunch-by-bunch FB system
d. More RF cavities and klystrons
e. Modifications of the RF systems for higher currents
f. New Crab cavities for SuperKEKB
g. Rapid-switching linac, damping ring.

Vacuum components

Beam current increase causes:

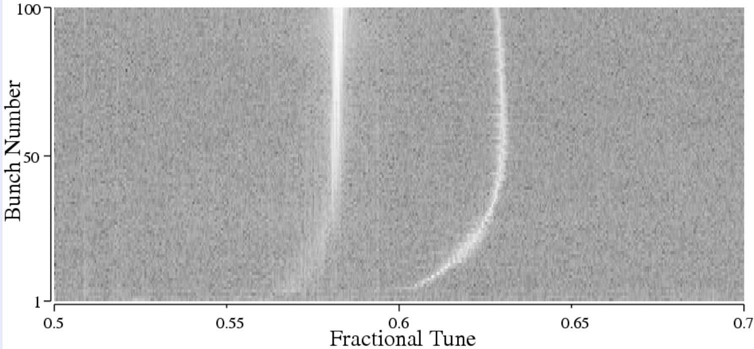
Intense Synchrotron Radiation power
- 27.8 kW/m in LER, twice as high as in KEKB
- 21.6 kW/m in HER, 4 times as high as in KEKB

High photon density
- Photon density ~$1x10^{19}$ photons/m/s in average
  - Large gas desorption
  - Gas load ~ $5x10^{-8}$ Pa m^3/s/m (for h = $1x10^{-6}$ molecules/photon)
  - Average pressure ~ $5x10^{-7}$ Pa for S ~ 0.1 m^3/s/m
  - Electron Cloud Instability (ECI) becomes a big issue in positron ring

Heating due to Higher Order Modes (HOM)
- For a loss factor of 1 V/pC, loss power ~ 200 kW

The Problem of Electron Clouds

- Photo-electrons produced at the beam pipe wall by synchrotron radiation, and secondary electrons produced by electron-wall collisions, are trapped in the region of the beam orbit in the positron ring (LER).
- The KEKB LER has suffered beam blow-up and luminosity loss due to interactions with these electron clouds, which cause a fast head-tail instability.
- Bunch-current blowup threshold can be raised by the use of solenoids around the beam pipe.



Bunch spectral signature of e-cloud instability observed at KEKB LER.
J.W. Flanagan et al., PRL 94, 054801 (2005).

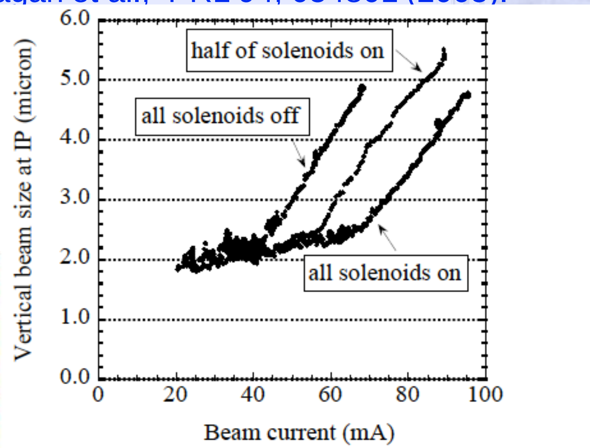


Figure 2: Vertical beam size as a function of the beam current. In the measurement two trains were injected on opposite sides in the ring. Each train contained 60 bunches. Bunch spacing was 4 rf buckets.

Fukuma et al., "Study of Vertical Beam Blow-up in KEKB LER," HEAC01 proceedings

However, KEKB performance is still limited by electron clouds.

Figure 1: Solenoids in the LER tunnel. The three solenoids on the right side are those installed in bellows-NEG pump sections. The long solenoid on the left side was installed in the first installation.

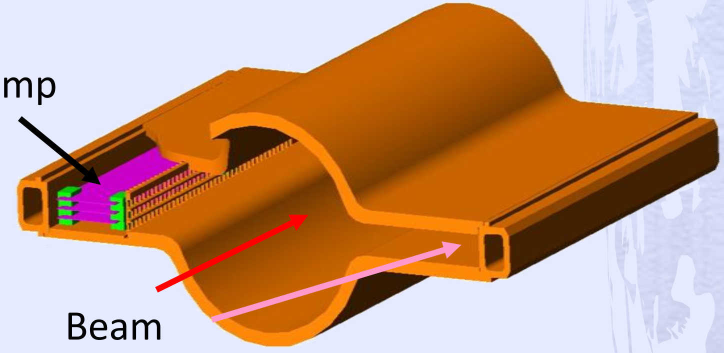
Beam duct

Copper beam duct with ante-chambers

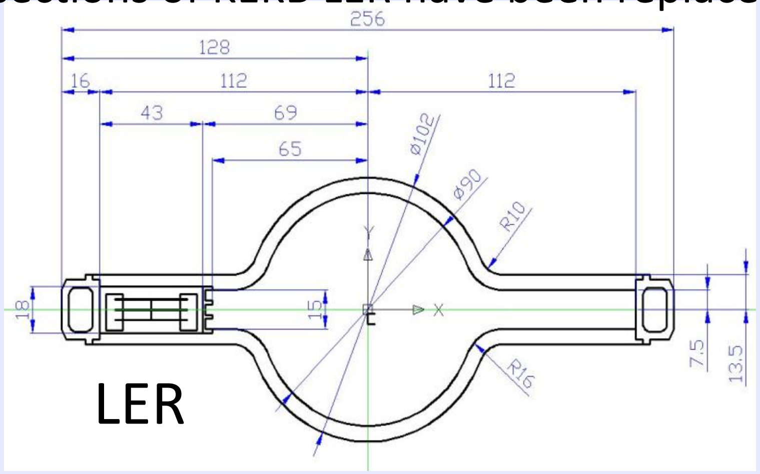
- Copper is required to withstand intense SR power

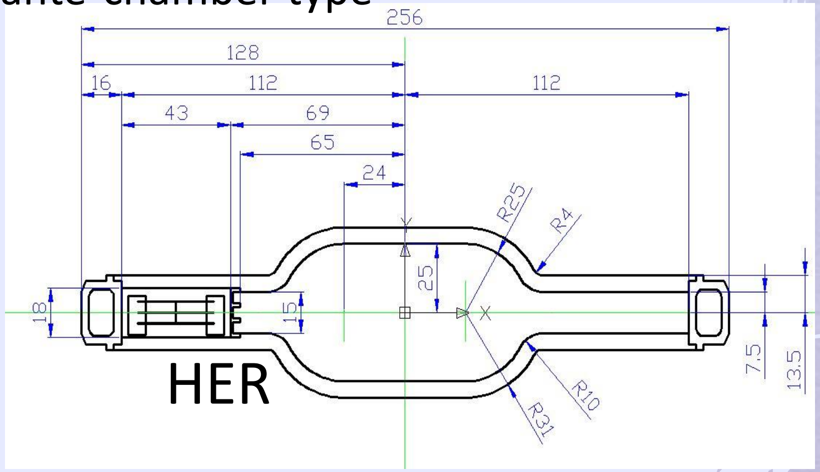
Features (compared to simple pipe):

- Low SR power density
- Low photoelectrons in beam pipe
- Low beam impedance
- Expensive



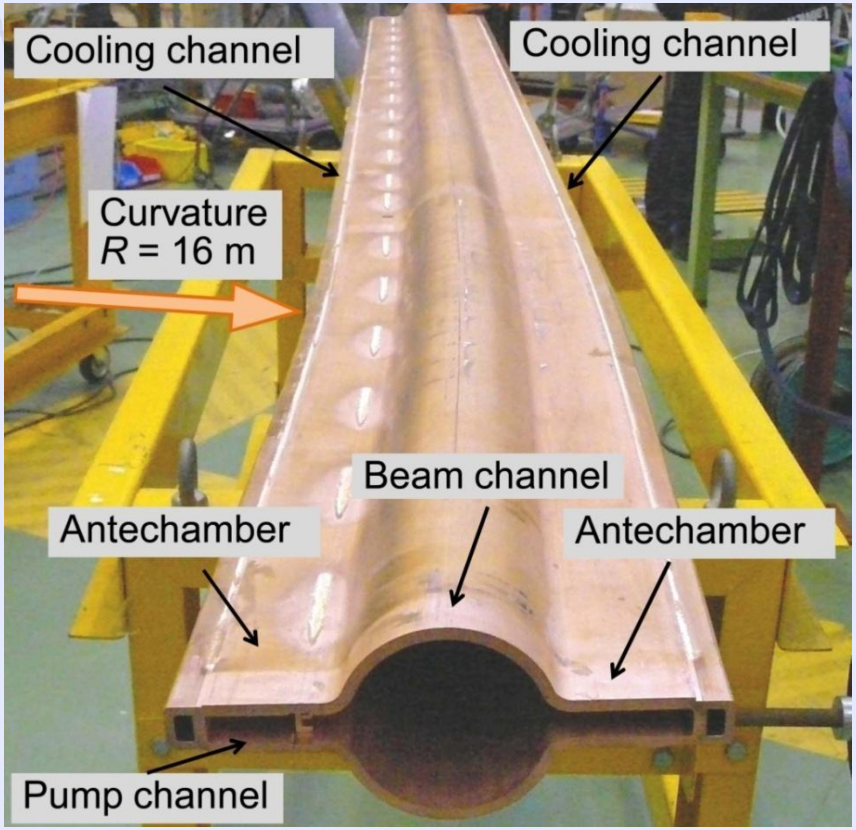
Some sections of KEKB LER have been replaced by ante-chamber type

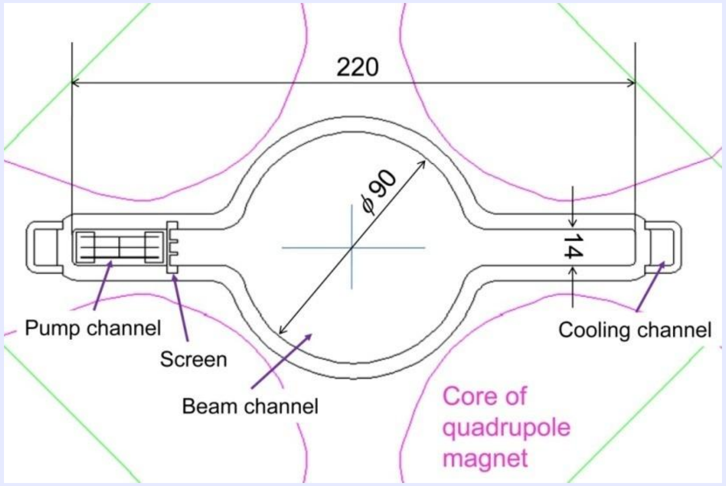


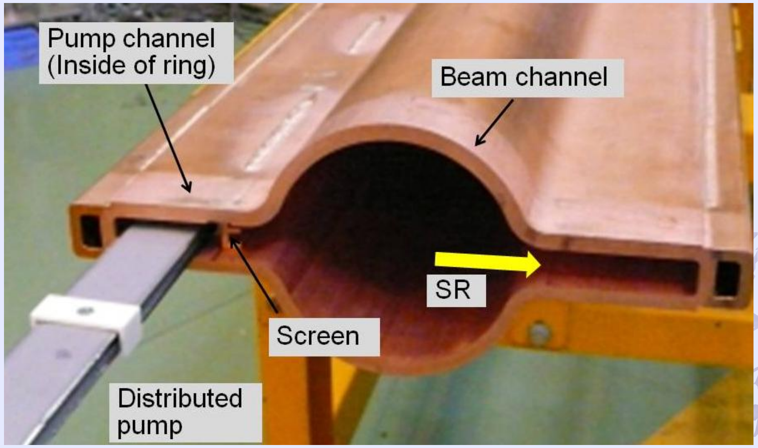


Trial model of a copper beam duct with ante-chambers for arc section

The duct is bent with a radius of 16 m







Y.Suetsugu

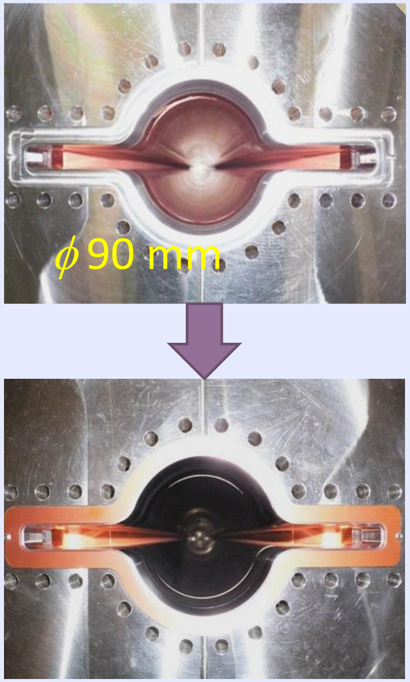
More on suppressing photoelectrons

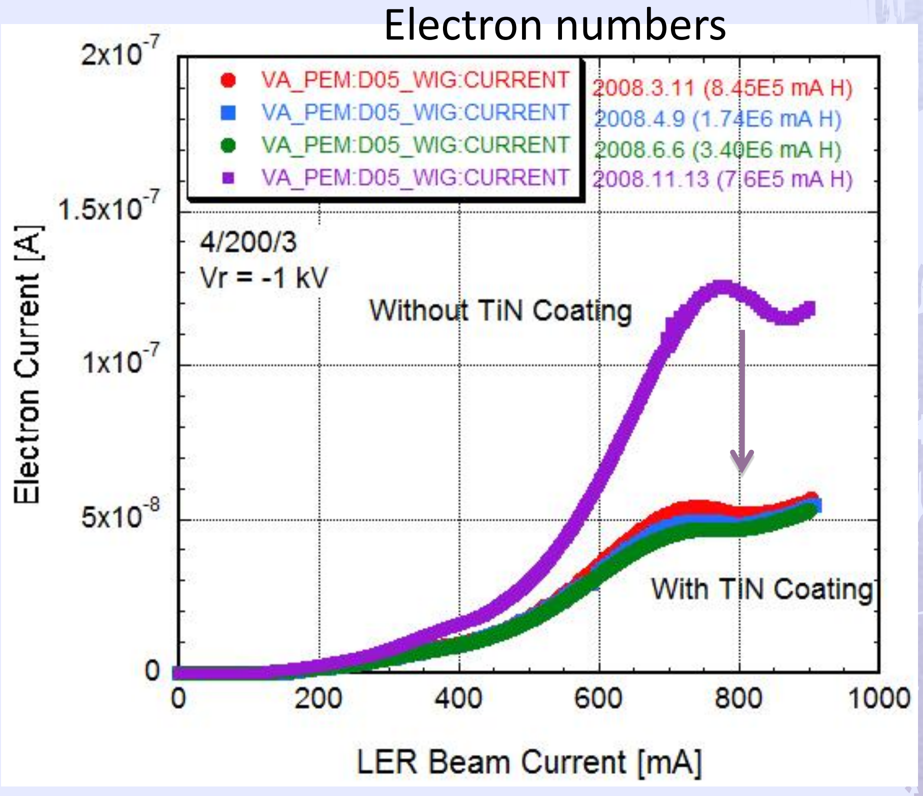
TiN (Titanium nitride) coating on inner surface

•Decrease secondary electron yield (SEY): Max. SEY ~0.9

•A test stand for the coating was built in KEK, and applied to a test duct with ante-chambers.

⇨Decrease of electrons at high current region was demonstrated.





Y.Suetsugu

And more on suppressing photoelectrons

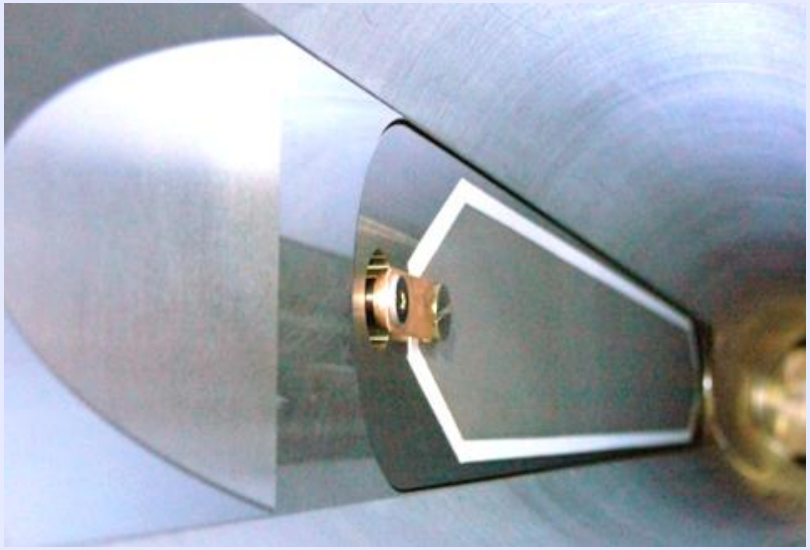
Clearing Electrode

- Can be used inside magnet, where solenoid fields are ineffective.

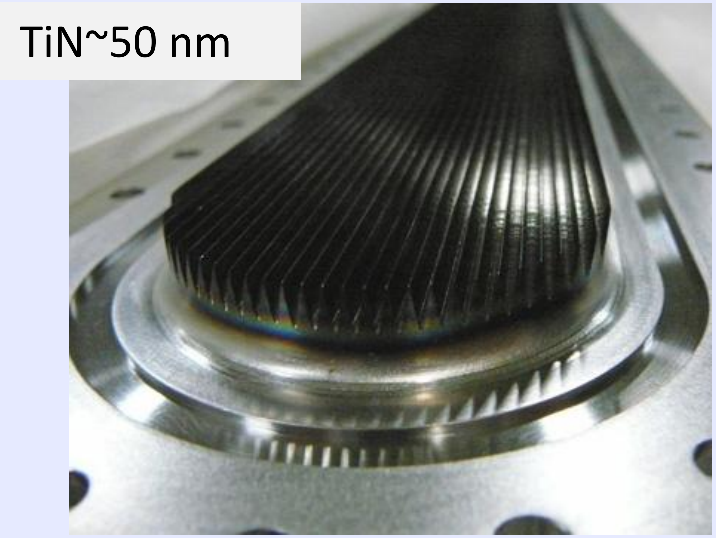
Grooved Surface (M. Pivi, SLAC)

- Can also be used inside magnet.
- Mechanically traps photoelectrons.

Clearing Electrode



Grooved Surface



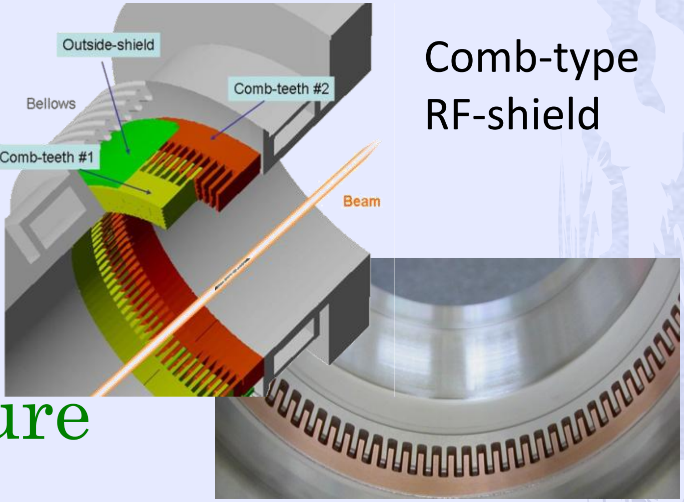
Effectiveness of both designs in reducing electron clouds has been demonstrated at KEKB LER.

R&D continuing in collaboration with Cornell (CesrTA) and SLAC.

Y.Suetsugu

For lower impedance: RF shielding

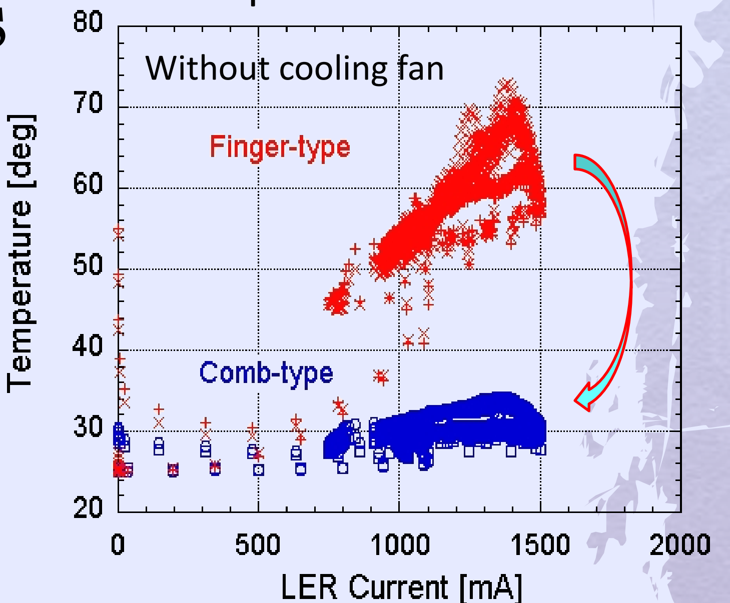
- Comb-type RF shield
- Features (compared to finger type):
  - Low beam impedance
  - High thermal strength
  - Applicable to complex aperture
  - Little flexibility (offset)



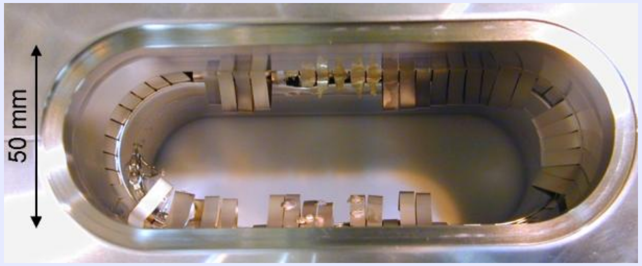
Comb-type RF-shield

- Effect of RF shielding was demonstrated in KEKB.

Temperature of bellows



- Finger-type as an option
  - If more flexibility is required.



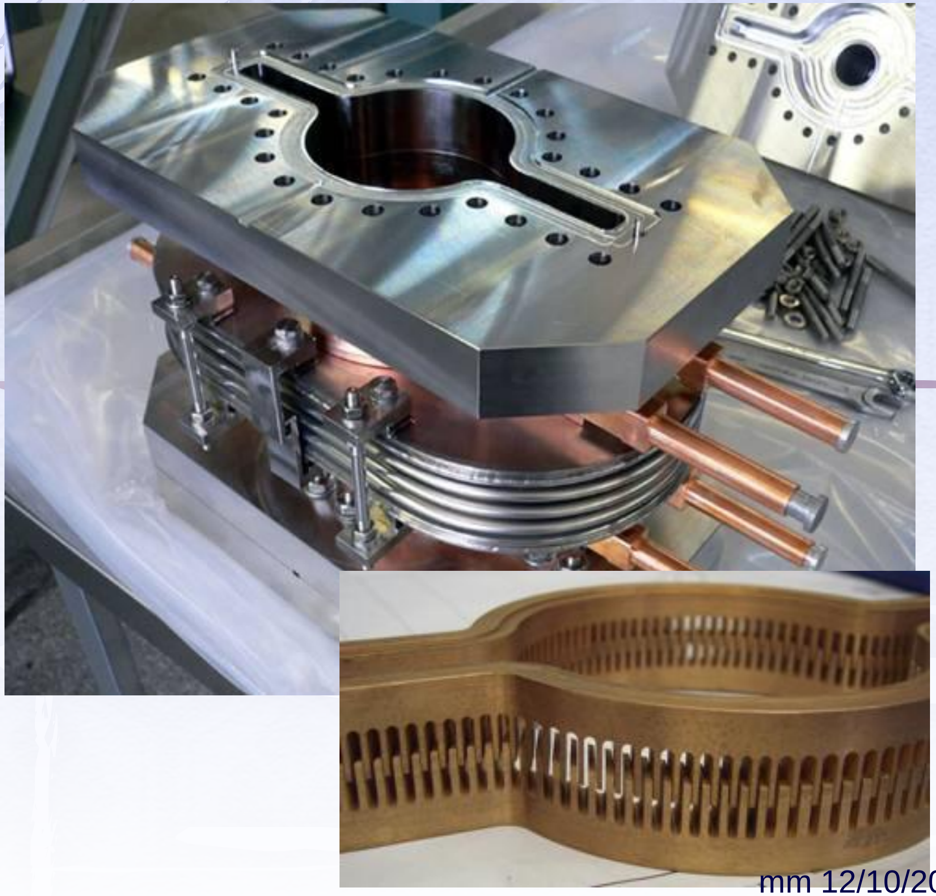
mm 12/10/2008

Y.Suetsugu

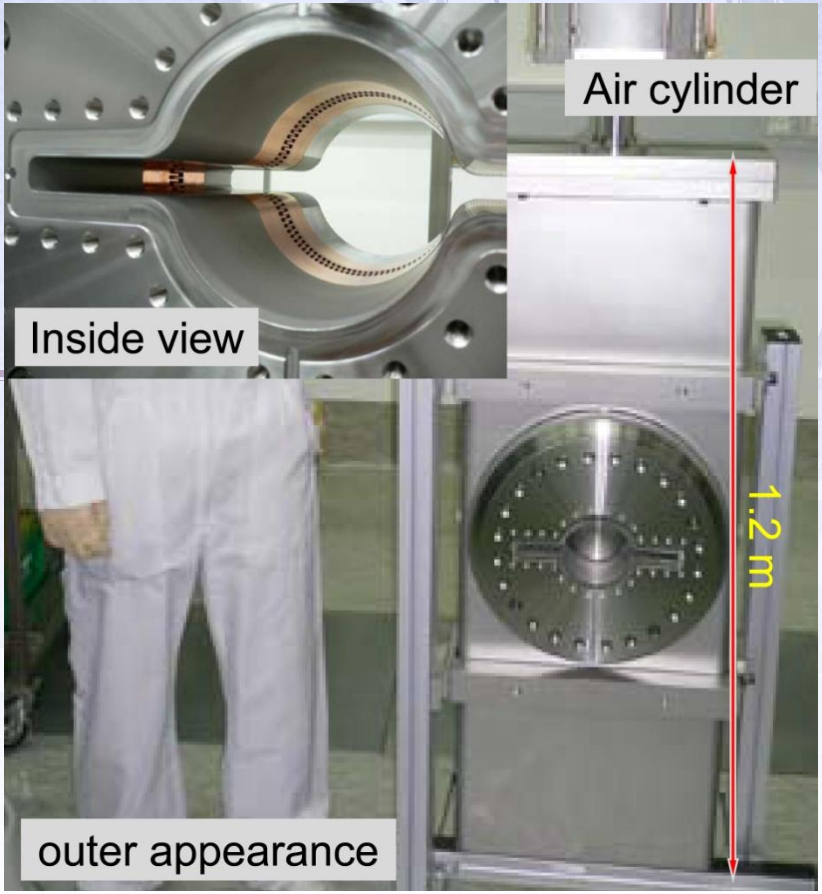
More for lower impedance: Bellows and gate valves

Comb-type RF shield is adaptable to a complicated aperture of beam duct with antechambers.

Bellows



Gate valve



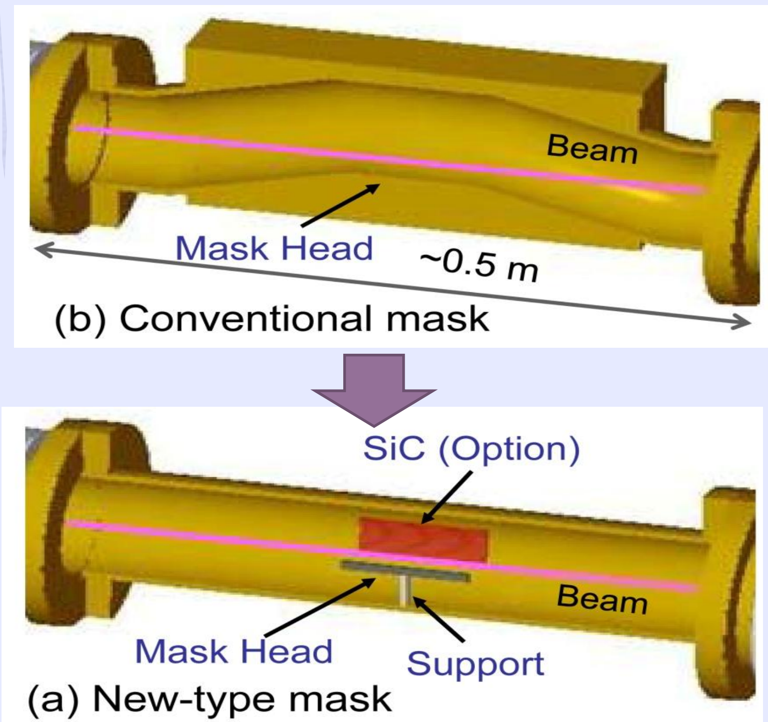
mm 12/10/2008

Y.Suetsugu et.al

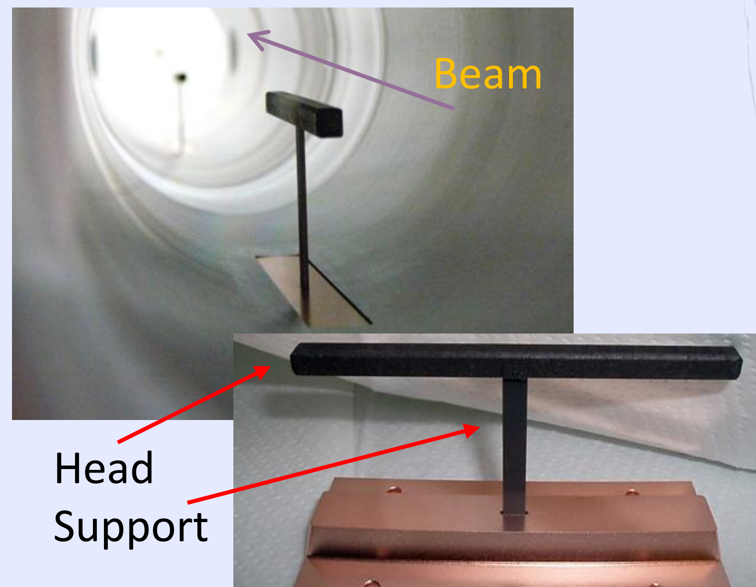
And more for lower impedance: Movable mask

Big impedance sources in the ring

- Planning to use “stealth” type (Ver.6)
- Low beam impedance
- Present Ver.4 ~ 1V/pC (ϕ 90 mm)→ 200 kW power loss
- Loss factor decreases to ~1/10 (ϕ 90 mm).
- Manageable by conventional HOM absorber

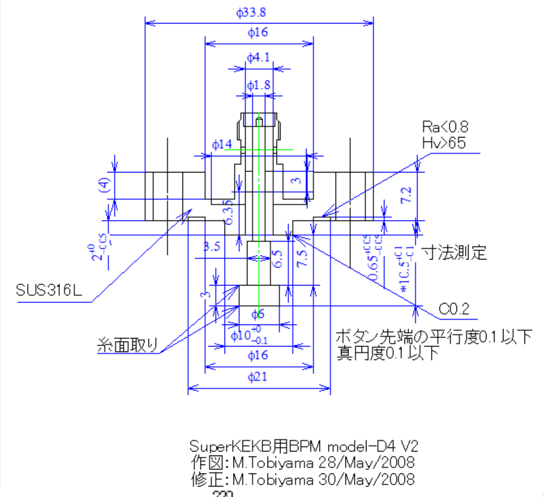


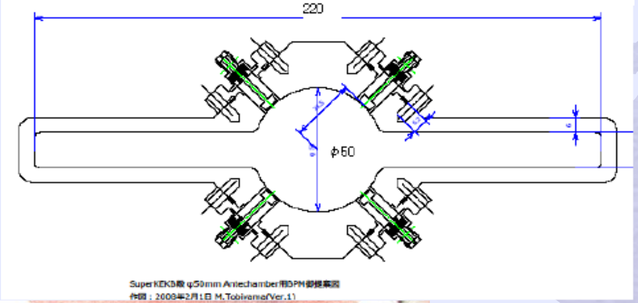
Head of Ver.6 (trial model)



Beam Instrumentation: Beam Position Monitors

- Electrodes redesigned for higher beam currents
  - 12 mm →6 mm diameter (may go to 9 mm for Nano-Beam Scheme)
- Have developed system for measuring and correcting offset of BPM relative to magnets.
  - Corrects for beam pipe flexing due to heating.
  - Already in use at KEKB.
- Single-pass readout electronics on some channels.
- High-speed readout being developed for fast orbit feedback.
  - Correct for floor vibrations

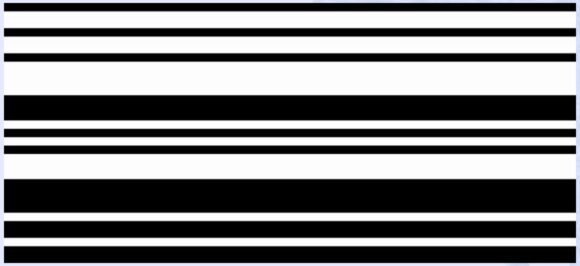




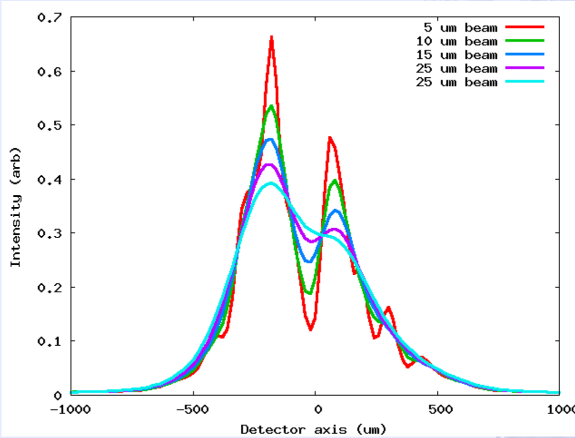
M. Tejima, H. Fukuma et al.

Beam Size Monitors

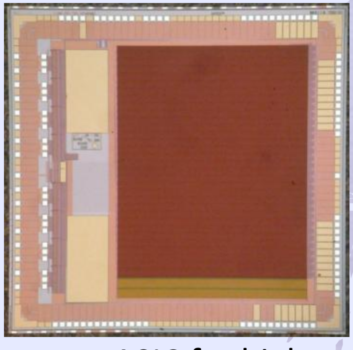
- **SR Interferometer**: Chamber redesign for high current.
- Working on design of low-distortion extraction mirrors.
  - Reduces beam image distortion at high currents.
  - Working on design of low-distortion mirrors.
- Strengthening foundation under optics huts, to reduce floor vibrations.
- Shift to lower measurement wavelength to measure nano-beam sizes (~30 um in LER, ~15 um in HER at SR source points).
- **X-ray monitor** being developed based on x-ray astronomy technique of Coded Aperture Imaging for high-bandwidth/high-speed readout with low beam current dependence. Critical for bunch-by-bunch measurements of low-emittance beams.
  - Collaboration with Cornell (CesrTA ILC damping ring study machine group) and U. Hawaii (Belle detector group).
  - Beam size measurements down to 15-20 μm demonstrated so far. Looks promising for SuperKEKB.



Uniformly Redundant Array (URA) for x-ray imaging being tested at CesrTA



Simulated detector response for various beam sizes at SuperKEKB HER



Prototype ASIC for high-speed readout (G. Varner).

Bunch-by-bunch Feedback system

●Transverse feedback similar to present design

→Target damping time 0.2ms

-Detection frequency 2.0→2.5 GHz.

-Transverse kicker needs work to handle higher currents

-Improved cooling, supports for kicker plates.

●Longitudinal feedback to handle ARES HOM & 0/π mode instability

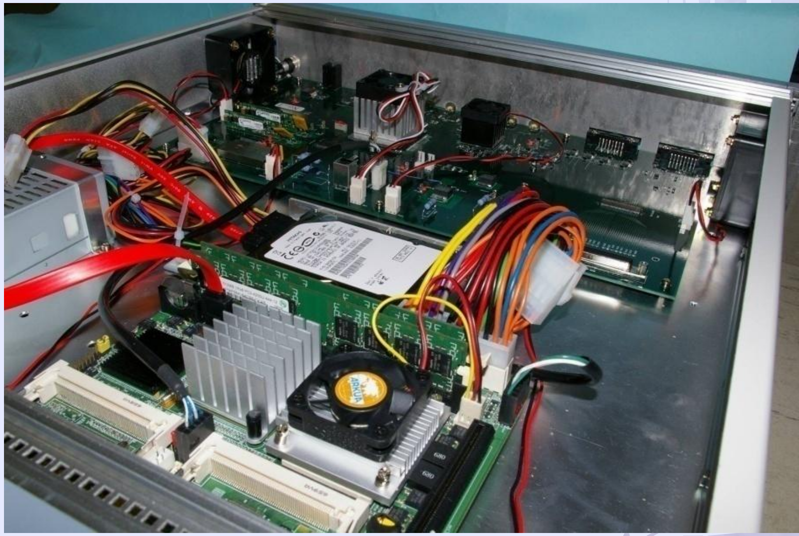
→Target damping time 1ms

-Use DAϕNE-type (low-Q cavity) kicker.

●Digital FIR and memory board to be replaced by new Gboard.

-Low noise, high speed (1.5 GHz), with custom filtering functions possible.

-Extensive beam diagnostics.



A prototype of the new bunch-by-bunch feedback system (G-board / Gproto) has been developed as a result of collaboration between SLAC, KEK and INFN, and successfully tested at KEKB, KEK ATF, KEK PF, SLAC, DAΦNE and CesrTA.

RF systems

Need RF systems which can store high beam currents and (for High-Current Option) handle shorter bunches.

ARES (normal-conducting cavity) for LER
ARES + SCC (Single-cell Superconducting cavity) for HER

Adopt the same RF frequency as KEKB and use the existing RF system as much as possible, with improvements as necessary to meet the requirements for SuperKEKB.

→Construction cost is greatly reduced.
→Technical uncertainties are relatively small.

Double number of klystrons -> one per cavity
For nano-beam scheme, the current number of cavities can be maintained.

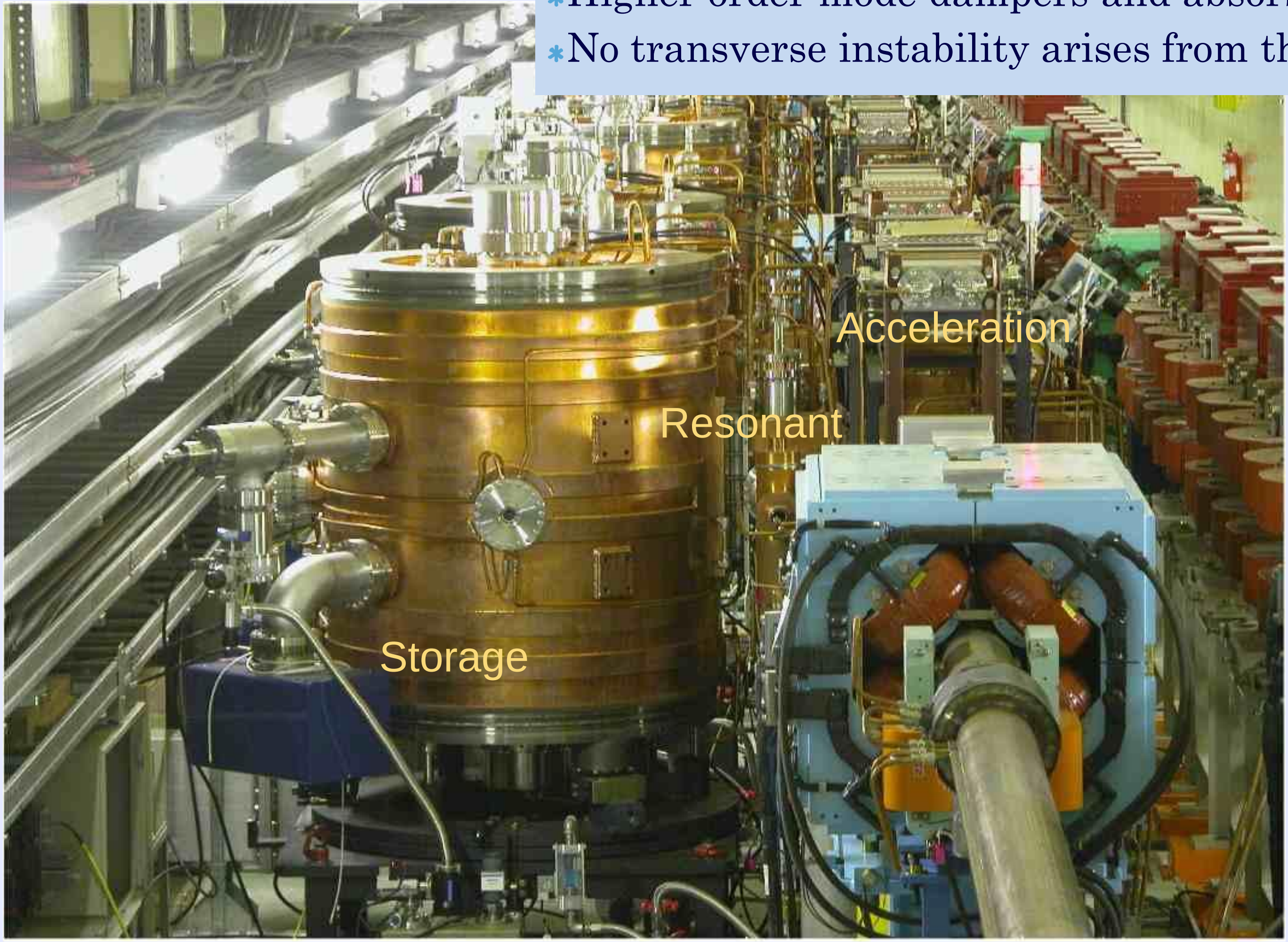
Input coupler improvements.

Akai et.al

The ARES Cavity

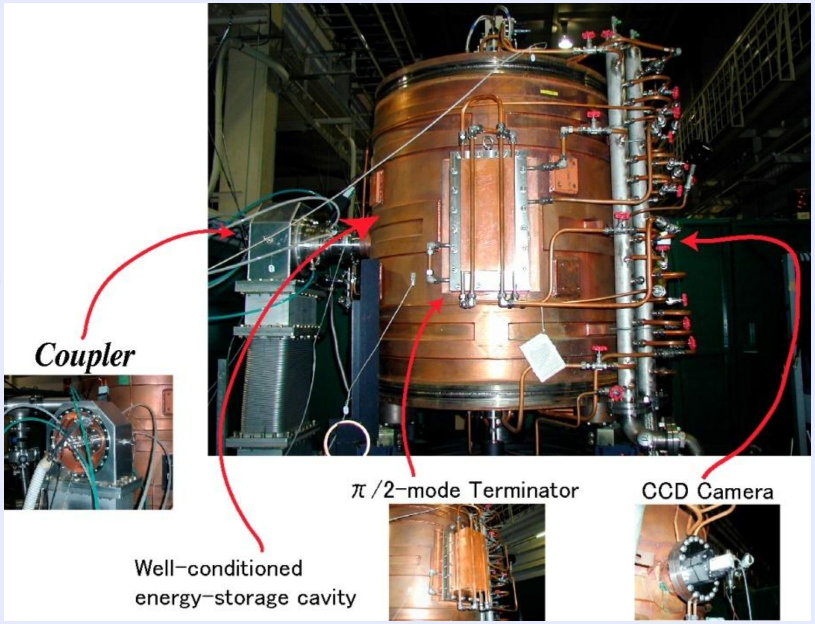
Accelerator Resonantly-coupled Energy Storage

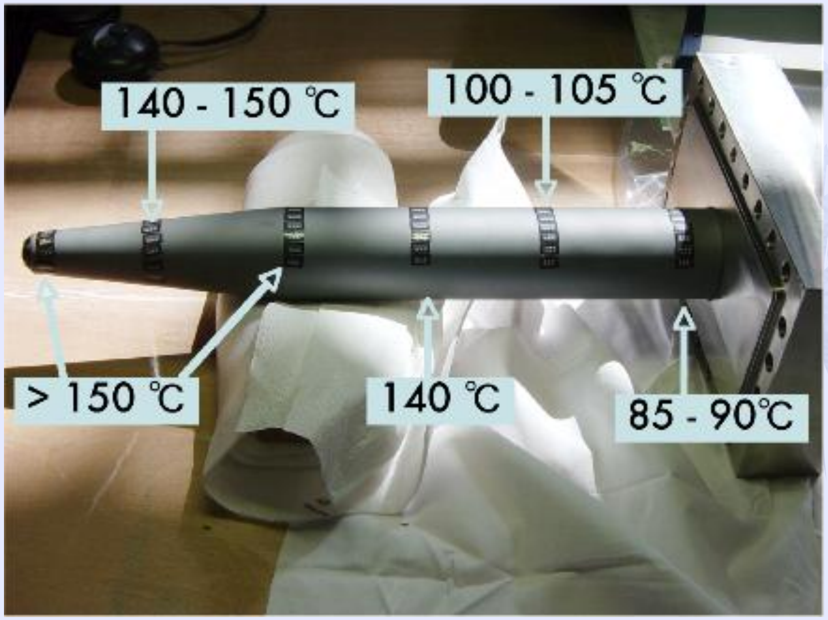
- Passive stabilization with huge stored energy.
- Eliminate unnecessary modes by coupling of 3 cavities.
- Higher order mode dampers and absorbers.
- No transverse instability arises from the cavities.



T. Kageyama, et al

High power RF R&D





- Higher HOM power

  Upgrade of HOM damper

- Higher input RF power

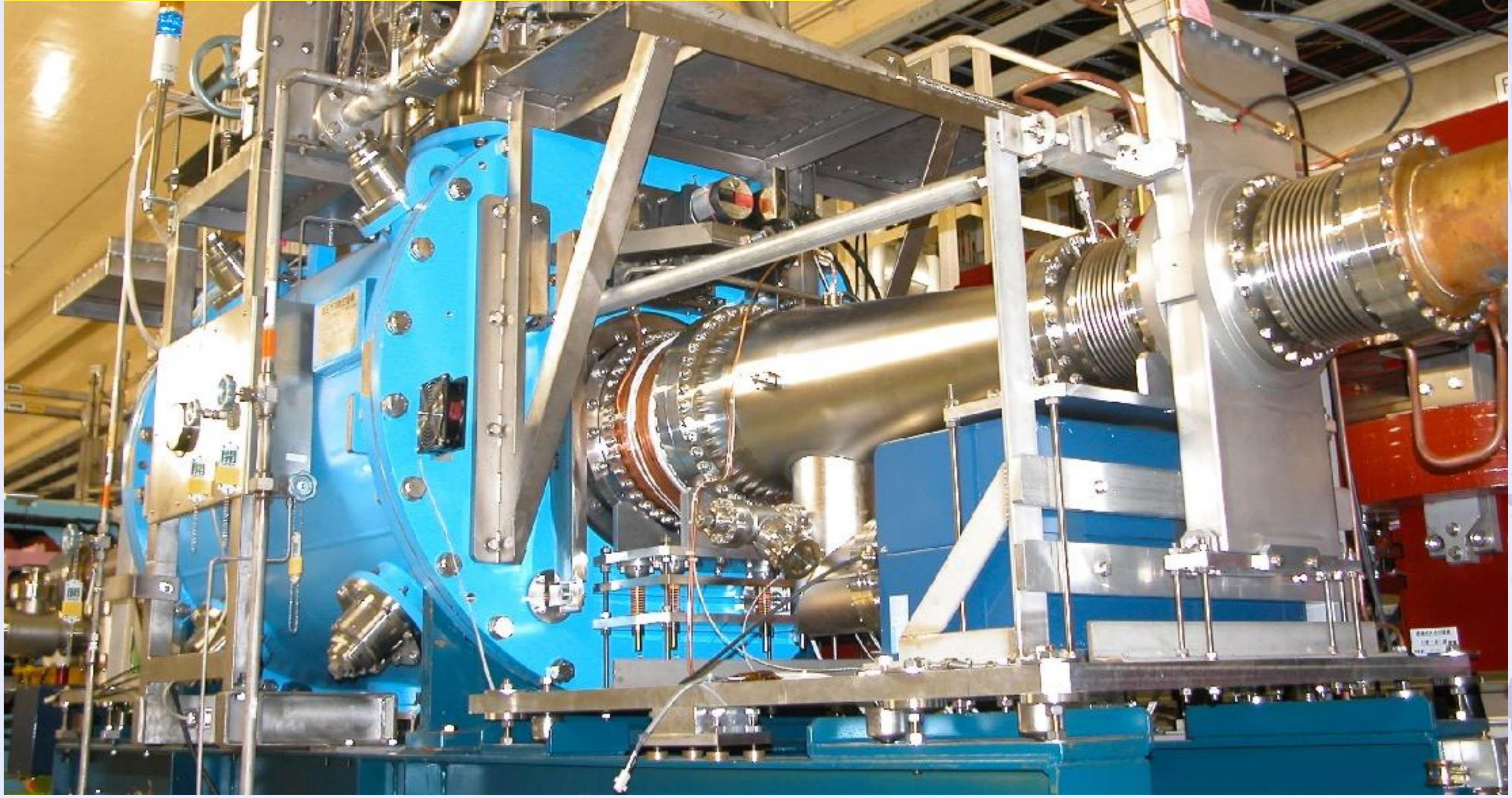
  400 kW/cavity -> 800 kW/cavity

  R&D of input coupler using new test-stand.

Y. Takeuchi, T. Kageyama, et al

Superconducting Cavity

SuperKEKB challenges:
The expected power load to the HOM absorber is 50 kW/cavity at 4.1 .
HOM damper upgrade needed for High-Current Option.



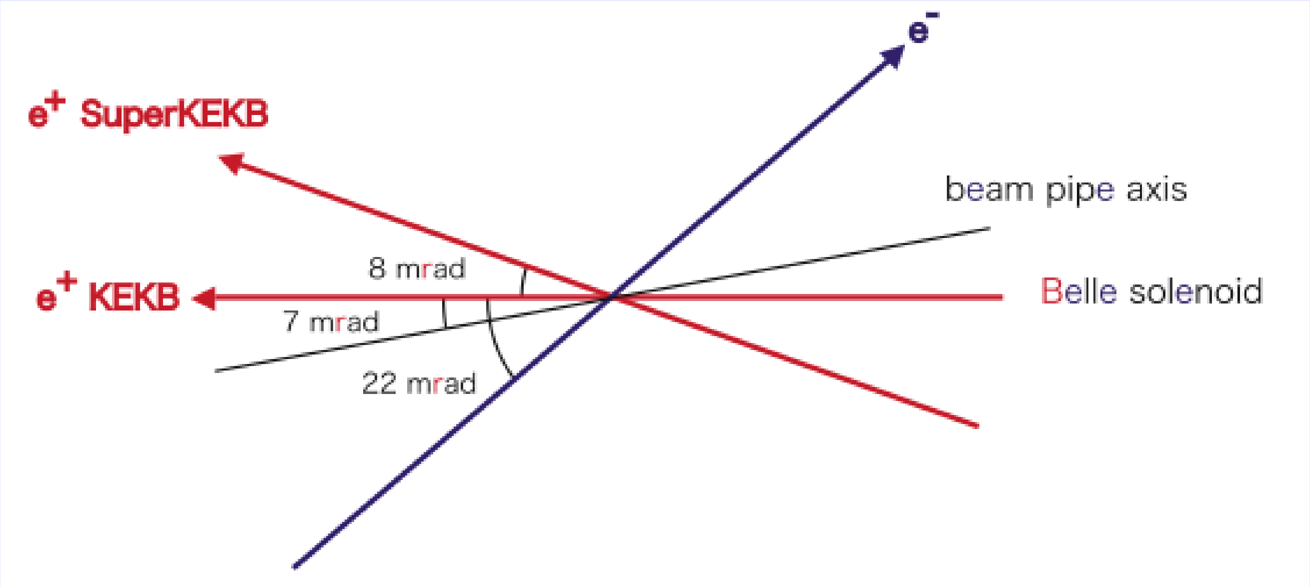
S. Mitsunobu, et al

Crab cavity with 10 A beam

- The original cavity is designed for 1-2 A beam
  - Simple structure, suitable for SC → High kick voltage is obtained by one cavity.
  - Sufficient damping of parasitic modes.
  - Not necessarily optimized for a 10 A beam.
- Possible problems at 10 A
  - Large HOM power (200 kW)
    - Loss factor is not very small, because the radius of coaxial beam pipe can not be widely opened.
    - Additional loss factor comes from the absorber on wide beam pipe.
  - Much heavier damping of HOM's may be needed, particularly for horizontal polarization of transverse modes (large β_x at crab).
- A new crab cavity has been designed, which can be used at 10 A.

For smaller β^*

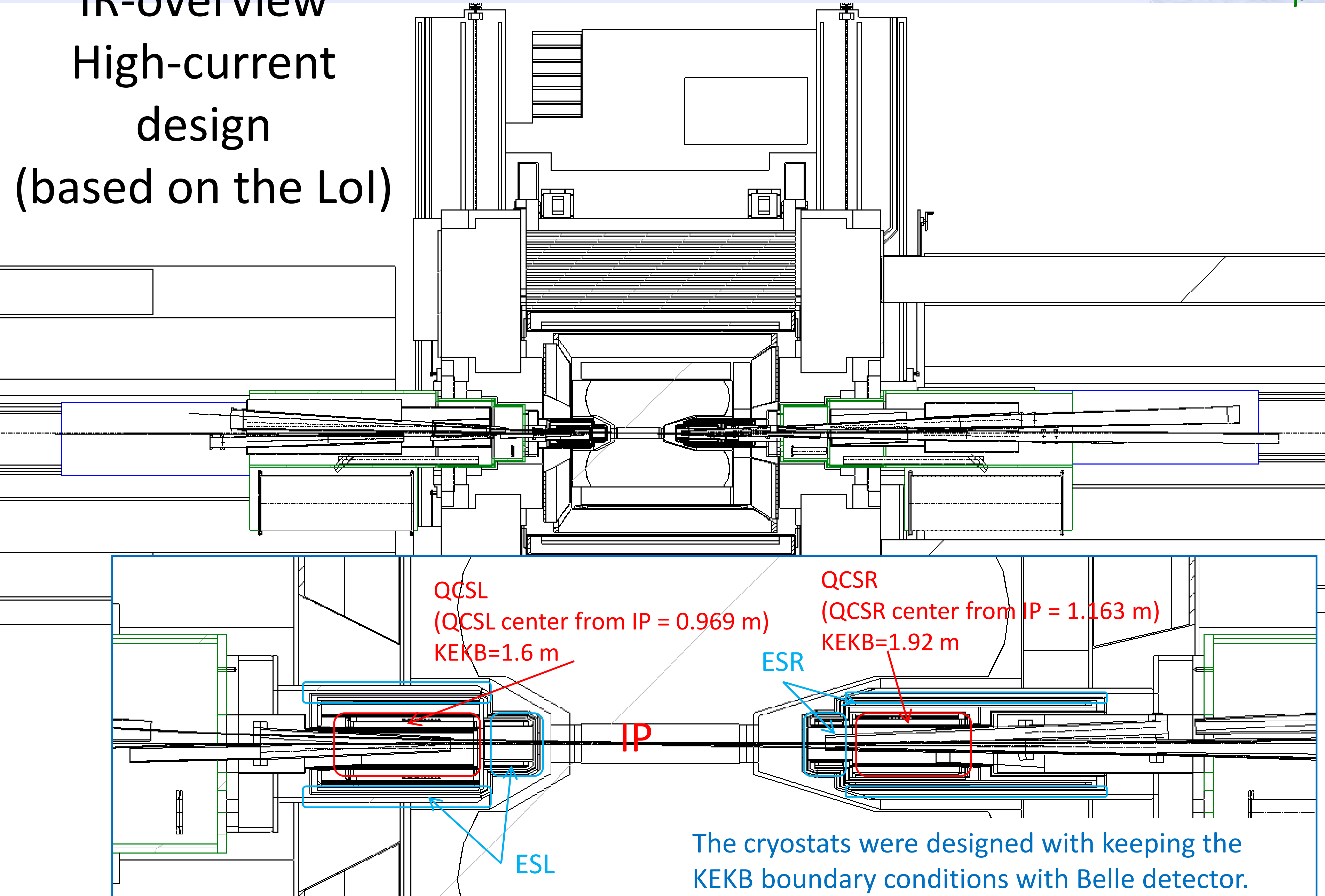
High-Current Option
IR layout



- Crossing angle: 22⇨30 mrad
- Move final focus quadrupoles closer to IP for lower beta functions at IP.
- Preserve current machine-detector boundary.
- QCS and solenoid compensation magnets overlap in SuperKEKB.

IR-overview High-current design (based on the LoI)

For smaller β^*

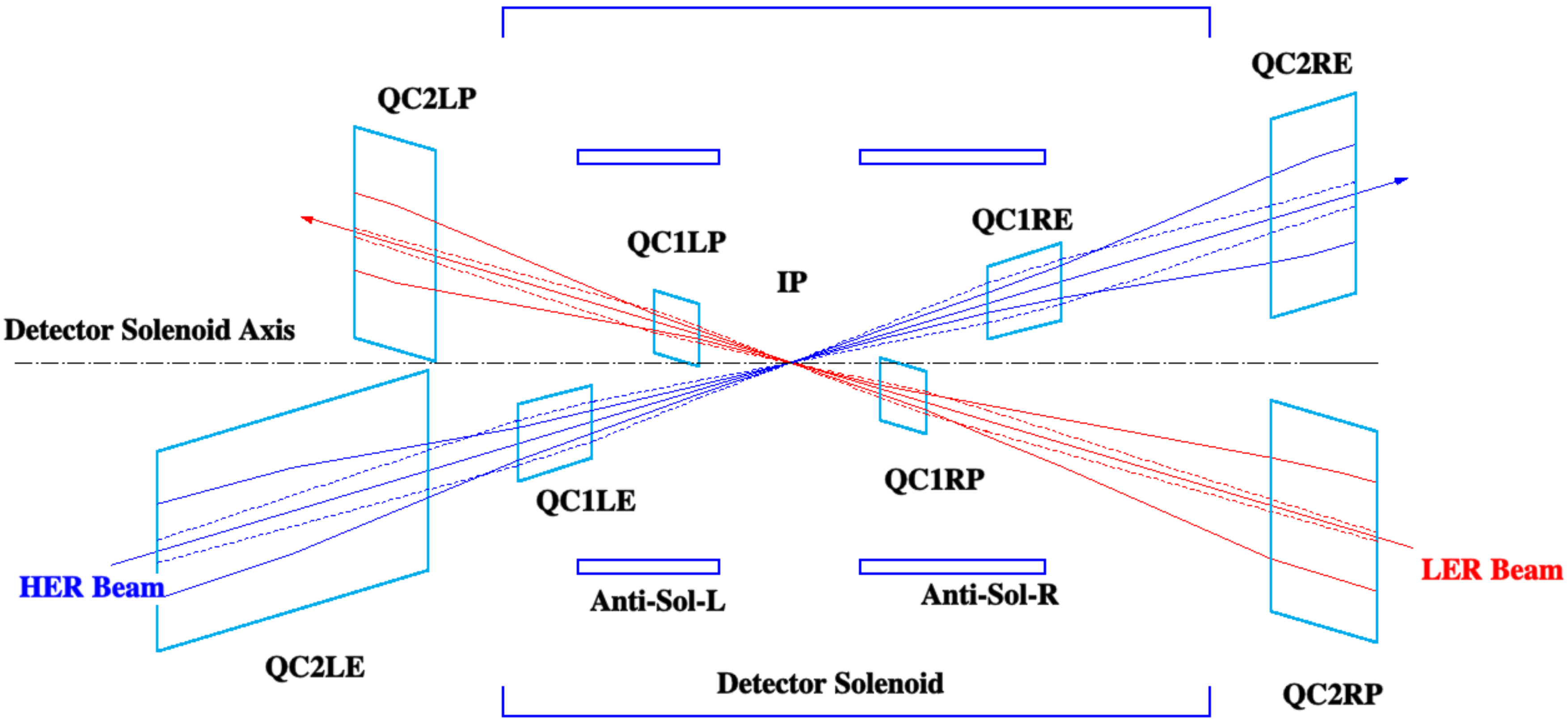


The cryostats were designed with keeping the KEKB boundary conditions with Belle detector.

N.Ohuchi

Nano-Beam Scheme IR Design:
60 mrad crossing angle & independent quads

Preliminary



N. Ohuchi

Design of superconducting final quad for Nano-LER

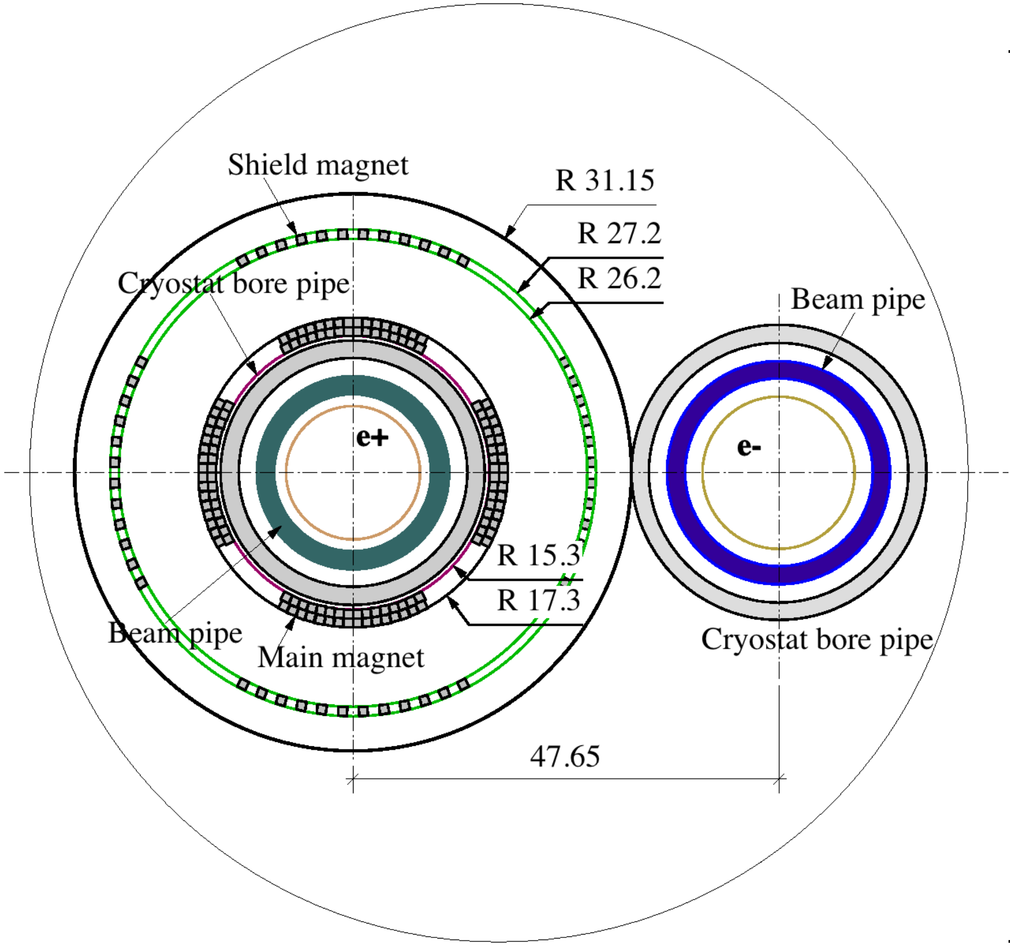


Figure 2: Cross section of QC1RP in the front end
Active shield quadrupole (corn type)

Table: Magnet parameters for QC1RP

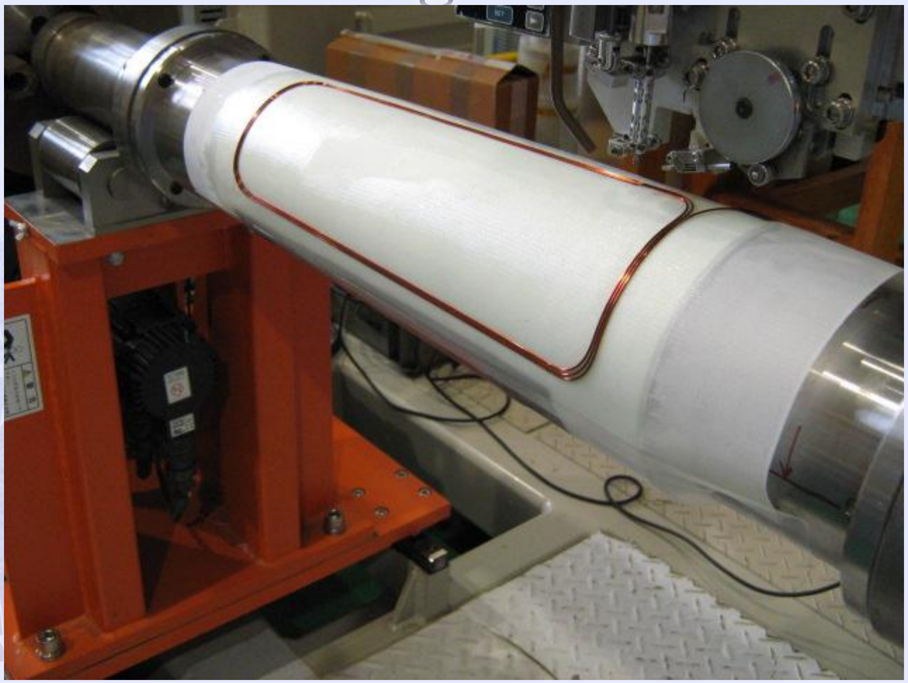
Main Coil	Two layers
Inner radius (front/rear end)	15.3 mm/16.97 mm
Outer radius (front/rear end)	17.3 mm/18.97 mm
Turn number/pole	16
Shield Coil	One layer
Inner radius (front/rear end)	26.2 mm/29.05 mm
Outer radius (front/rear end)	27.2 mm/30.05 mm
Turn number/pole	6
Magnet as QC1RP	
S.C. cable / cable size	NbTi/1mm × 1mm
S.C. cable Cu ratio	1.2
Operation current	1288.6A
Field gradient (front/rear end)	88.35 T/m/72.95 T/m
Effective magnetic length	0.2238 m
Maximum field in the coil	1.43 T
Operation temperature	4.4 K

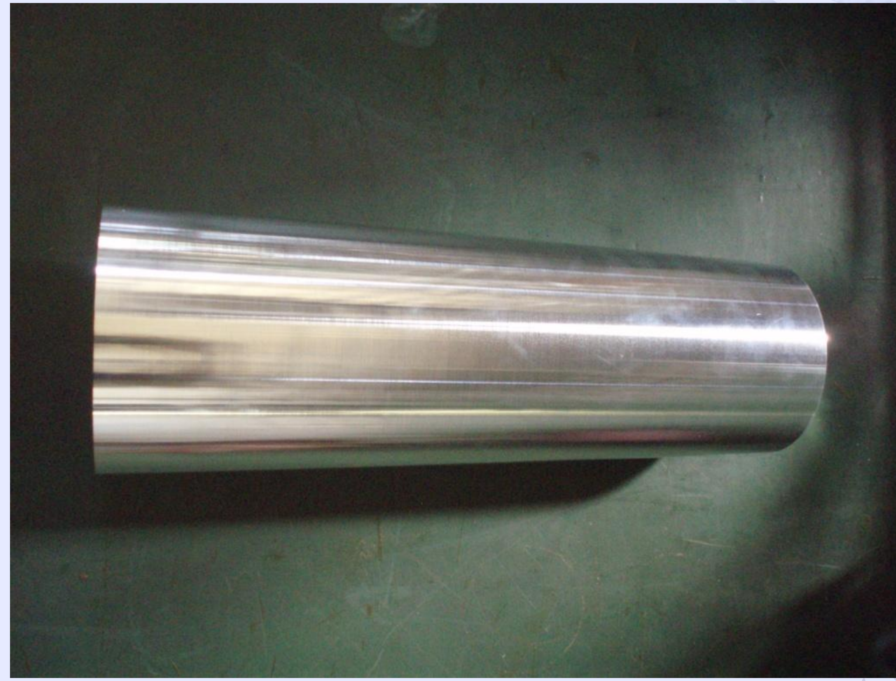
N. Ohuchi

Preliminary

IR magnets (QC1&QC2) : R&D on coil winding

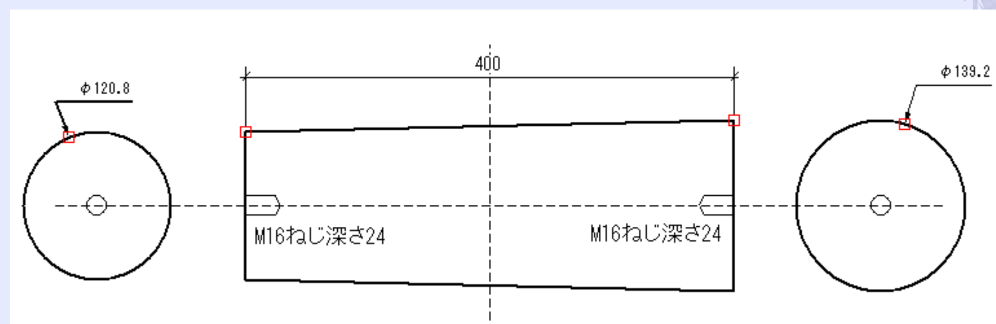
For smaller β^*





Coil winding on a cone shaped bobbin

R&D work required for a winding tool



N.Ohuchi

IR magnets (QCS R&D) : Field measurement results

For smaller β^*

Field gradient at 1186.7A

G=40.05 T/m was obtained (Design *G*=40.124T/m)

Multipoles

Data at r=48mm

•a_3= -0.86 units, b_3= 0.91 units

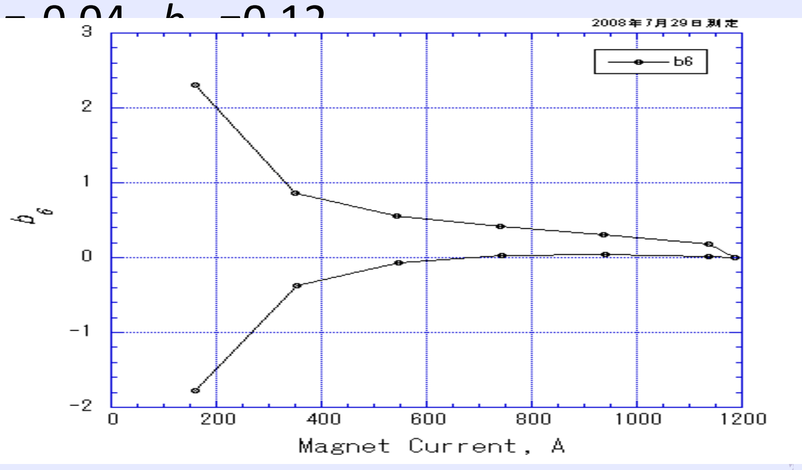
•a_4= -1.27 units, b_4= 0.40 units

•a_5= 0.11 units, b_5= -0.80 units

•a_6= -0.55 units, b_6= -0.00 units （I units = $10^{-4} \times b_2$）

Design at R_{ref} = 50 mm

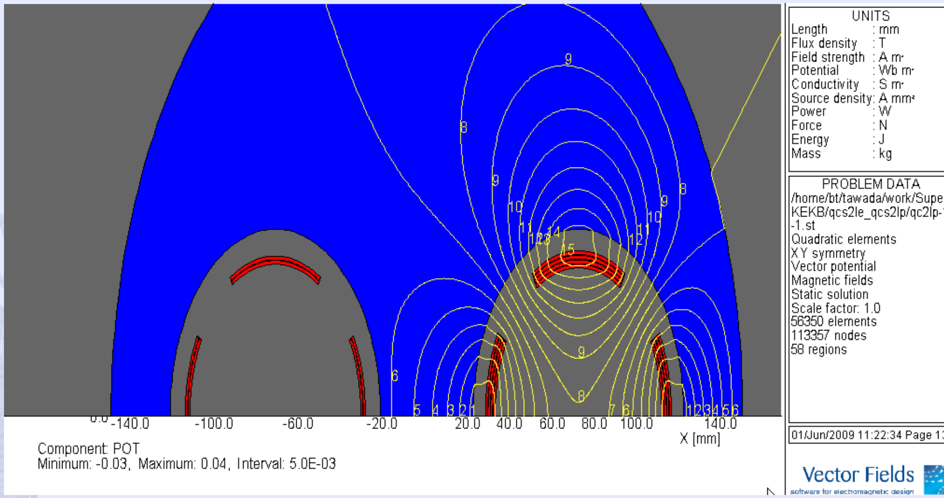
•b_6=0.12, b_{10}

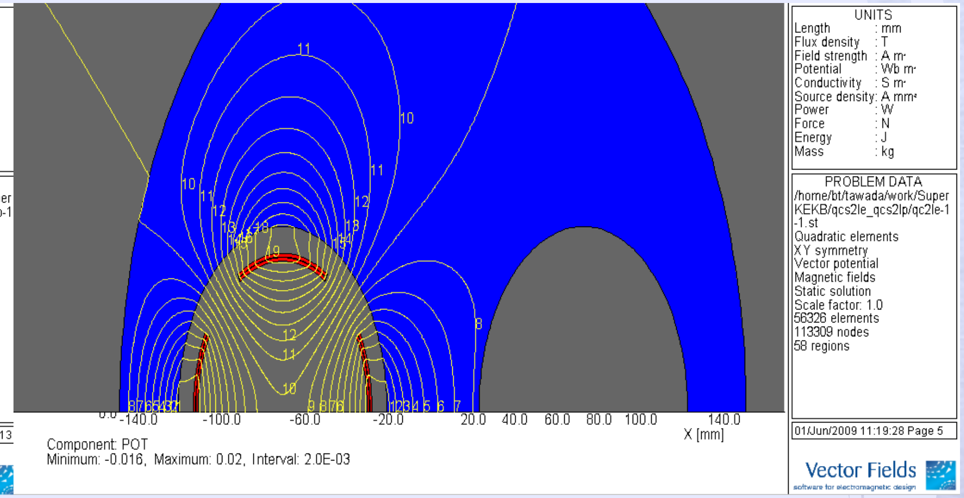


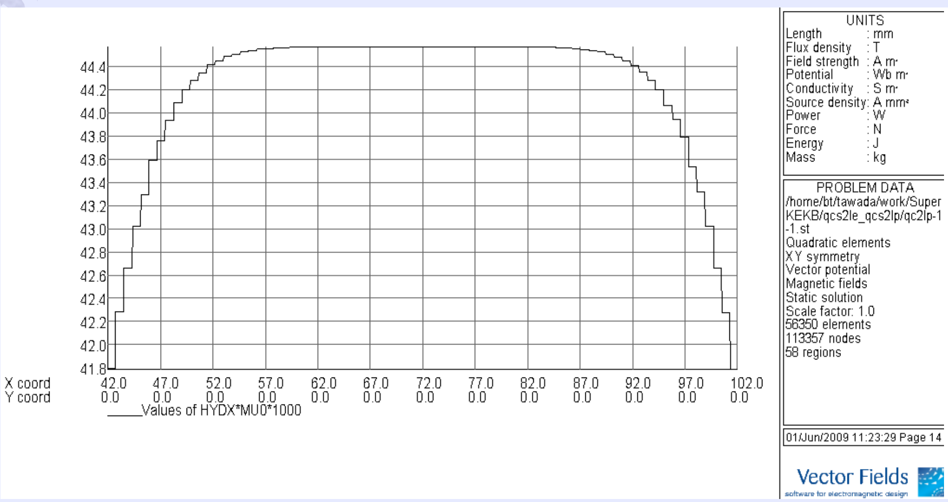
N.Ohuchi

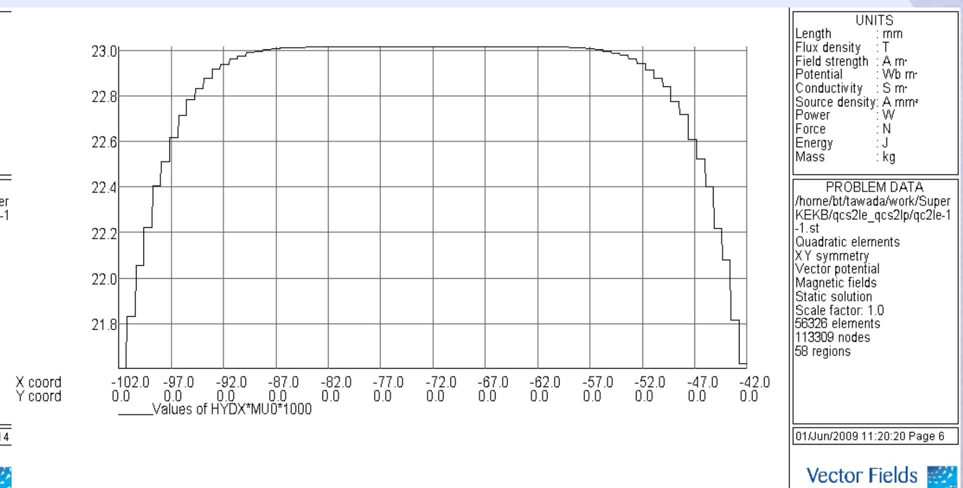
QCS2LP

QCS2LE





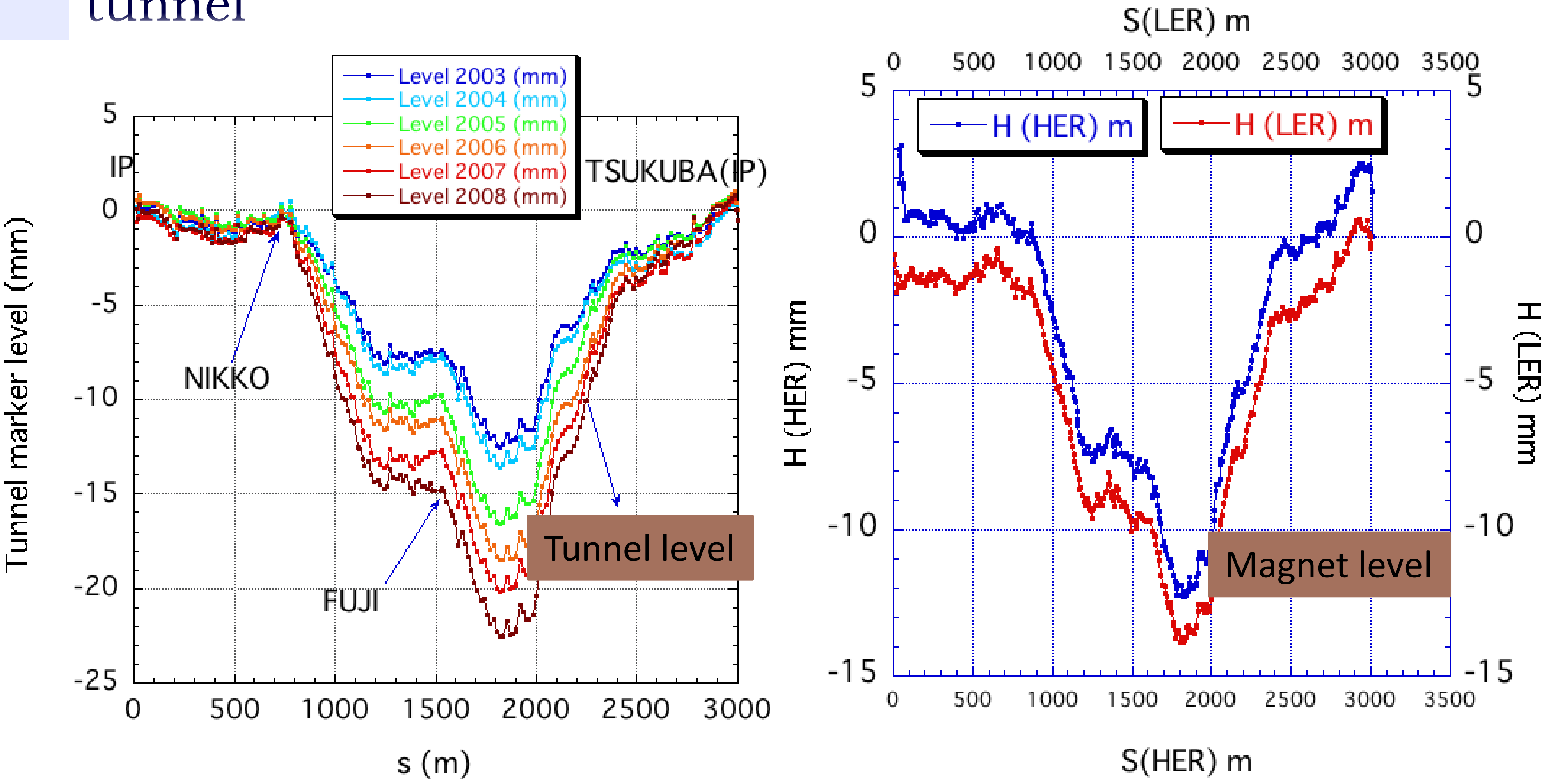




M. Tawada

Better magnet alignment
For higher ξ_y

KEKB tunnel continues to sink and magnets follow the tunnel



Measurement data were used as alignment errors and simulation was done by Ohnishi.
No need for leveling the tunnel but local ups and downs better be corrected.
We also found that the magnets are rotated, horizontal position moved and so on…

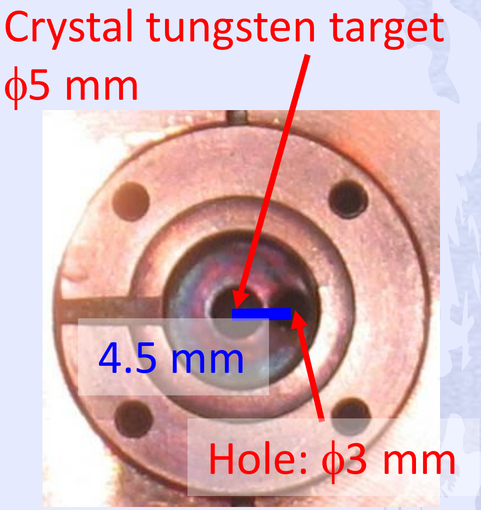
Injector upgrade

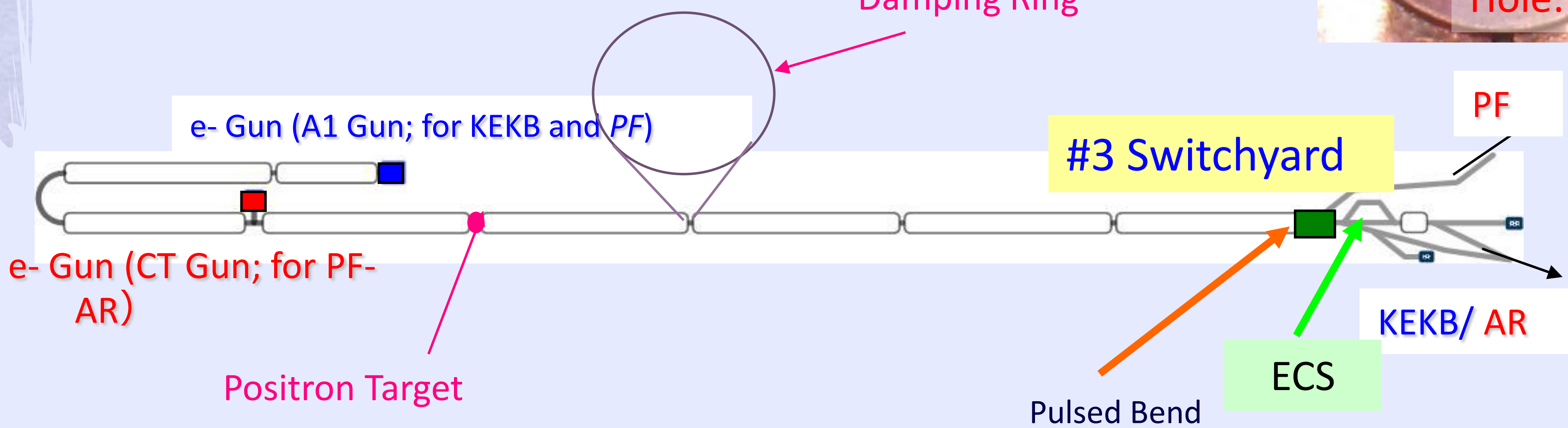
Simultaneous (pulse-by-pulse) injection of KEKB LER/HER/PF

Damping Ring

Simultaneous injection of e^- and e^+ is desirable in view of thermal stability of components and an ability of the operation with shorter beam lifetime.

Fast beam switch between KEKB e^-, PF e^- and KEKB e^+ by using an e^+ target with a hole in it, and pulsed steering magnets.

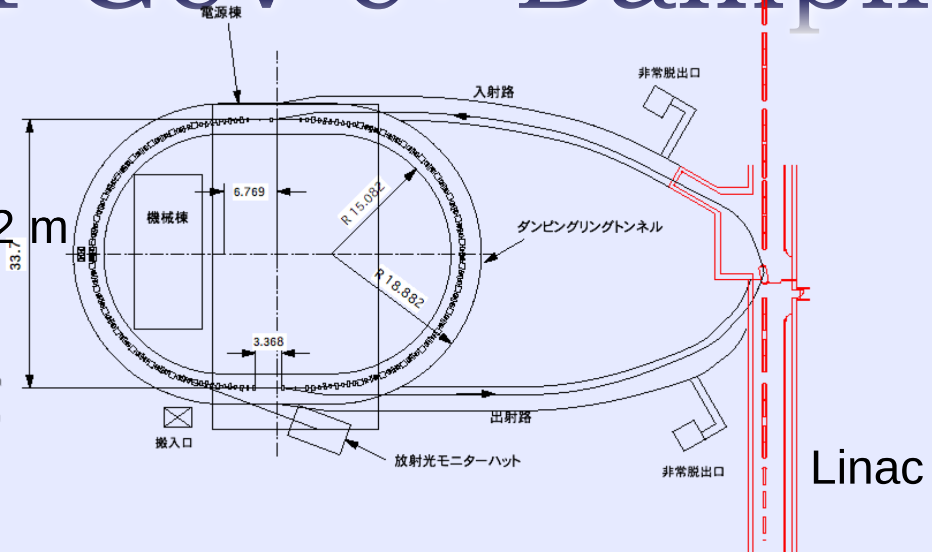




Damping Ring needed for injection into reduced dynamic aperture. Lattice design is based on FODO cells with alternating sign bends, for large dynamic aperture with low momentum compaction factor and accelerating voltage.

M. Kikuchi

1 GeV e+ Damping Ring

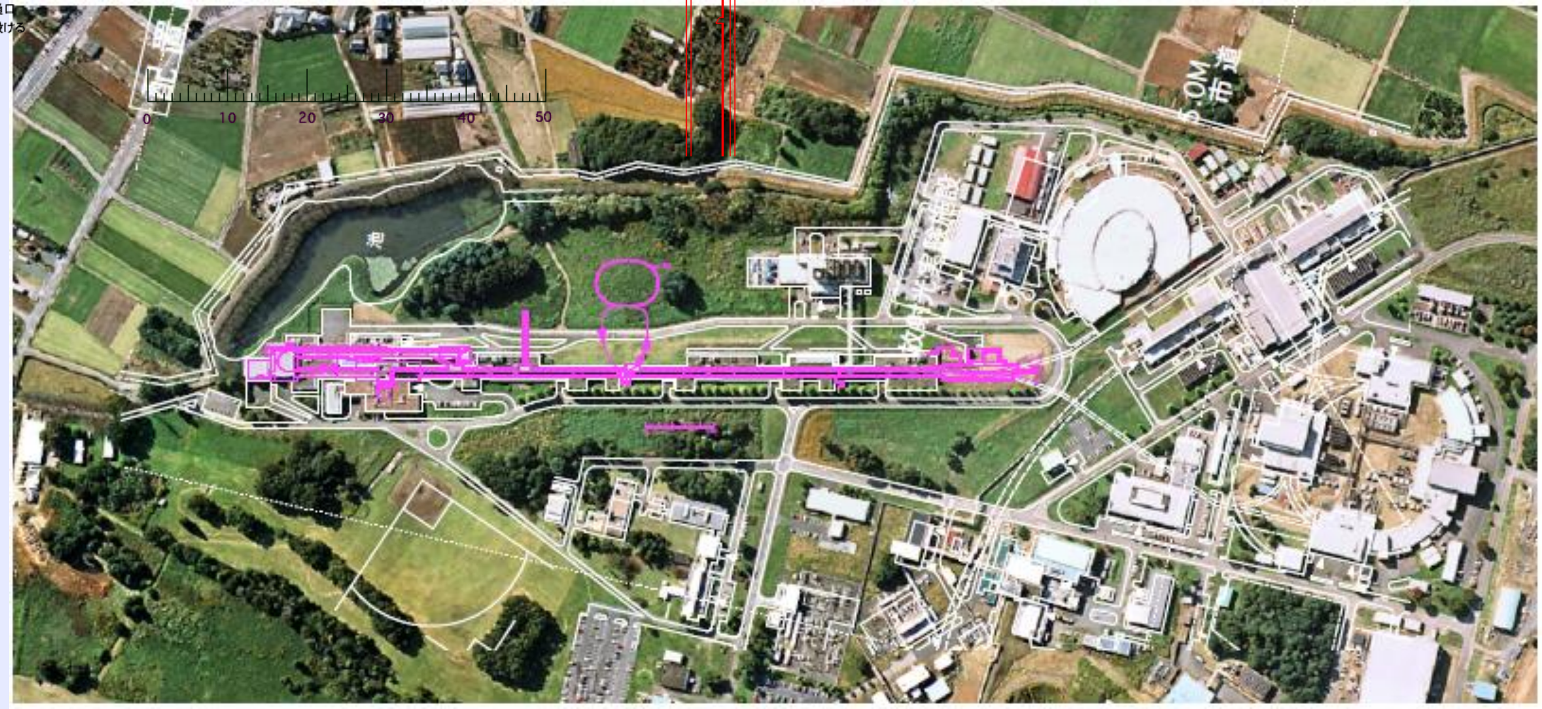


陽電子用ダンピングリングトンネル構造

1. リング部全長 132 m
    1.1 内空断面(標準部) W 3.8 m H 2.7 m
2. BT部全長 136 m
    2.1 内空断面(標準部) W 3.5 m H 2.7 m

3. 要求性能
    3.1 ビームレベル FL+1.2 m
    3.2 インストール: エアパレット搬送
    3.3 空調性能: 25℃±1℃
    3.4 冷却水性能:往 30℃ 復 ℃

4. その他考慮すべき点など
    4.1 Linacとの接続部の構造; ビーム及びケーブル貫通口
    4.2 直線部に導波管用貫通口及びケーブル貫通口を設ける
    4.3 放射光モニターハット(7×4m2)を
      ビームラインと同一レベルに設ける(耐振構造)
    4.4 機器搬入口 1箇所
    4.5 非常脱出口合計3箇所
    4.6 土盛り上部は周辺監視区域
    4.7 エレベータを設置する



N. Iida, KEKB Review (2009)

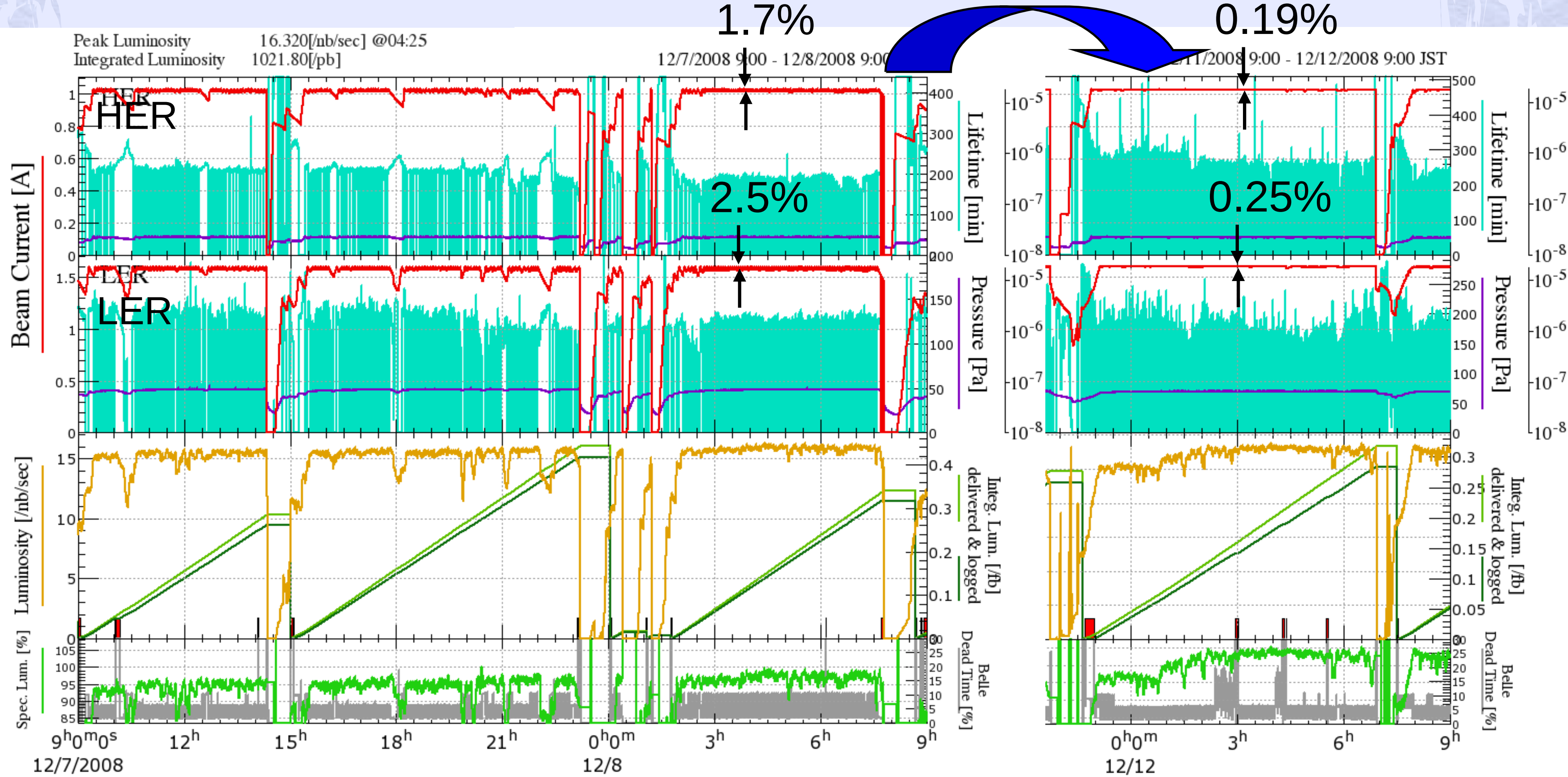
"Simultaneous Injections"

1. PF/HER injection — Achieved!
   - Fast switching beam injection
     - Switching time ~ 2 sec.
     - Used in operation (Oct./2007 ~ 10/Dec./2008)
   - Pulse-to-pulse switching
     - Conditional test injection was succeeded.
2. HER/LER injection
   - Fast alternating beam injection
     - Switching time = 2 sec.
     - Used in operation (11 ~ 25/Dec./2008)
3. HER/LER Pulse-to-pulse switching injection
   - Planned to be done in Apr./2009 ←DONE
4. PF/HER/LER Pulse-to-pulse switching injection
   - Planned to be done in Oct./2009

N. Iida, KEKB Review (2009)

HER/LER Fast Alternating Beam Injection

- In 12/Nov/2008 HER/LER could be successfully switched in 2 sec.
- The injection ratio is good as usual.
- The beam current variations are one order decreased in both rings.
- Quality of luminosity tuning is much improved.
- Time for luminosity tuning cycle has speeded up.



Design Status

- **High-Current Option** has been extensively studied, including R&D on high-current components.
  - CSR will present a serious impact on performance, which can be partially mitigated by travelling waist scheme and more aggressive tune settings.
  - Crab cavity performance still under study.
    - Tuning with new skew sextupoles underway.
- **Nano-Beam Scheme** also been under consideration in parallel.
  - Initially thought to be more difficult, but demonstration of high-speed orbit feedback and low-emittance tuning techniques at other machines (light sources, ILC study machines) suggest that this issue may be tractable. (Note: ILC will face similar issues.)
  - Many points of commonality with High-Current Option.
  - Lower beam currents → reduced operating cost
- **Nano-beam Scheme** is now the basis for the SuperKEKB upgrade plan.

Hardware Considerations with Nano-Beam Scheme

Design Item	Purpose	Issues
Interaction Region	•Squeeze β functions at the IP, less than 1/10 of the present KEKB, to achieve nano-beam collision.	•Reduction of the dynamical / physical aperture. •Needs strong superconducting final quadrupoles, combined with permanent magnets. •Special beam pipes. •Good excavation of synchrotron light to avoid detector background. •Procedure to assemble such components together with the detector.
Ring Lattice	Achieve 1 nm equilibrium emittance with sufficient dynamic aperture, matching to the IR optics.	•Replace arc dipoles in the LER. •Add 60% more dipoles, quads, and sexts in the HER arc. •Rearrangement of Tsukuba straight section is necessary to install local chromaticity correction, while keeping the existing tunnel boundary.

K. Oide

Hardware Considerations with Nano-Beam Scheme

Design Item	Purpose	Issues
Damping Ring & Positron Source	•Damp the emittance of the injecting beams to match the small acceptance of the ring. •Increase positron production as the beam lifetime will be short.	•Both e+ and e- need damping rings. •Choices of the positron target: a flux concentrator or a superconducting solenoid. •Construction while keeping Linac in operation for Photon Factory rings.
Beam Pipes	•Suppress e-cloud in the LER. •Capability for higher currents in both rings.	•Choice of e-cloud suppression techniques in dipoles: clearing electrode or groove. •HER needs new pipes as the arc lattice is changed to low emittance.
Beam Diagnostics & Feedback	Maintain collision of nano-beams as well as good x-y coupling, small emittance.	•Suppression of vibration of beam below 1/10 of the present KEKB. •Tuning strategy for nano-beam. •Observation of beam profile both in the arcs and at the IP. •Reduction of feedback noise.

K. Oide

Progress in the NANO-BEAM SCHEME

- Lattice: solutions exist, preserving the present tunnel.
- Optimization of dynamic aperture is going on.
- IR: large crossing, independent quads for both beams.
- LER emittance must be higher than 2.5 nm @ 3.5 GeV, considering intra-beam scattering.
  - 4/7 Gev possible, but not preference of detector group.
- Electron cloud mitigation has been studied at KEKB. Results from CesrTA will be also important.
- Design of e+ damping ring has been done.

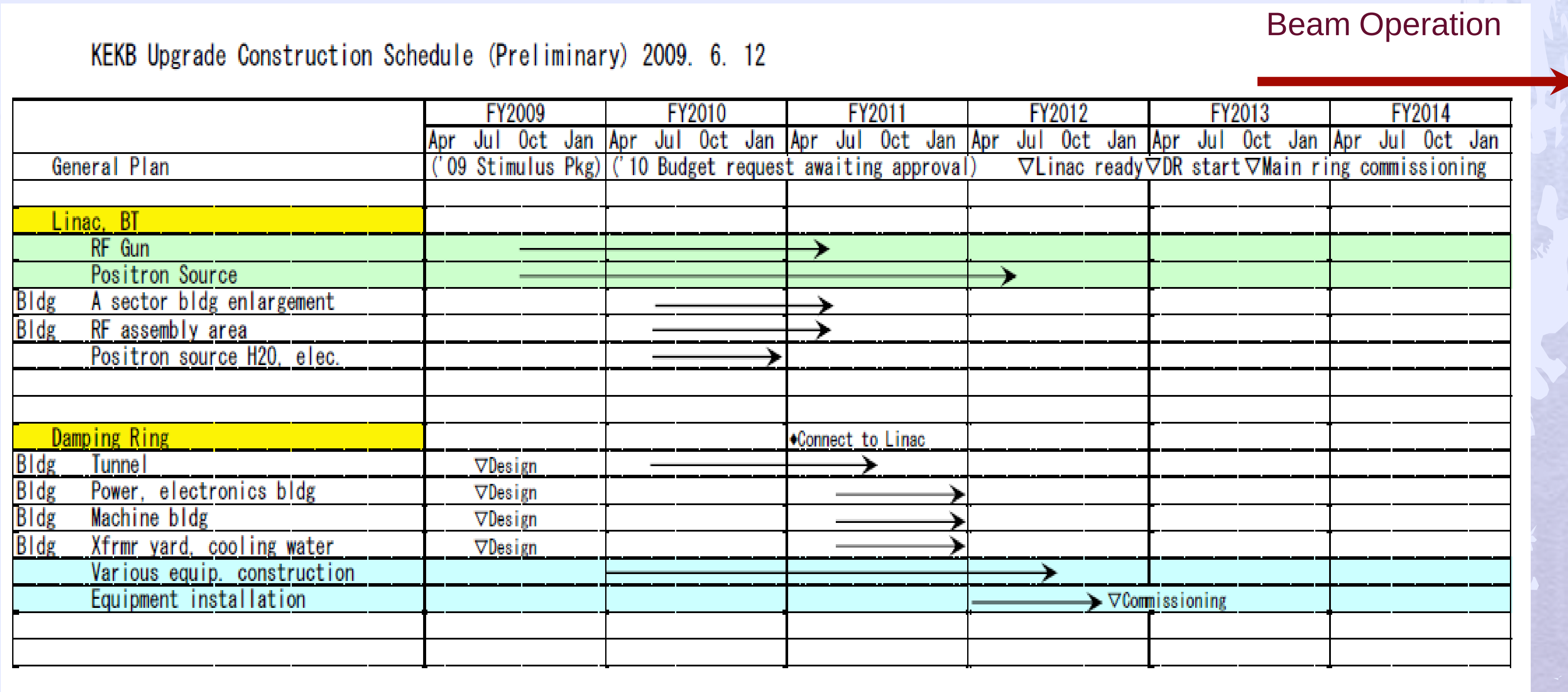
Oide

Project Status

- SuperKEKB is a lab priority.
- The Japanese government has allocated 27 oku-yen ($27 M, €19 M) for upgrade R&D in FY 2009, as a part of its economic stimulus package.
- KEK has submitted a budget request for FY 2010 and beyond of $350 M for construction.
- We are proceeding with R&D while awaiting approval of the construction budget request.

Construction Schedule (preliminary)

K. Akai



Construction Schedule (preliminary)

K. Akai

Beam Operation

		FY2009	FY2010	FY2011	FY2012	FY2013	FY2014
		Apr Jul Oct Jan	Apr Jul Oct Jan	Apr Jul Oct Jan	Apr Jul Oct Jan	Apr Jul Oct Jan	Apr Jul Oct Jan
	General Plan	('09 Stimulus Pkg)	('10 Budget request awaiting approval)		▽Linac ready	▽DR start ▽Main ring commissioning	
	Main Rings						
	Magnets, vac. chamb. removal	▽Survey					
	Vac. chambers related:						
	Fabricate (LER)						
	TiN coating (LER)		(Setup)				
	installation (LER)			▽Start(Outer)	▽(In♦完了		
	Fabrication (HER)						
	Installation (HER)				▽(Outer) ▽(In♦Complete		
	Fabrication (Straights, IR)						
	TiN coating (Straight secs.)				▽Start		
	Installation (Straights, IR)						
	Magnets, power supplies						
	Fabrication						
	Baseplate installation						
	Field measurement						
	Magnet installation						
	Alignment (Initial)						
	Alignment (2nd)						
Bldg	Vac. Deposition facility						
Bldg	Vac. Chamber storage facility						
Bldg	Mag. Test facility construction						
Bldg	Mag. PS bldg construction				▽PS installation		
Bldg	Cooling water system (bldg)						
	Cooling water system (pipes)						
	BPM installation						
	Monitor sys. dev., fabrication						
	Control sys. Upgrade						
Bldg	PS floor+earthquake strengthening						
	RF install+expand (above ground)						
	RF cav. upgrade (inp. coupler, etc.)						
	QCS/IP						
	R&D design+fabrication						
	QCS construction						
Bldg	Compressor bldg. expansion						
	Cryo. moving, upgrade						
	QCS install, test operation						
						♦Belle Roll In?	

Summary

- The High-Current Scheme for upgrading KEKB has some issues which are not easily resolved: CSR, IR design, high ξ_y with crab crossing, and construction/operation costs for high current.
- Mitigation methods such as Travelling Waist may work, but also introduce more complexity.
- Attention is now focusing on the Nano-Beam Scheme, and the design work is on-going in that direction.
  - Many components common with High-Current Option.
- KEKB needs collaboration with accelerator scientists around the world for the success of this challenging project.

Spares

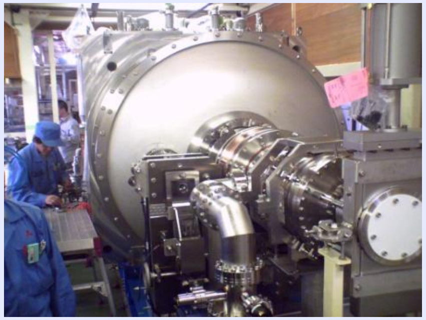
Parameters for Super B Factories

a) b-b simulation, b) geometrical

preliminary

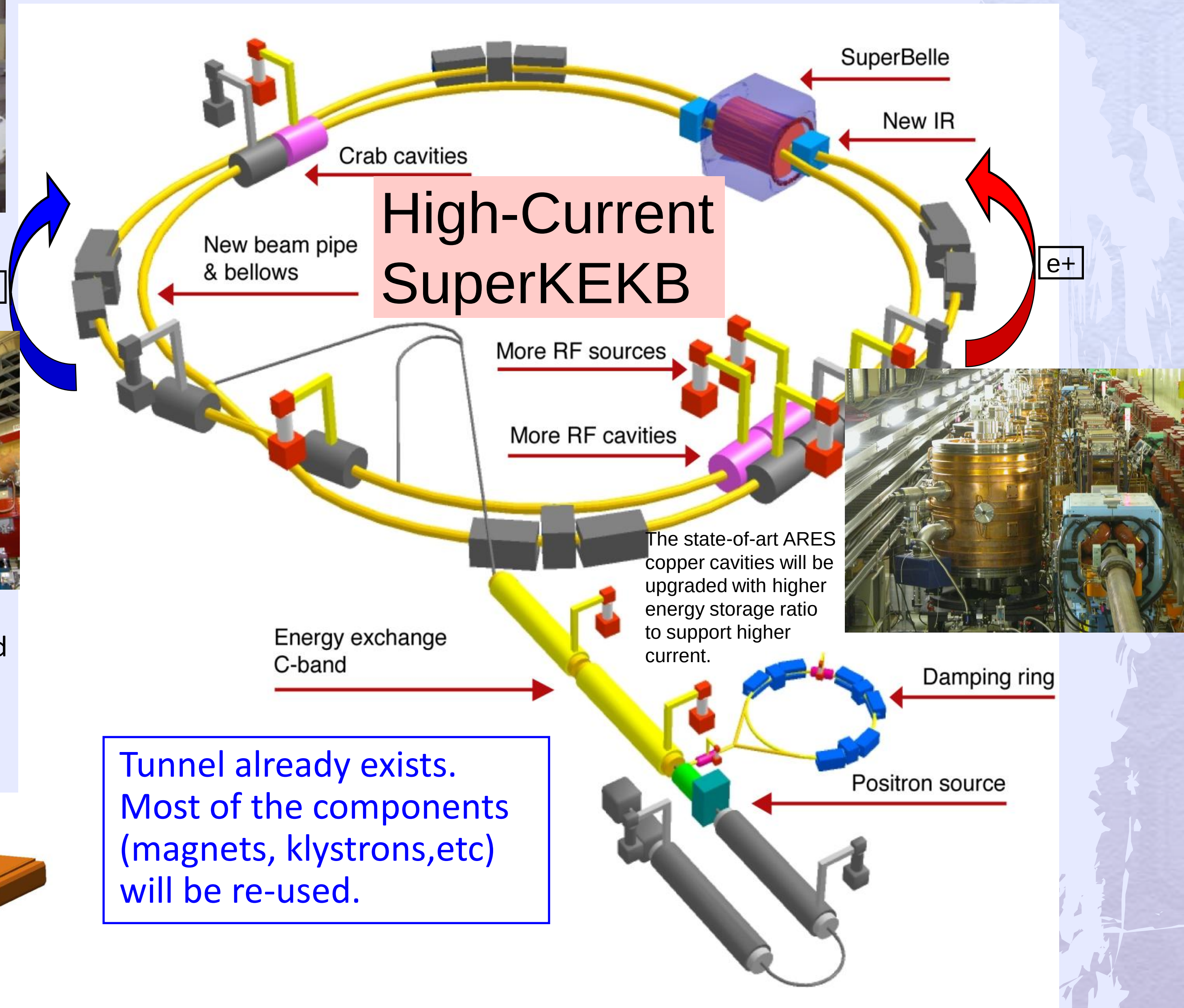
	SuperKEKB	NanoBeam A2	NanoBeam B2	NanoBeam A3	NanoBeam B3
εx (nm) (L/H)	24/18	2.8/2.0	2.8/2.0	2.8/2.0	2.8/2.0
εy(pm)	240/90	33.6/10.7	33.6/10.7	29.4/13.9	29.4/13.9
κ (%)	1/0.5	1.2/0.53	1.2/0.53	1.0/0.70	1.0/0.70
βx (mm)	200/200	44/25	44/25	44/25	44/25
βy (mm)	3/6	0.21/0.37	0.21/0.37	0.24/0.37	0.24/0.37
σx (μm)	69/60	11/7.07	11/7.07	11/7.07	11/7.07
σy (μm)	0.85/0.73	0.084/0.063	0.084/0.063	0.084/0.072	0.084/0.072
σz (mm)	5/3	5/5	5/5	5/5	5/5
φσz/σx	0/0	14/21	14/21	14/21	14/21
σx/φ(mm)	∞/∞	0.37/0.24	0.37/0.24	0.37/0.24	0.37/0.24
np / ne $\times 10^{10}$	12/5.25	10.7/6.17	9.36/7.05	10.7/6.17	9.36/7.05
Ebp/Ebe (GeV)	3.5/8	3.5/8	4/7	3.5/8	4/7
I_{beam} (A)	9.4/4.1	3.42/1.97	3.00/2.26	3.61/2.08	3.16/2.38
#bunch/Cir(m)	5000/3016	2011/3016	2011/3016	2119/3016	2119/3016
φ (mrad) (half crossing angle)	0	30	30	30	30
ξy	0.30/0.51	0.090/0.090	0.090/0.090	0.090/0.090	0.090/0.090
Lum	5.3×10^{35} a)	8.0×10^{35} a)	8.0×10^{35} a)	8.0×10^{35} a)	8.0×10^{35} a)

High-Current SuperKEKB



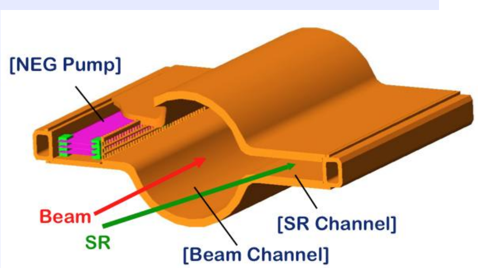
Crab cavity (High-Current Option)

The superconducting cavities will be upgraded to absorb more higher-order mode power up to 50 kW.



Tunnel already exists.
Most of the components (magnets, klystrons,etc) will be re-used.

The state-of-art ARES copper cavities will be upgraded with higher energy storage ratio to support higher current.



The beam pipes and all vacuum components will be replaced to reduce electron clouds and handle higher currents.