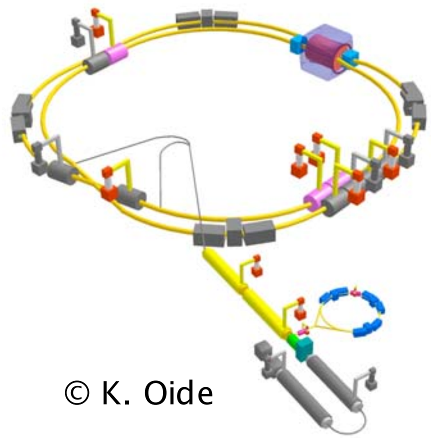
SuperKEKB status and comments for new ideas

Y. Ohnishi
KEK

2nd Workshop on Super B-Factory
at Frascati
March 16-19, 2006



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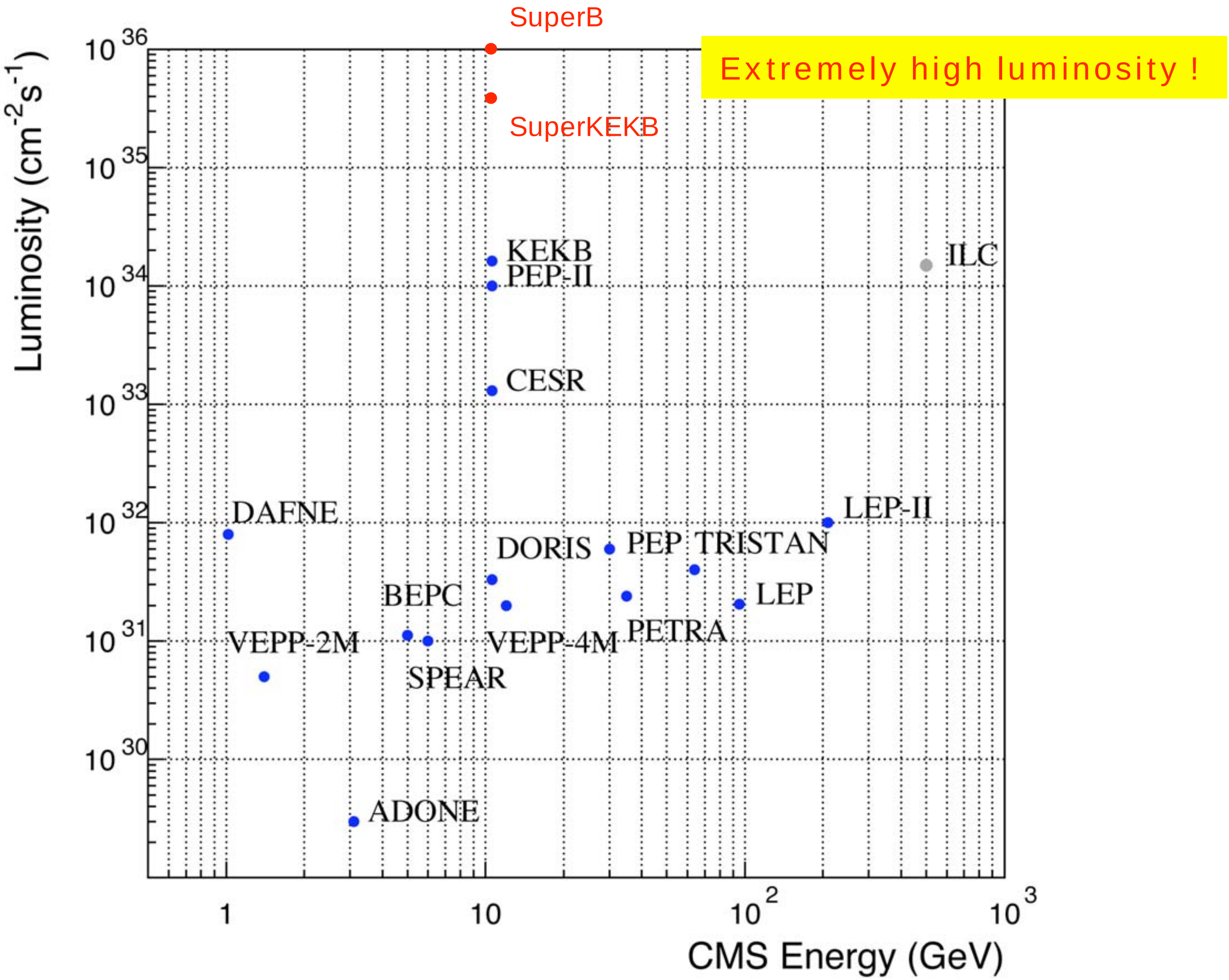
Luminosity-energy of colliders in the world



History of activity for SuperKEKB

Workshops(8)

- 2001 August 23-24, 1st SuperKEKB Workshop, KEK
- 2002 January 29-30, 2nd SuperKEKB Workshop, KEK
- 2002 August 6-7, 3rd SuperKEKB Workshop, Hayama
- 2003 February 4, 4th SuperKEKB Workshop, KEK
- 2003 September 24-26, 5th SuperKEKB Workshop, Izu
- 2004 January 19-22, Joint Super B Factory Workshop, Hawaii
- 2004 November 16-18, 6th SuperKEKB Workshop, KEK
- 2005 April 20-22, 2nd Joint Super B Factory Workshop, Hawaii

Documents(2)

- 2002 January 10, Expression of Interest (EoI)
- 2004 April, Letter of Interest (LoI) ,
  - 452 pages includes physics/detector/accelerator !

  See http://belle.kek.jp/superb/ or http://www-kekb.kek.jp/SuperKEKB/Documents.html

Luminosity

- Luminosity formula (well-known)

Number of particles/bunch (e+)

Number of particles/bunch (e-)

Collision frequency

$$L = \frac{N_{e+} N_{e-} f}{4\pi \sigma_x^* \sigma_y^*} R_L$$

Luminosity reduction
due to geometrical effect

Horizontal beam size at IP

Vertical beam size at IP

Luminosity

- Luminosity formula for machine design

Beam current
1.8/1.35 A (KEKB)→ 9.4/4.1 A (SuperKEKB)

It correlates with many things.

Beam-beam parameter
(Strength of interaction between colliding beams)
0.055 (KEKB)→ 0.19 (SuperKEKB)

Limited by beam-beam effect

Lorentz factor

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

Geometrical factor
due to hour-glass effect
and crossing angle
0.8 ~ 1 (short bunch)

Classical electron radius

Beam size ratio
1 ~ 2 % (flat beam)

Vertical beta function
(Focal depth)
6.5 mm/6.2 mm (KEKB)
→ 3 mm/3 mm(SuperKEKB)

Limited by bunch length

Luminosity
1.63×10^{34} $cm^{-2}s^{-1}$ (KEKB)
→ 4.0×10^{35} $cm^{-2}s^{-1}$ (SuperKEKB)

Bunch length ($s_z < b_y^*$)
~7 mm (KEKB)→ 3 mm (SuperKEKB)

Limited by HOM, CSR

Luminosity is proportional to beam currents, beam-bea[m parameter]
and inverse of vertical beta function at IP.

Strategy of SuperKEKB

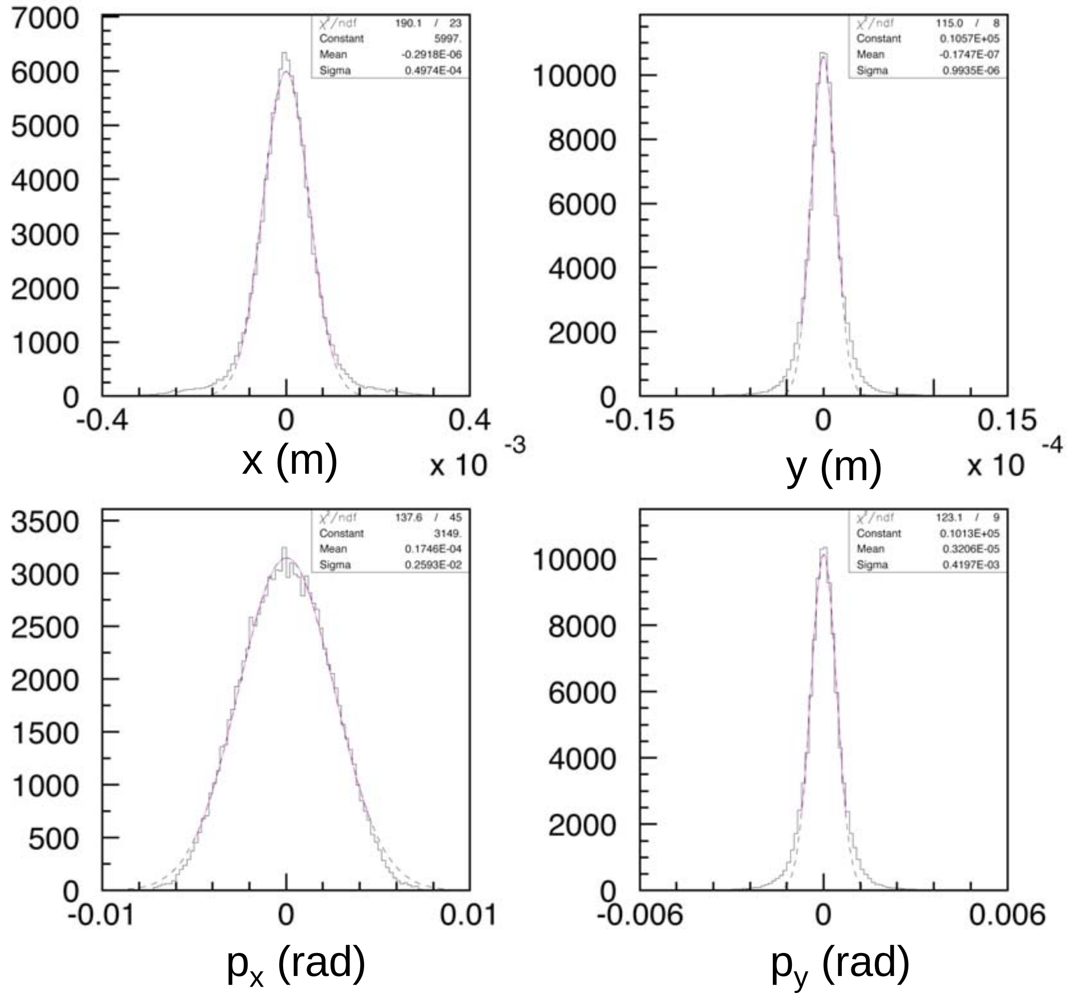
- Accomplishment of higher luminosity
  - Brute-force
    - Higher beam currents
      - Large number of RF cavities and stations to obtain RF power
      - Frequency detuning due to beam loading
      - Cure of HOM power
      - Handling of SR power
      - Cure of electron cloud instability and ion instability
      - Bunch-by-bunch feedback system (transverse and longitudinal)
      - Powerful injector
    - Smaller beta function at IP
      - New QCS+special magnets at IR
      - Need short bunch length (Cure of CSR should be necessary.)
  - New idea
    - Higher beam-beam parameter
      - Head-on collision which is realized by crab cavities.

Luminosity estimation using strong-strong simulation

$L = 4 \times 10^{35}$ $cm^{-2}s^{-1}$ at head-on collision(crab-crossing)

Beam currents: 9.4/4.1 A Beam-beam: 0.19

LER beam distributions at IP



Dynamic(beam-beam) effect changes beam parameters.

Beam size:

s_x* = 50 mm ← 69 mm(w/o beam-beam)

s_y* = 1 mm ← 0.73 mm(w/o beam-beam)

Twiss parameters obtained from beam distributions:

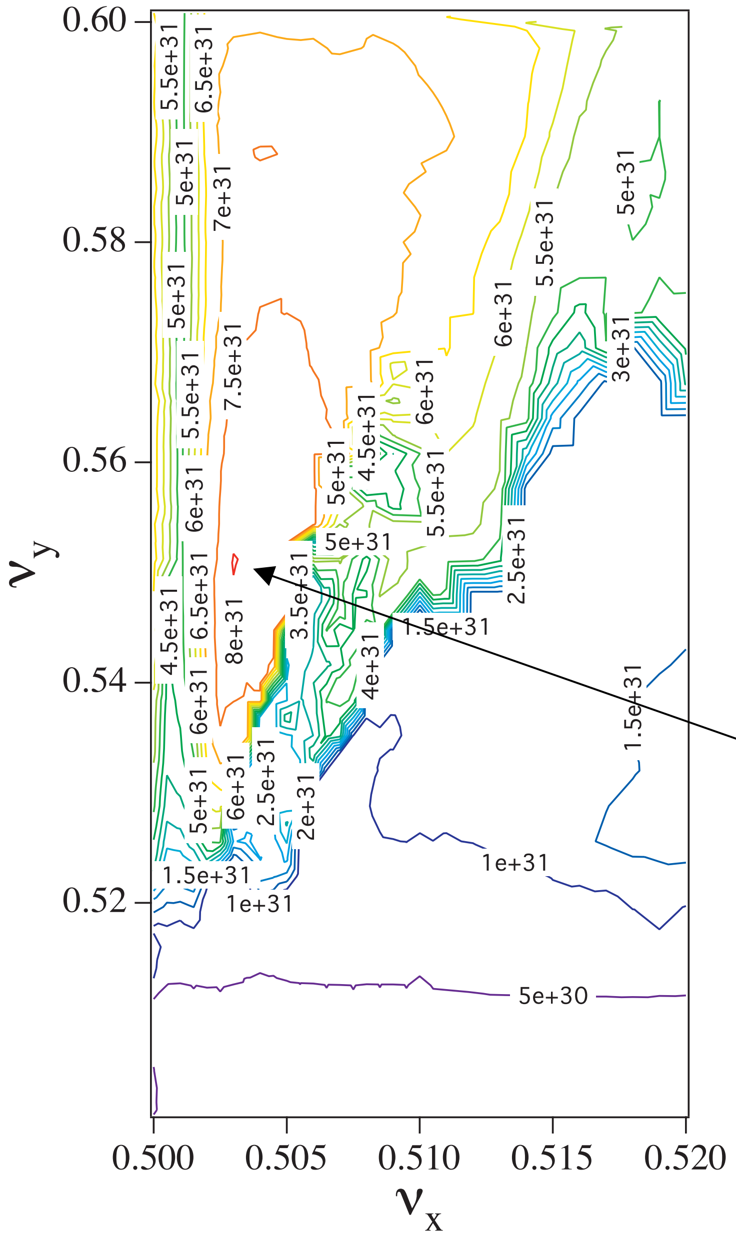
e_x = 130 nm ←24 nm(w/o beam-beam)

b_x* = 1.92 cm ←20 cm(w/o beam-beam)

b_y* = 2.38 mm ←3 mm(w/o beam-beam)

Emittance and beta functions change due to dynamic effect.

Tune scan with beam-beam simulation



Tune Survey in SuperKEKB
without parasitic collision effect.

$L_{peak}=4.0\times10^{35}cm^{-2}s^{-1}$
$(L/bunch=8.0\times10^{31}, Nb=5000)$

Head-on

(.503, .550) } ξ_y ~0.19

Very close to half integer !

Simulation by K. Ohmi and M. Tawada

Lattice parameters w/o and w/ beam-beam effect

SuperKEKB		bare lattice	with beam-beam	unit
Beam current (LER/HER)	I	9.4/4.1	9.4/4.1	A
Beam energy (LER/HER)	E	3.5/8.0	3.5/8.0	GeV
Emittance	e_x	24	130	nm
Horizontal beta at IP	b_x*	20	1.9	cm
Vertical beta at IP	b_y*	3	2.4	mm
Horizontal beam size	s_x*	69	50	mm
Vertical beam size	s_y*	0.73	1.0	mm
Beam size ratio	$r = s_y^*/s_x^*$	1.1	2.0	%
Crossing angle (30 mrad crab crossing)	q_x	0	0	mrad
Luminosity reduction	R_L	0.86	0.82	
x_x reduction	R_{xx}	0.99	0.98	
x_y reduction	R_{xy}	1.11	1.16	
Reduction ratio	R_L/R_{xy}	0.78	0.70	
Horizontal beam-beam (estimated with S-S simulation)	x_x	0.152	0.030	
Vertical beam-beam (estimated with S-S simulation)	x_y	0.215	0.187	
Luminosity	L	4.0×10^{35}		$cm^{-2}s^{-1}$

Dynamic effect

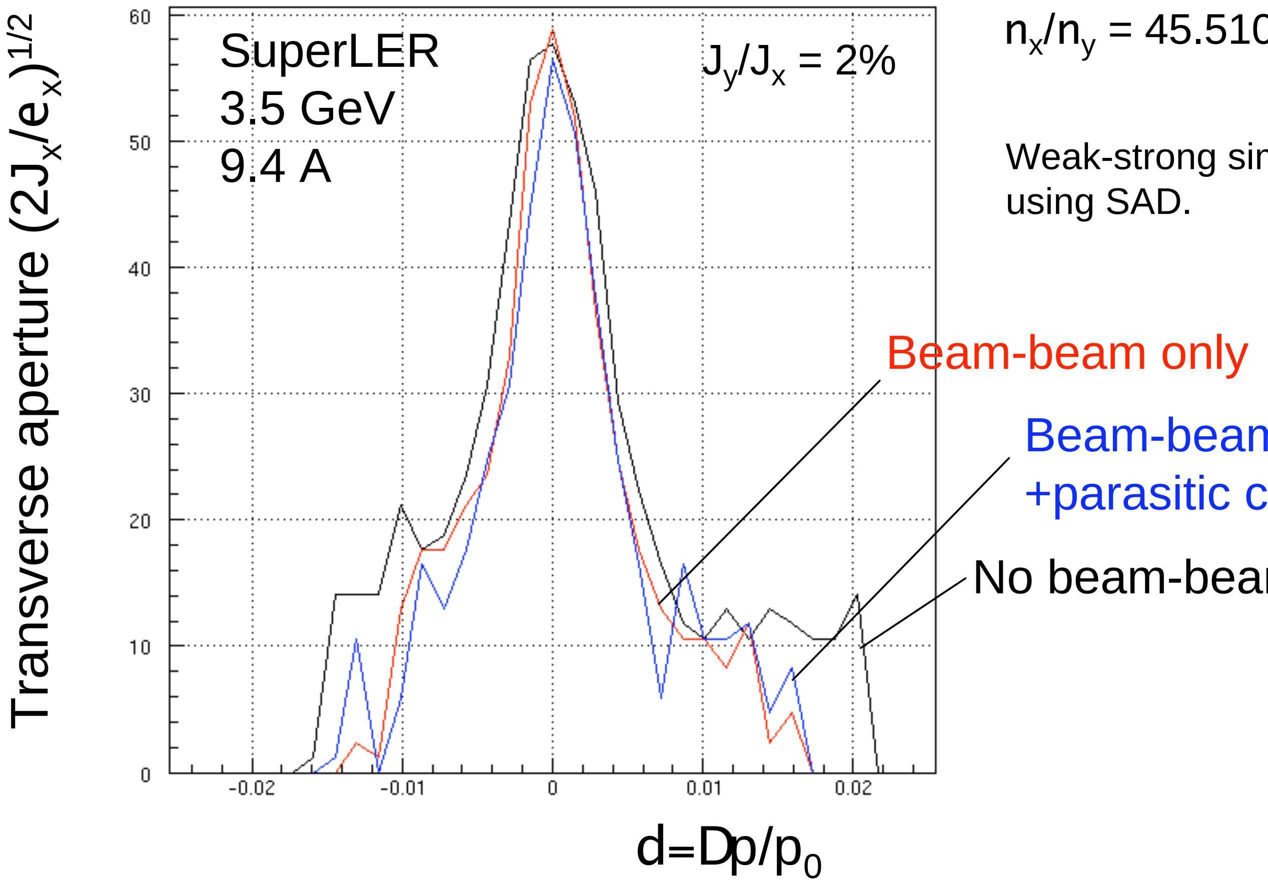
Beam dynamics issues

- Beam-beam effect
  - Nonlinear, collective, chaotic effects
- Dynamic aperture (lifetime, injection)
  - Lattice design, nonlinearity due to sextupoles
- Fast ion instability
  - Interaction between electron beam and ions(residual gas: CO, H_2, H_2O, ...)
- Electron cloud effect
  - Interaction between positron beam and electron cloud from pipe which SR hits
- Coherent synchrotron radiation
  - It occurs in case of extremely short bunch length.

    Photons have the same phase(Electric field$\propto$N, Power$\propto N^2$).

Dynamic aperture with beam-beam and parasitic collision (SAD)

Effect of parasitic collision is not significant.



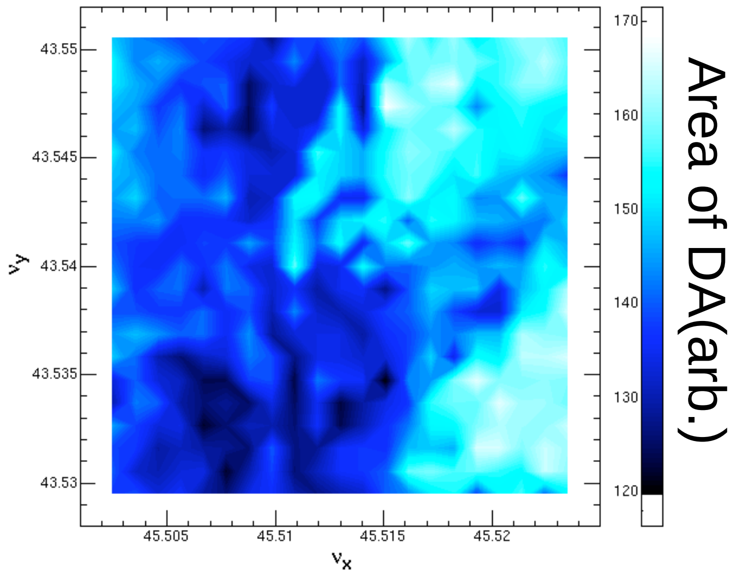
$n_x/n_y = 45.510/43.545$

Weak-strong simulations using SAD.

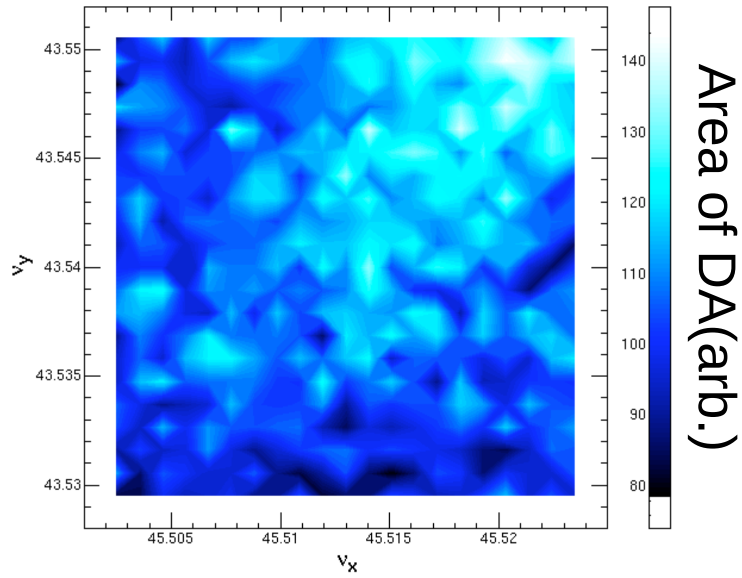
Lifetime(collision/no collision) = ~40 min/~50 min @LER(9.4 A)

Tune scan for SuperKEKB-LER (SAD)

No Beam-beam



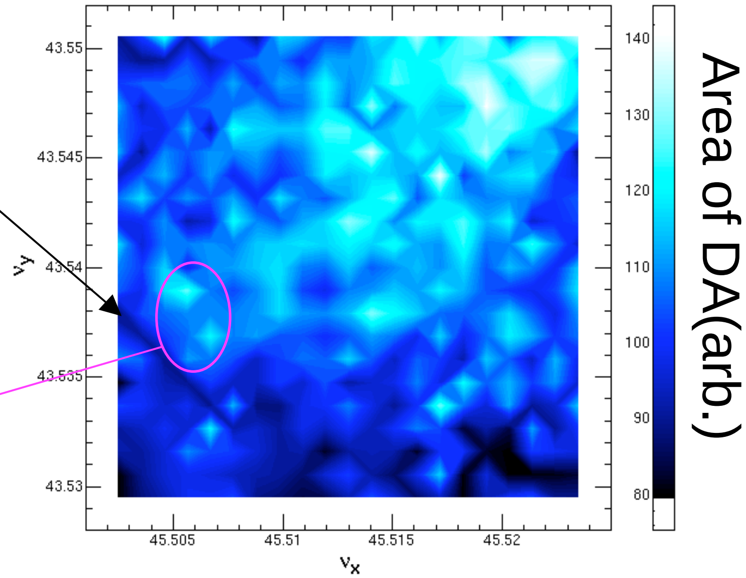
Beam-beam only



Lighter color indicates larger dynamic aperture.

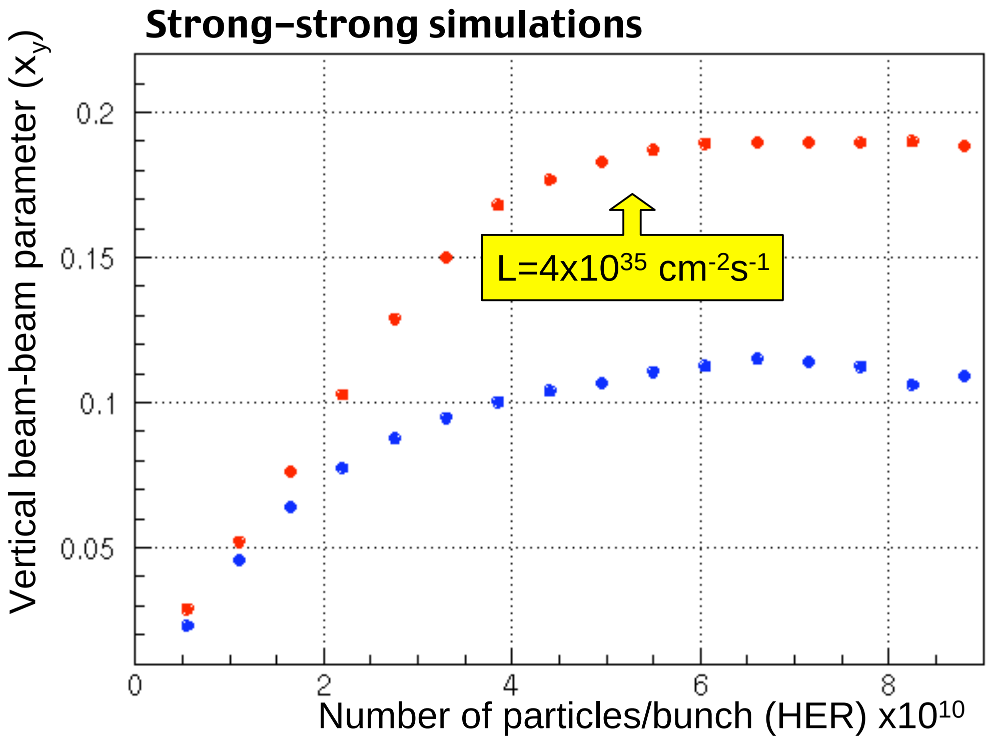
Beam-beam + parasitic collision

$n_x+n_y+n_s = \text{int.}$



Working point at KEKB

Head-on and finite-crossing collision



Head-on (crab-crossing)

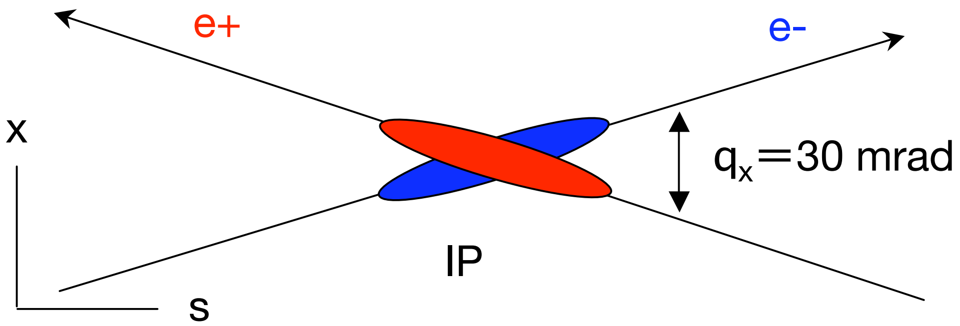
ν_x/ν_y = .503/.550

Crossing angle: 30 mrad

- Head-on collision will boost the beam-beam parameter up to 0.19.
- Crab cavity is one of the most important components, because it can realize head-on collision.

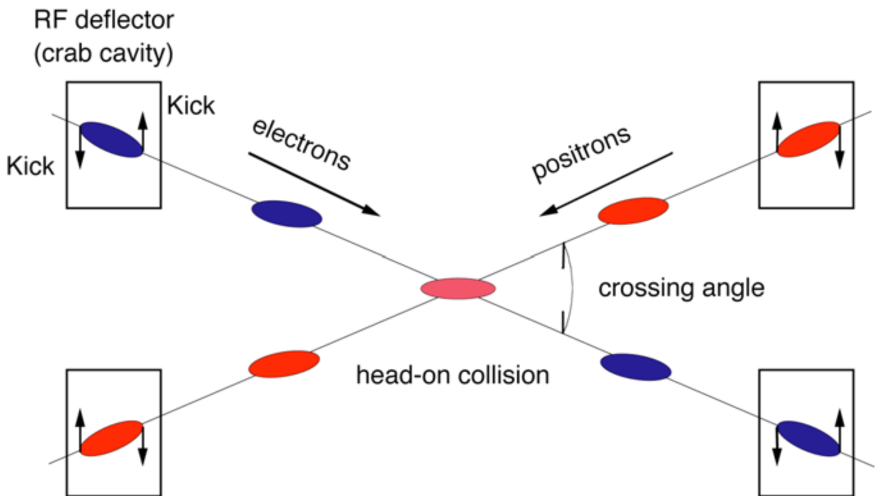
Head-on collision with crab cavity

Finite-crossing collision without crab cavity

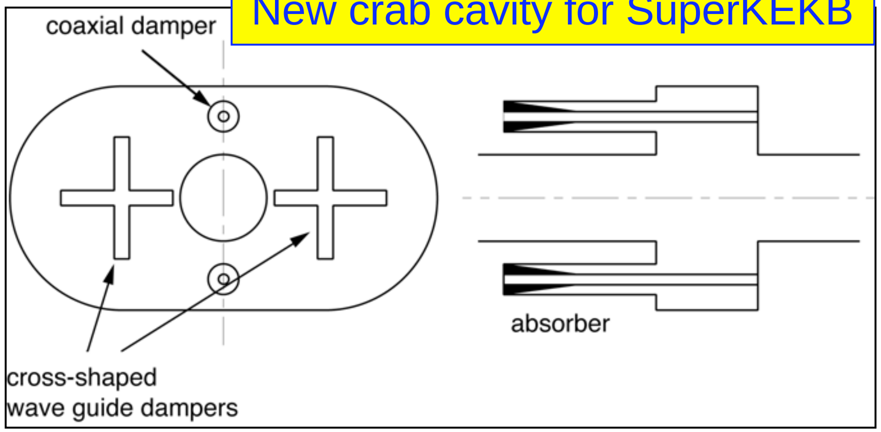


Crab cavity tilts the beam to make head-on collision.

Development of crab cavity applicable for high beam current(~10 A)



New crab cavity for SuperKEKB



This is different from the cavity will be installed at KEKB.

Status of R&D

Crab cavity for KEKB

QCS(final focus magnet) for SuperKEKB

Superconducting magnet in IR region

Superconducting crab cavity for KEKB

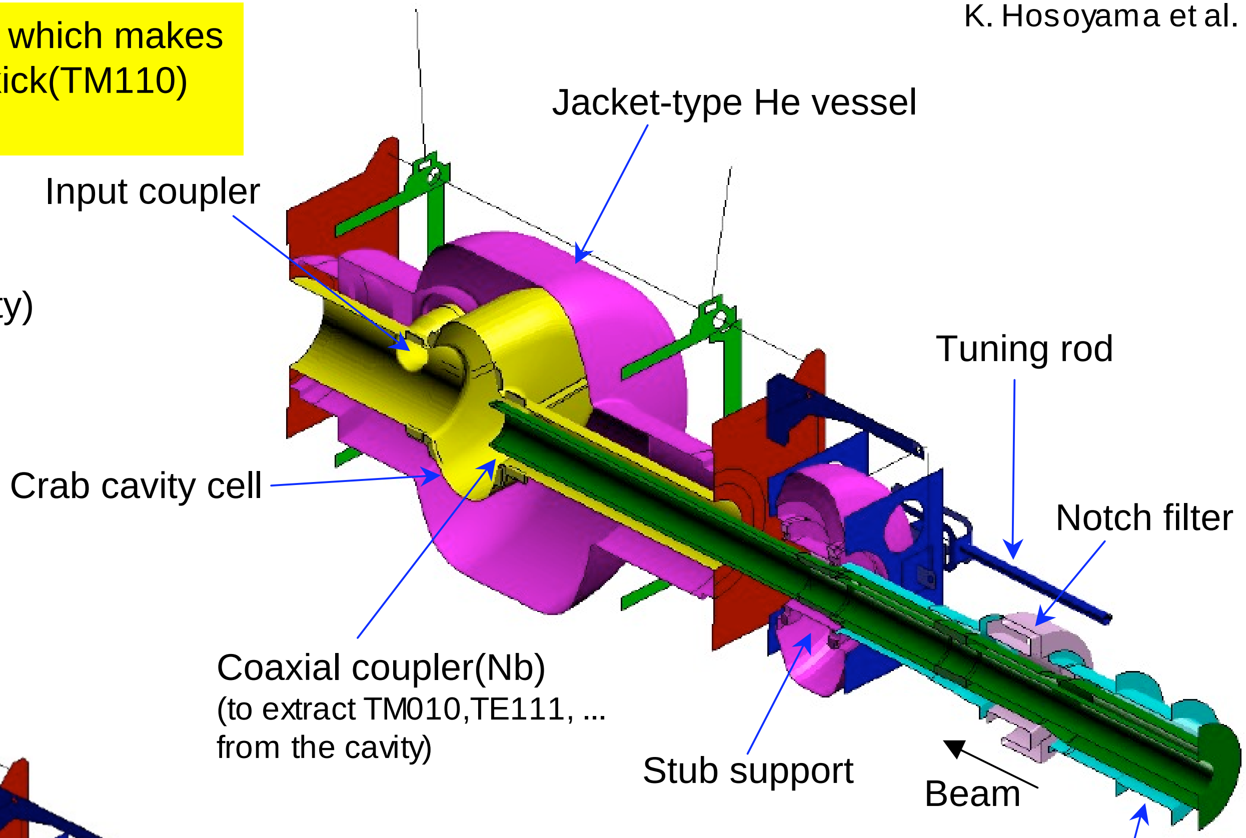
K. Hosoyama et al.

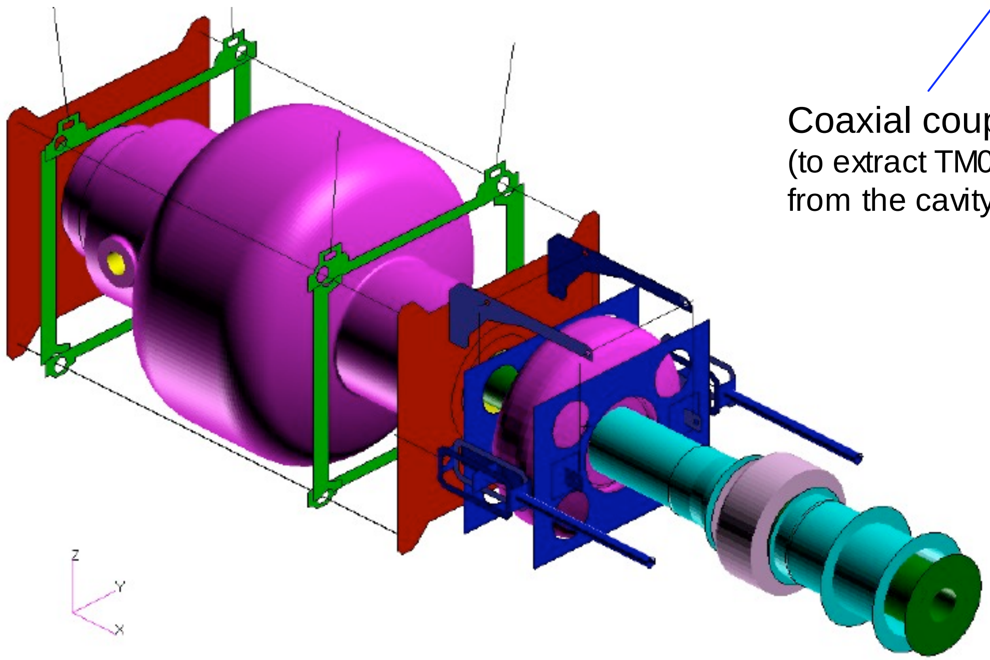
Crab cavity is the RF deflector which makes a time-dependent transverse kick(TM110) to tilt the beam.

$$V_{\perp} = \frac{cE}{\omega_{RF}\sqrt{\beta_x^* \beta_x^{crab}}} \tan\theta_x$$

(one cavity)

$$\Delta\Psi_x^{crab-IP} = 2n\pi \pm \frac{\pi}{2}$$



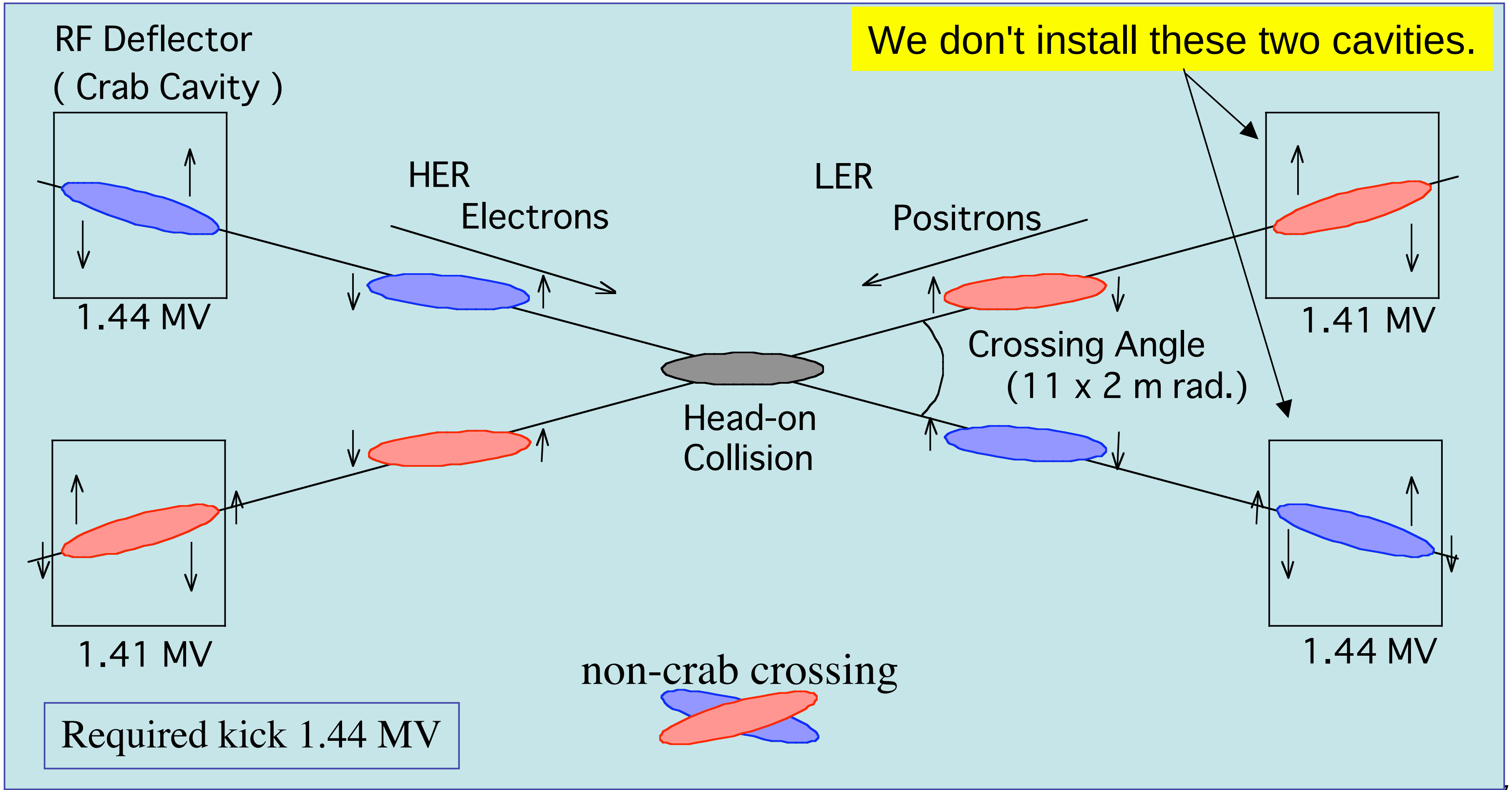


	LER	HER	
E	3.5	8	GeV
w_{RF}	509		MHz
q_x	22		mrad
b_x^*	0.59	0.56	m
b_x^{crab}	44	235	m
$V_{\perp}$	1.41	1.44	MV

KEKB Crab Crossing

The crab crossing scheme allows a large crossing angle collision without introducing any synchrotron-betatron coupling resonances. [1, 2)]

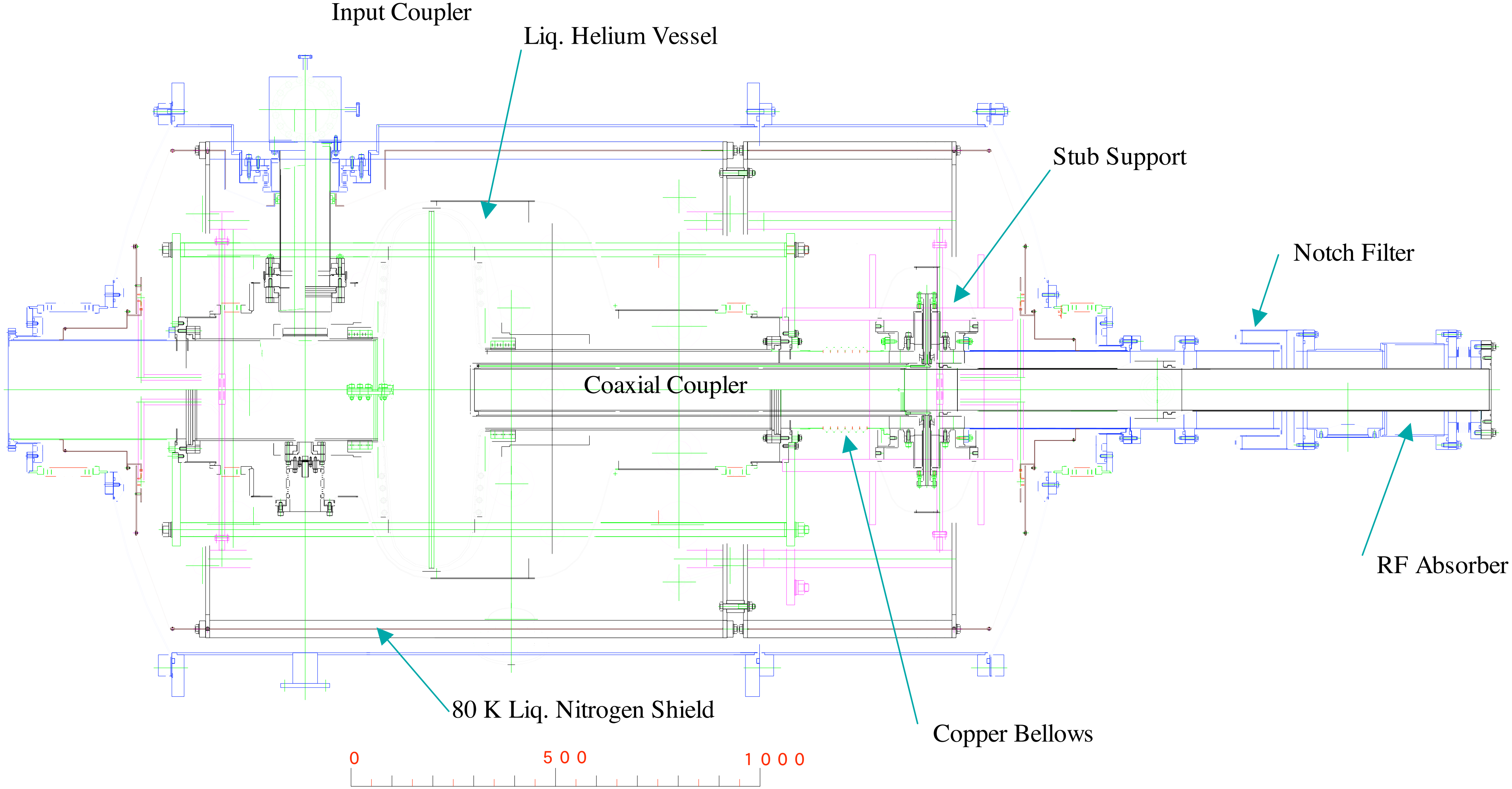
1) R.B.Palmer, SLAC-PUB-4707,1988
2) K.Oide and K.Yokoya, SLAC-PUB-4832,1989



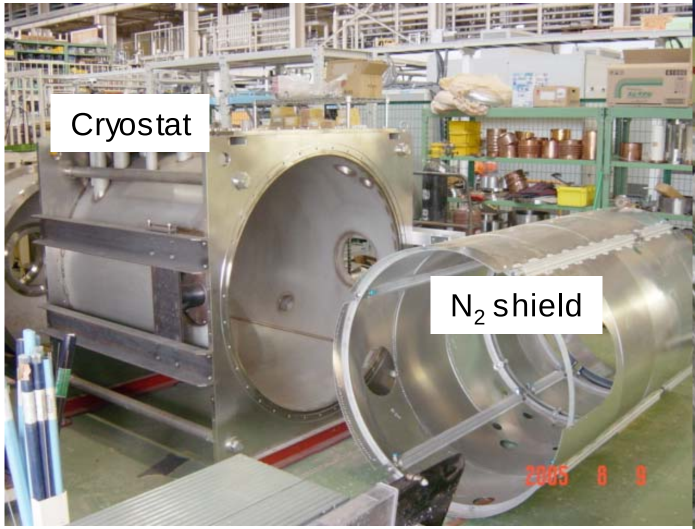
Crab Cavity in Cryostat (Top View)

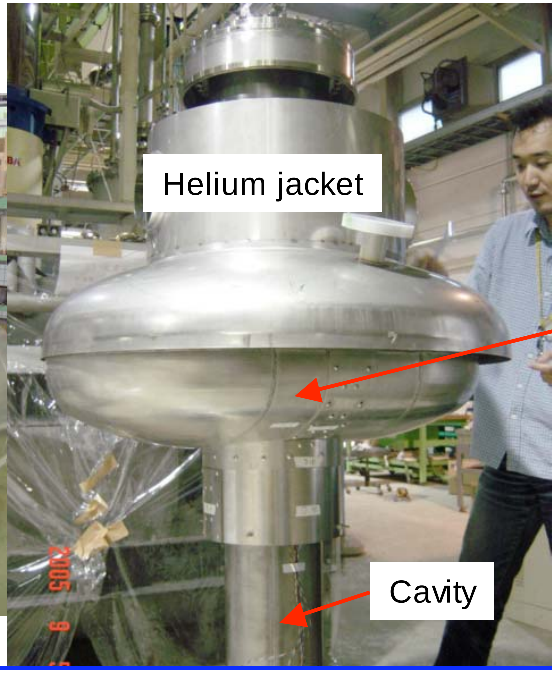
Heat Loss

80K	110 W
4.2K	15 W

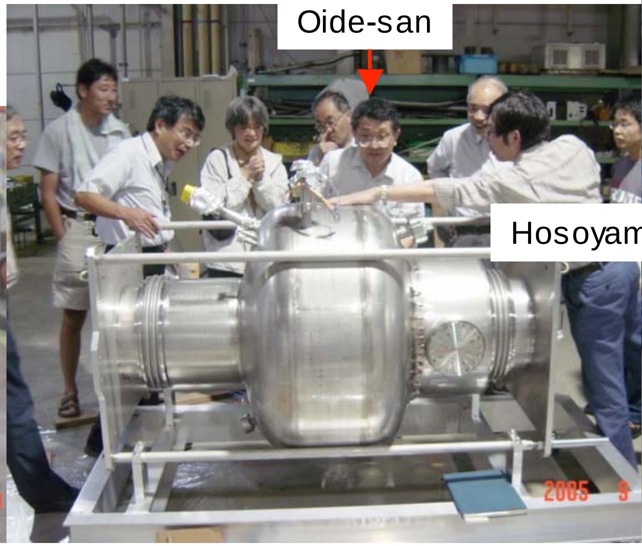


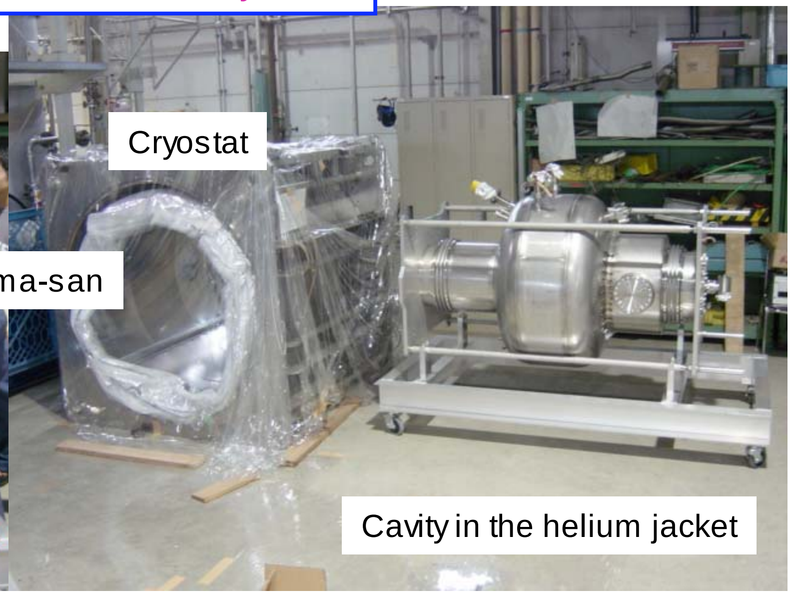
Prototype crab cavity fabrication





The prototype cryostat was designed and assembled by KEK.



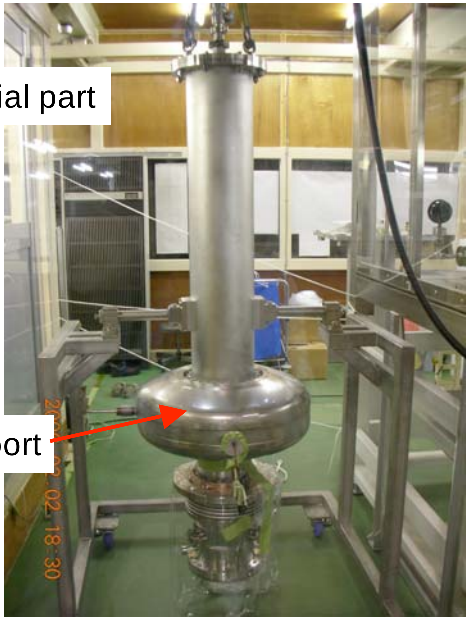


HER crab cavity assembly (cont'd)

The final assembly was started from February/8/2006.

Cryostat arrived at KEK.

Input coupler installation

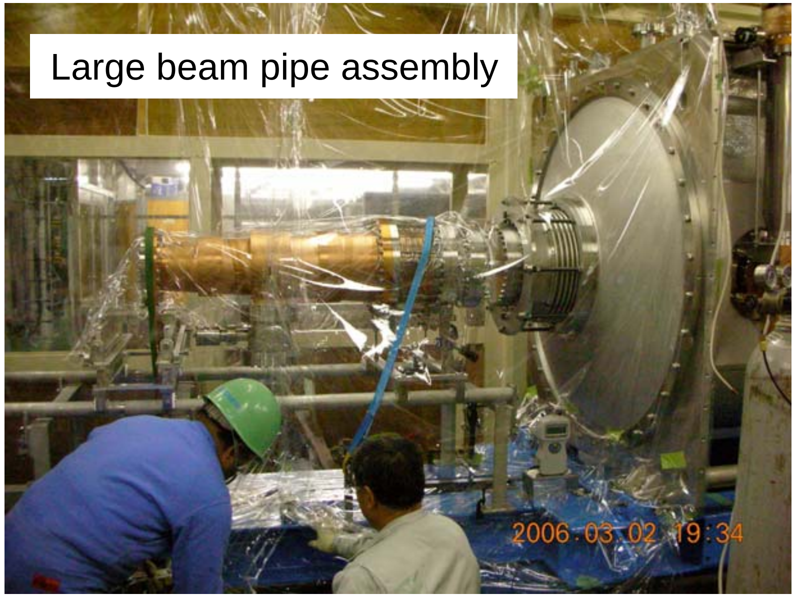


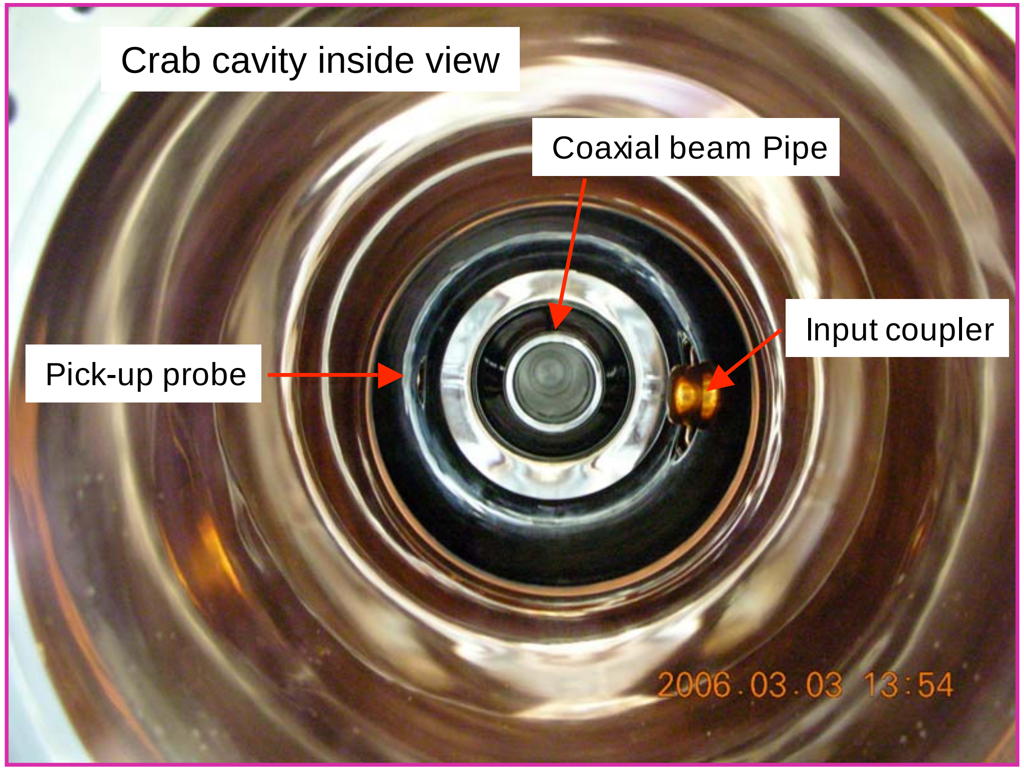
Coaxial part

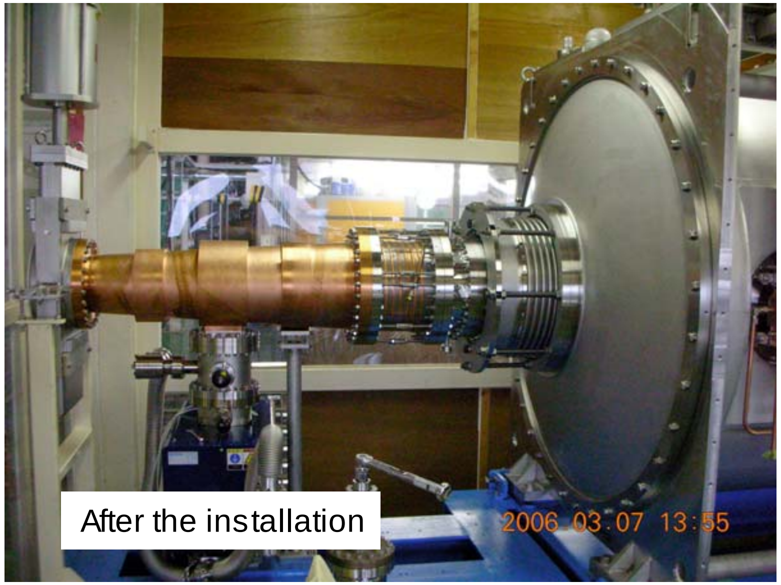
Stub support

Coaxial part installation

HER crab cavity assembly (cont'd)





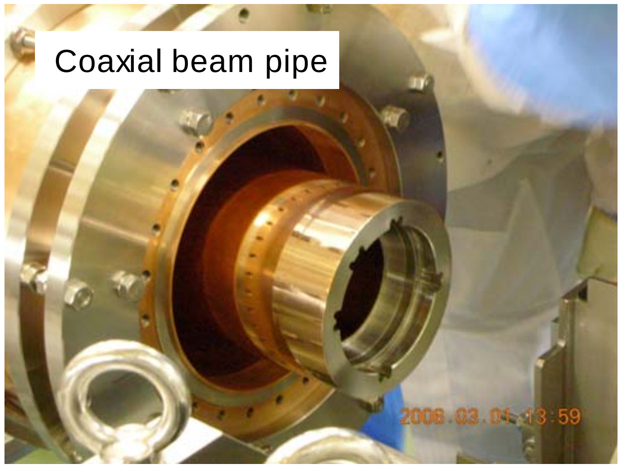


HER crab cavity assembly (cont'd)

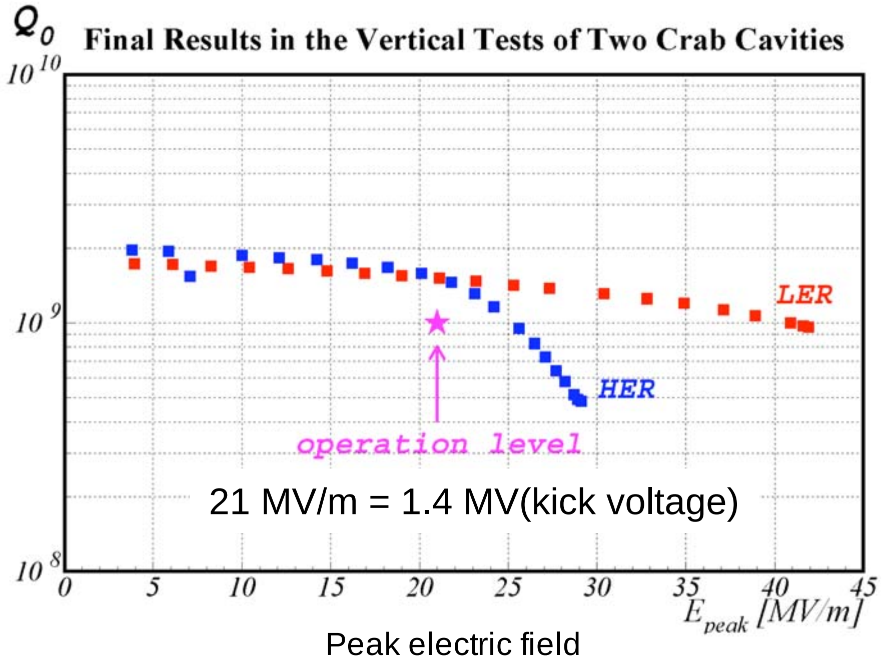
Coaxial beam pipe

It was very difficult to install them !

Now we are trying it…



Results of Q-value at the vertical test for two crab cavities



LER cavity has achieved the best performance for the peak electric field.

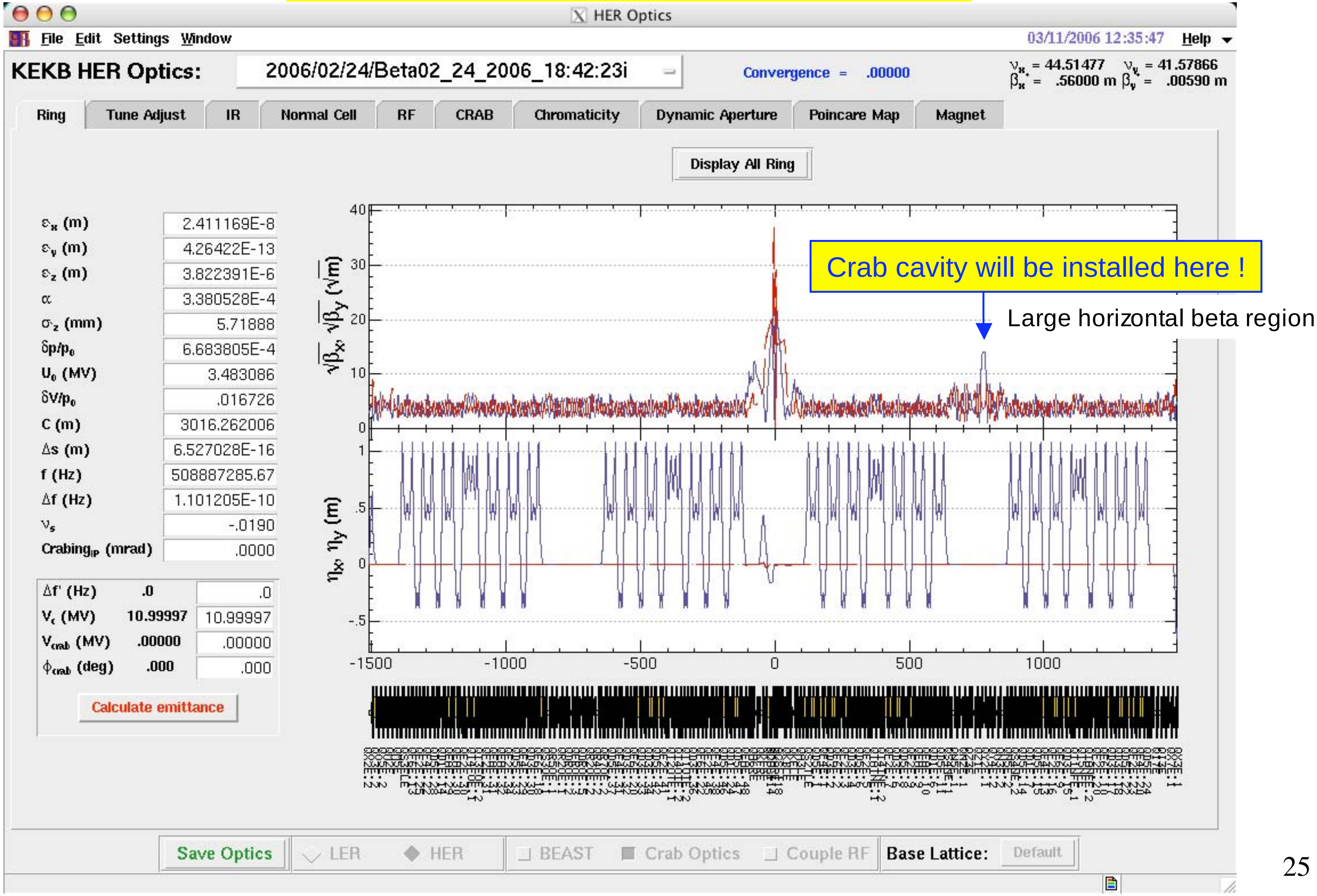
HER cavity is worse performance than that of LER, however it satisfies the requirement.

Crab cavity construction schedule

- Horizontal test of HER crab cavity will be started from the middle of March.
  - cavity/coupler conditioning
  - coupling measurement
  - static loss measurement
  - mechanical/piezo tuner operational test under 4.2 K.
  - Q-value measurement
- LER crab cavity assembly will be started from the middle of March.
- HER crab cavity will be installed into beam-line at the end of March.
- LER crab cavity will be installed into beam-line at the end of April.
- Beam operation will be started at the beginning of May.
- Purpose of this crab cavity is to confirm simulations obtaining twice of magnitude of beam-beam parameter at KEKB.

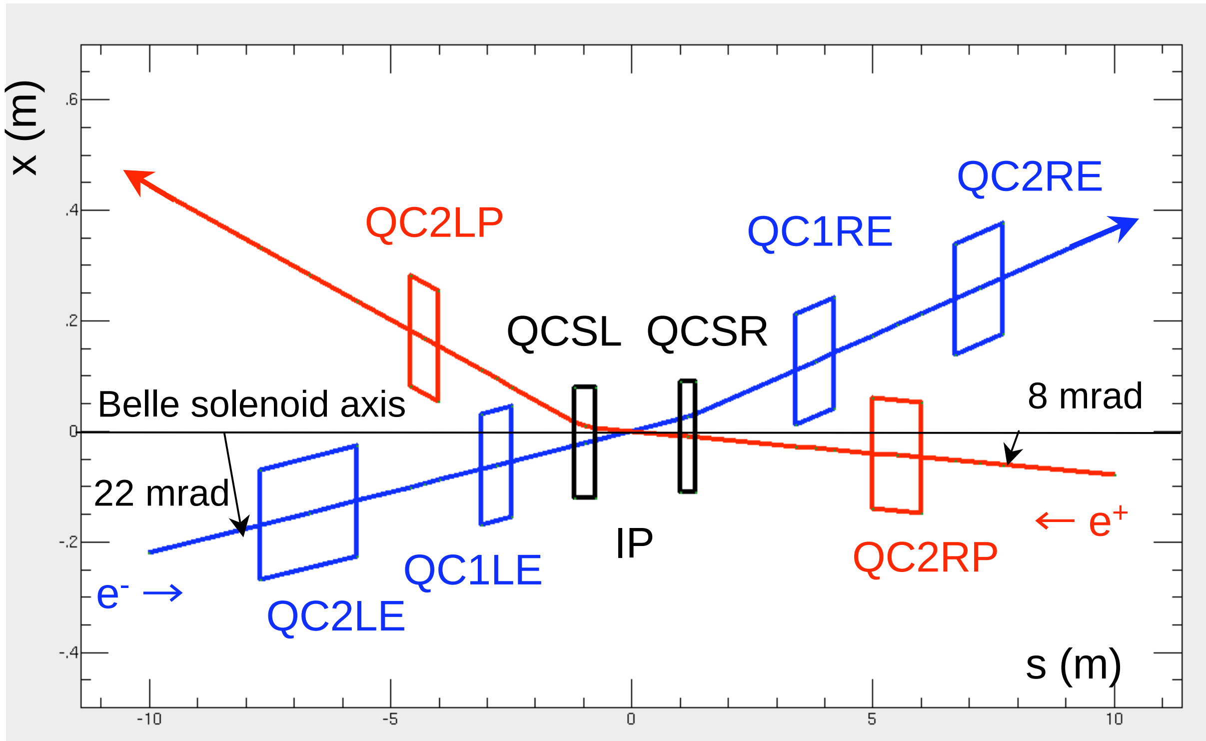
Optics for crab cavity

We have already used crab optics for luminosity run.

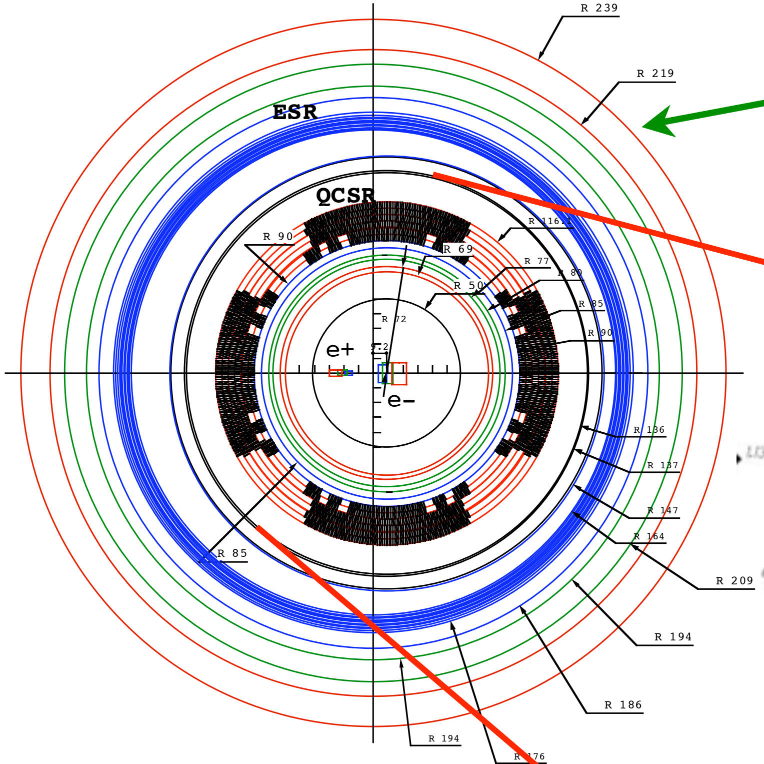


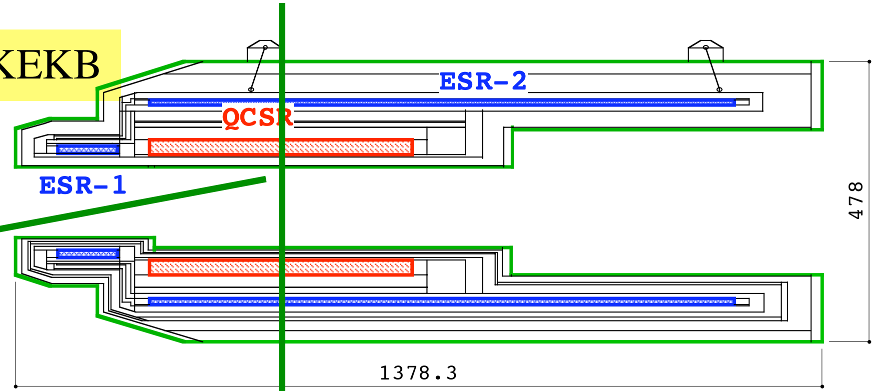
Squeezing beta function at IP

- Beta function at IP: 20 cm/3 mm
- QCS magnets closer to IP
  - Special magnets vicinity of IP are also moved closer to IP.
  - 30 mrad finite-crossing (22 mrad at KEKB)

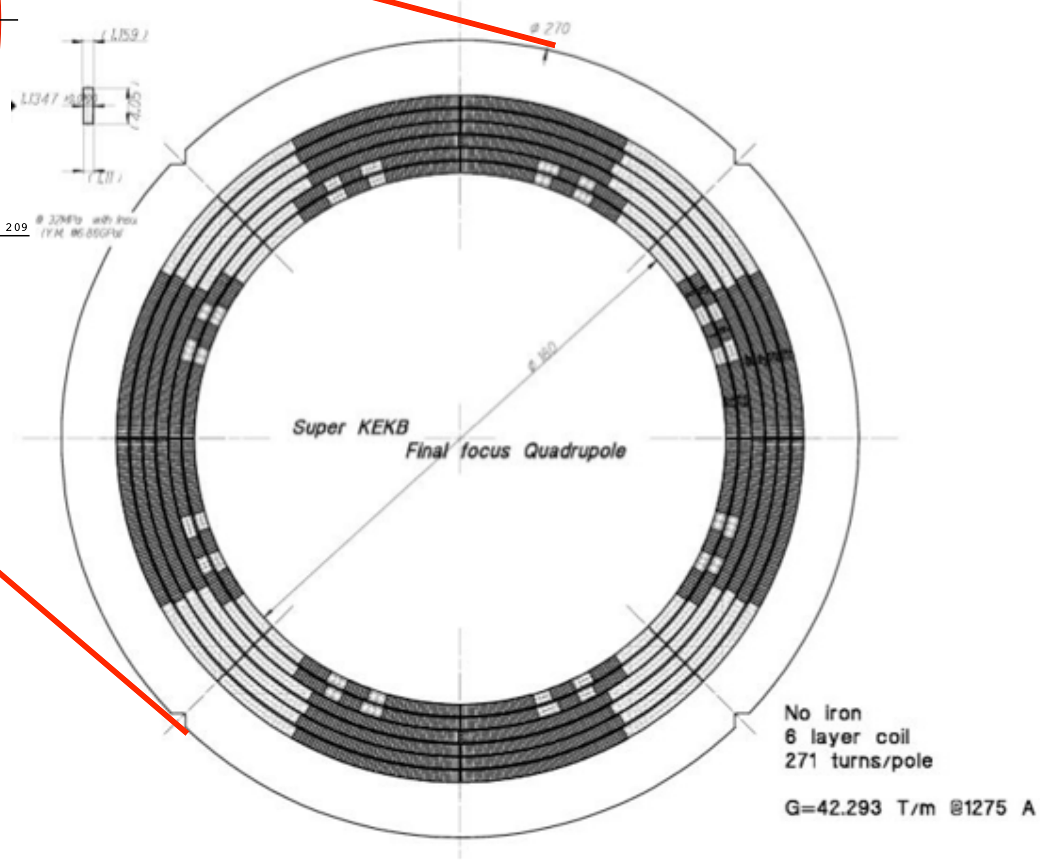


Cross Section of QCS (R side) R&D Magnet for SuperKEKB





Longitudinal Cross Section of Super KEKB QCS (R-side) R&D Magnet

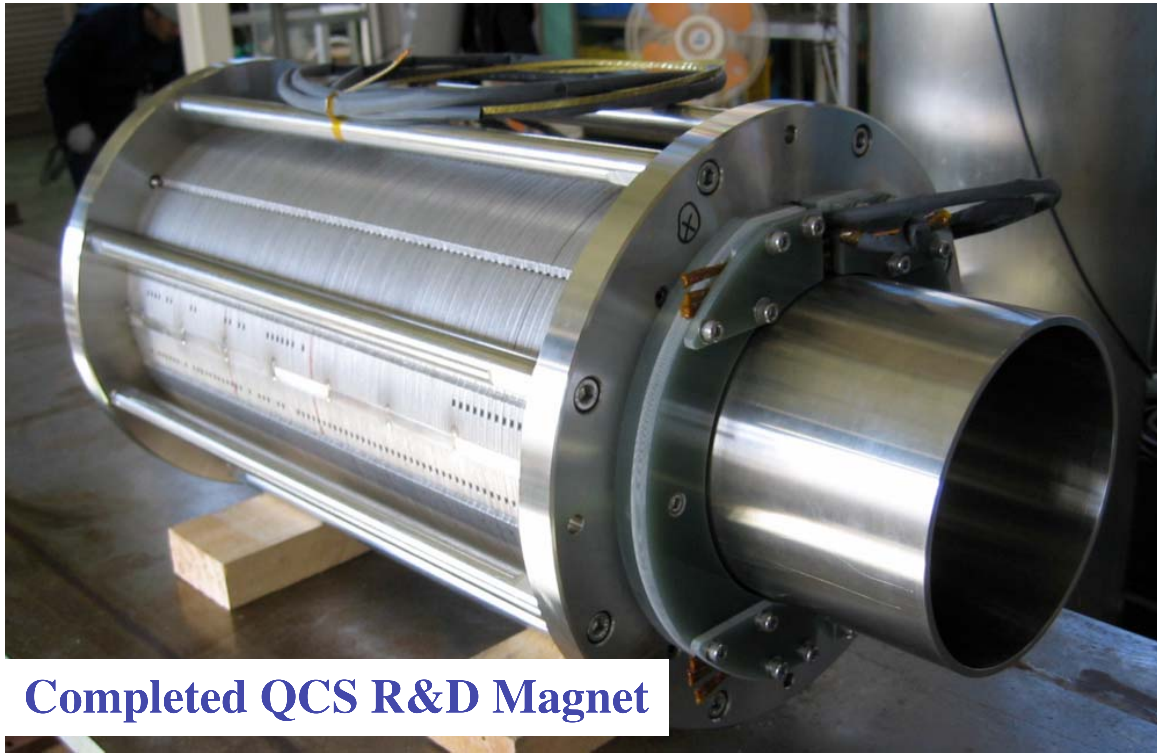


QCS R&D Magnet Parameters

- 6 layer coils
- Inner coil radius : 90.0 mm
- Cable size : 1.1mm × 4.1mm
- Number of turns : 271 in one pole
  - 1st layer = 38, 2nd layer = 39
  - 3rd layer = 46, 4th layer = 47
  - 5th layer = 50, 6th layer = 51
- Field gradient : 40.124 T/m
- Magnet current : 1186.7 A
- Magnetic length : 0.299 m

Construction of QCS realtype magnet for R&D

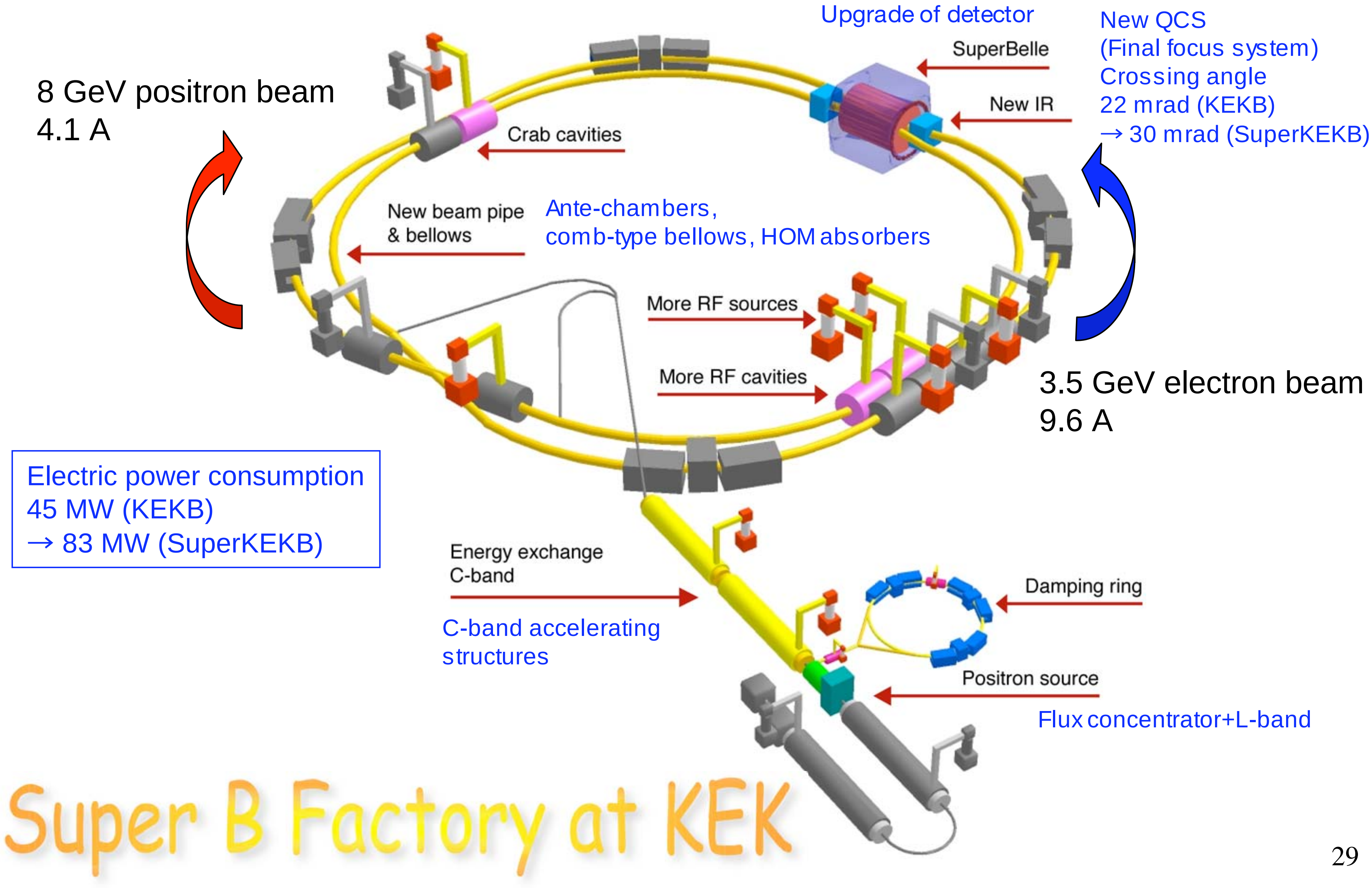
12 double pancake coils for the one magnet



Completed QCS R&D Magnet

Preparation for the vertical test

Upgraded components for SuperKEKB



Electric power consumption
45 MW (KEKB)
→ 83 MW (SuperKEKB)

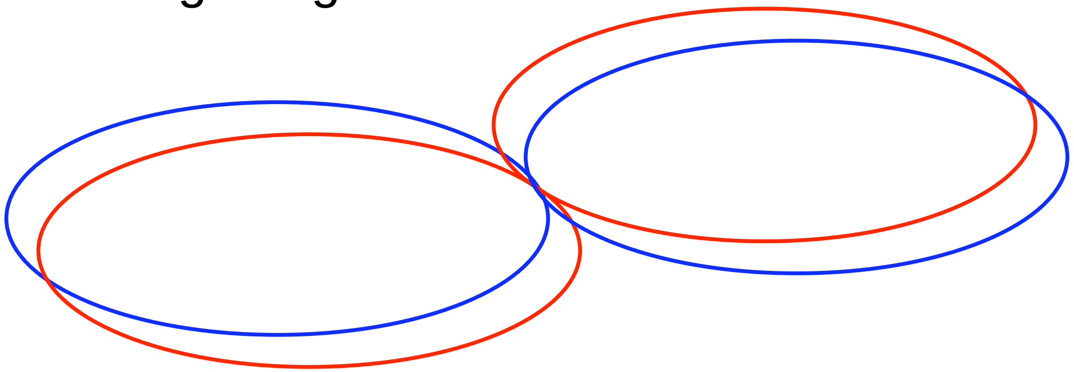
Comments on new ideas

Four-beam scheme

Traveling focus scheme

Four-beam scheme

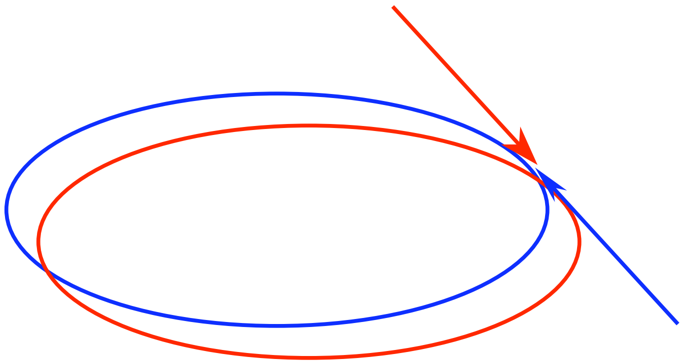
4-storage ring

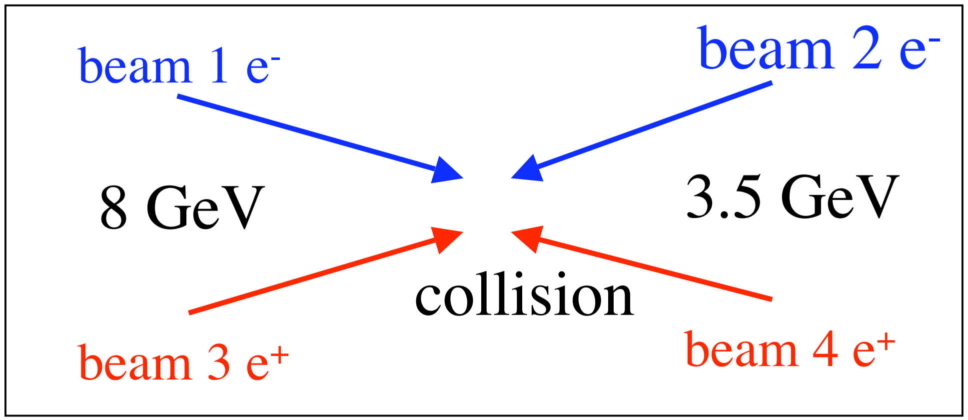


What is four beams ?

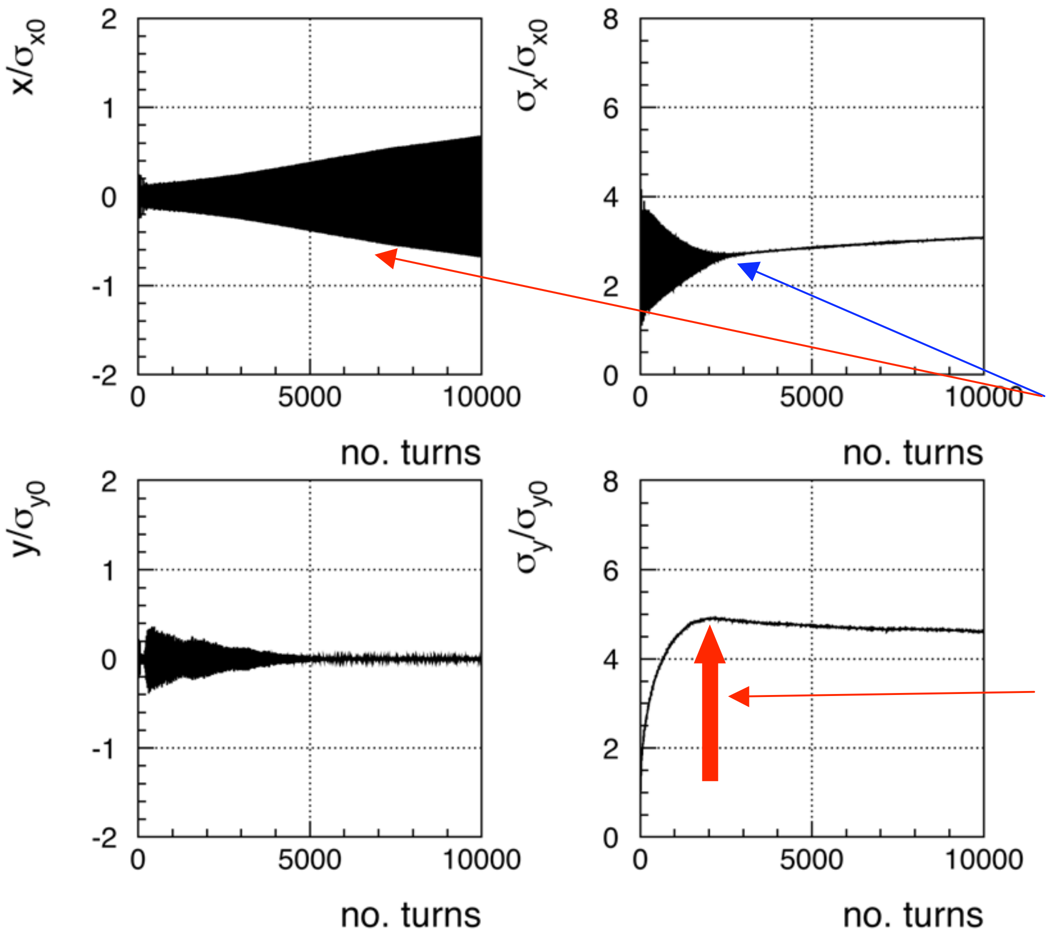
- Four beams is one method to compensate beam-beam effect to increase luminosity.
- The colliding bunches have neutral net charges and produce no beam-beam forces.
- This scheme was studied at DCI (Orsay) in 1975~1980.

2-storage ring with 2-linear accelerator
(Beam-beam compensation scheme)





Four-beam scheme: Strong-strong simulation



Four-storage ring scheme
tune = (.515,.55)
bunch-by-bunch feedback ON
(damping time = 1 msec (100 turns))

Horizontal quadrupole oscillation is damped,however dipole oscillation amplitude is increasing.

Vertical beam size blow-up is observed.

Four-beam scheme (cont'd)

- The stable working region becomes small if one try to get higher beam-beam parameter.
- Coherent dipole motion and incoherent quadrupole motion
- The important point is how to cure higher-order motions even though the dipole motion can be controlled by using (powerful) bunch-by-bunch feedback system.
- Coherent dipole motion does not occur in the case of 2-storage ring with 2-linear accelerator.
- Four-linear beam is better ?

Traveling focus

V.A. Balakin, N.A. Solyak, NIM A355 (1995) 142-149

Beam disruption

Beam disruption is defined by the ratio of the bunch length to the focal length:

$$D_{x,y} = \frac{4\pi\xi_{x,y}}{\beta^*_{x,y}}\sigma_z \qquad \text{where} \quad \xi_{x,y} = \frac{r_e N \beta^*_{x,y}}{2\pi\gamma\sigma^*_{x,y}\left(\sigma^*_x + \sigma^*_y\right)}$$

$$= \frac{2 r_e N \sigma_z}{\gamma\sigma^*_{x,y}\left(\sigma^*_x + \sigma^*_y\right)}$$

Beam disruption indicates strength of "pinch effect" produced by beam-beam interaction.

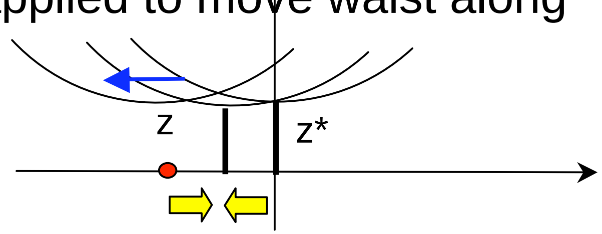
"LinearB" D_x/D_y = 1.6/223 (LEB)
D_x/D_y = 0.9/128 (HEB)

Vertical disruption is very high !
This induces vertical emittance growth.

Traveling focus improves pinching and relaxes the requirements on the vertical emittance, enhancing the luminosity.

Traveling focus with RF quadrupole(?) can be applied to move waist along the colliding bunch.

$$y = y + czp_z \qquad (c = -1)$$



Preliminary parameters of "Linear SuperB"

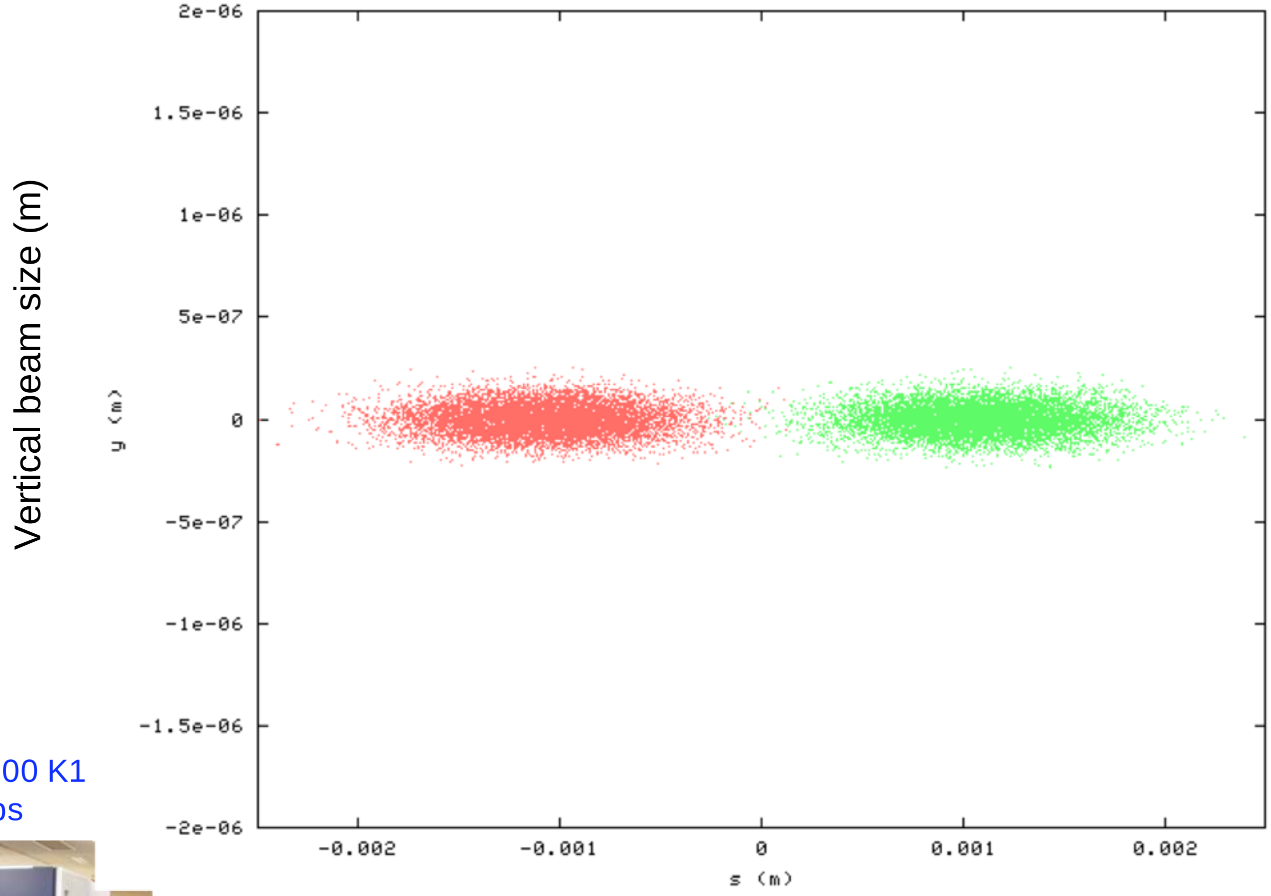
SuperB: a linear high-luminosity B Factory
INFN Roadmap Report, INFN-AE 05-08, 20 December 2005

		LEB	HEB	
Beam Energy	E	4	7	GeV
Number of bunches	n_b	10000		
Collision frequency/bunch	f_{col}	120		Hz
Energy spread at IP	$s_{Dp/p}$	0.125	0.1	%
#particles/bunch	N	10^{11}		
Horizontal beta at IP	b_x*	22		mm
Vertical beta at IP	b_y*	0.5		mm
Horizontal emittance	e_x	0.7		nm
Vertical emittance	e_y	0.0016		nm
Bunch length	s_z	0.35		mm
Horizontal beam size at IP	s_x*	4		mm
Vertical beam size at IP	s_y*	0.028		mm
Luminosity	L	$1x10^{36}$		$cm^{-2}s^{-1}$

Beam-beam simulation with traveling focus

We have just started.

code by K. Ohmi



Hitachi SR11000 K1
2.15 TFlops

L = 1.04×10^{32} $cm^{-2}s^{-1}$/bunch
128x1024 (Dx=5×10^{-7}, Dy=8×10^{-9} m)
10^6 macro-particles

- This idea also implies longer bunch length can be applied with keeping high luminosity.
  - Advantage to relax HOM power and beam instabilities, especially for high beam-current storage ring

- How to realize "traveling focus" ?
  - Can RF-Q provide enough focus?

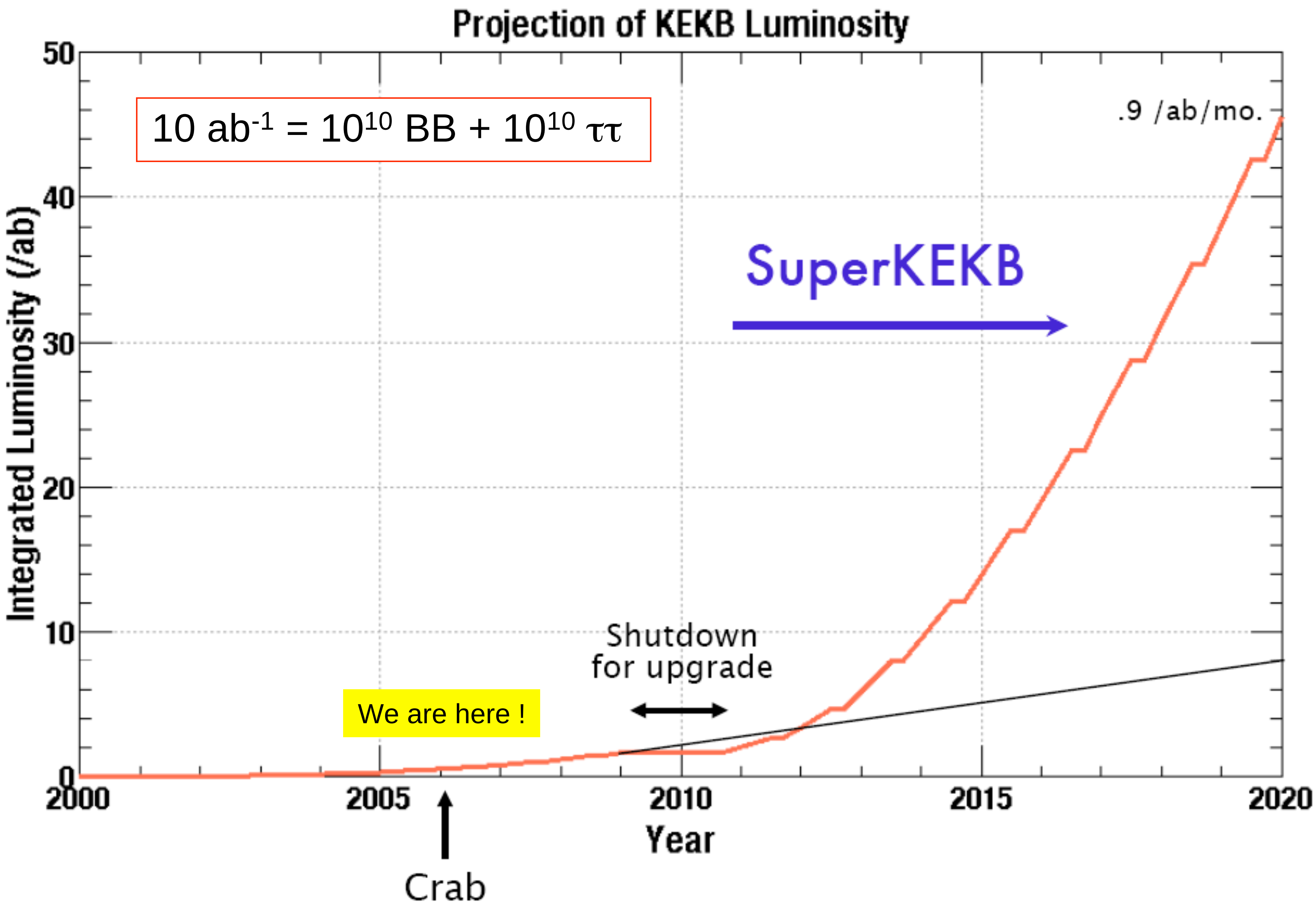
Non-scientific arguments (in my personal opinion)

- SuperKEKB R&D is in engineering phase not in conceptual phase.
  - Crab cavity, ante-chamber, new bellows, C-band structures, upgraded ARES, development of powerful bunch-by-bunch feedback system, new QCS, ...
  - These items have already been or will be tested at KEKB.
- However, we have a lot of other projects in Japan:
  - J-PARC, ILC, ERL, X-FEL, ...
  - Nobody can decide which has priority.
  - Budget of SuperKEKB: ~415 M$ in total is too expensive for particle physics in the current Japanese economy.
- We need an international agreement that a super B-factory should be constructed in the world.
  - International collaboration is obviously necessary.
- We will continue R&Ds for future high-luminosity machine unless KEKB is running.

Backup slides

Machine Parameters of the KEKB (Dec. 19 2005)

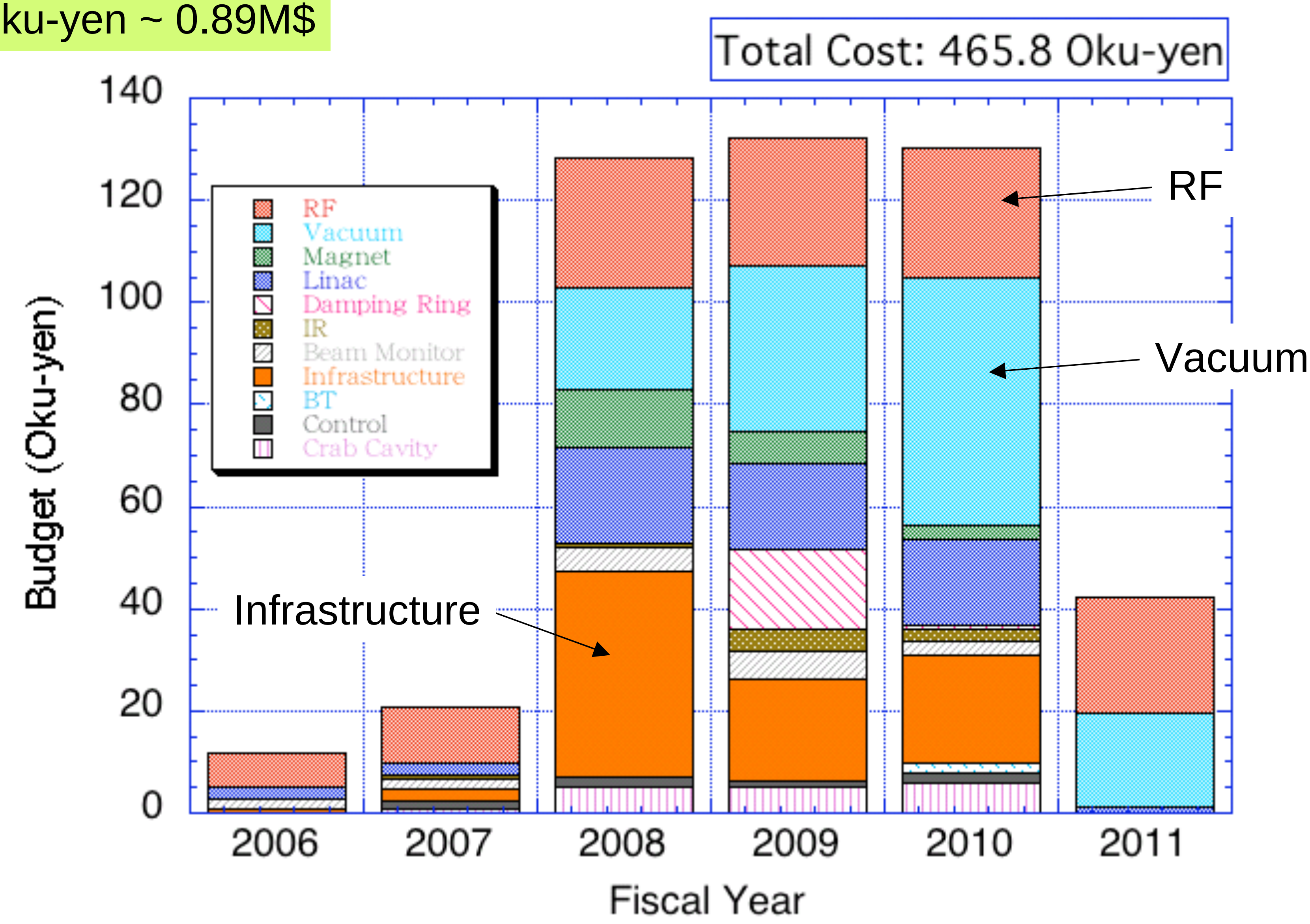
	LER	HER	
Horizontal Emittance	18	24	nm
Beam current	1719	1347	mA
Number of bunches	1388		
Bunch current	1.23	0.970	mA
Bunch spacing	2.1		m
Bunch trains	1		
Total RF volatage Vc	8.0	15.0	MV
Synchrotron tune ν_s	−0.0249	−0.0226	
Betatron tune ν_x / ν_y	45.506/43.531	44.512/41.578	
beta's at IP β_x^* / β_y^*	59/0.65	56/0.62	cm
Estimated vertical beam size at IP σ_y^*	2.1	2.1	μm
beam-beam parameters ξ_x / ξ_y	0.117/0.096	0.073/0.055	
Beam lifetime	135@1719	222@1347	min.@mA
Luminosity (Belle CsI)	16.27		10^{33}/cm^2/sec
Luminosity records per day / 7days/ 30days	1.183/7.358/29.02		/fb



Projection of KEKB Luminosity
10 ab-1 = 1010 BB + 1010 ττ
.9 /ab/mo.
SuperKEKB
Shutdown
for upgrade
We are here !
Integrated Luminosity (/ab)
Year
Crab
50
40
30
20
10
0
2000
2005
2010
2015
2020

SuperKEKB Budget Profile

Oku-yen ~ 0.89M$



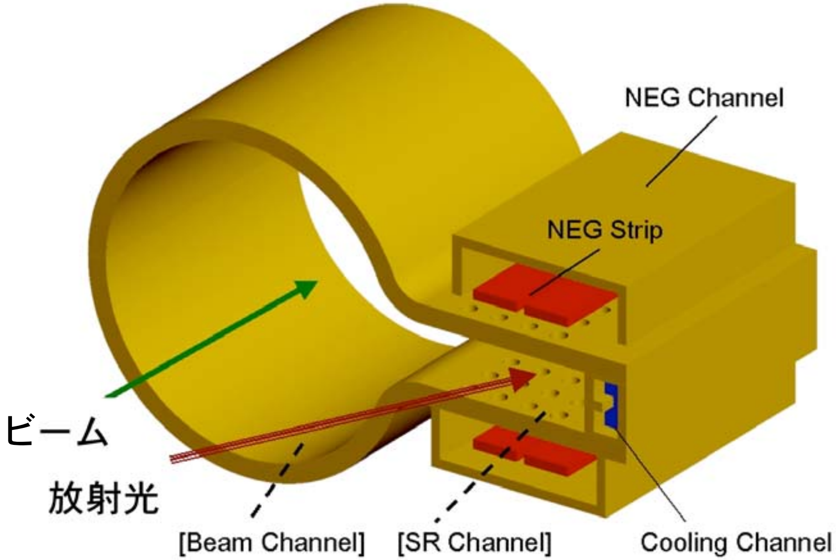
Other R&D status

Vacuum system

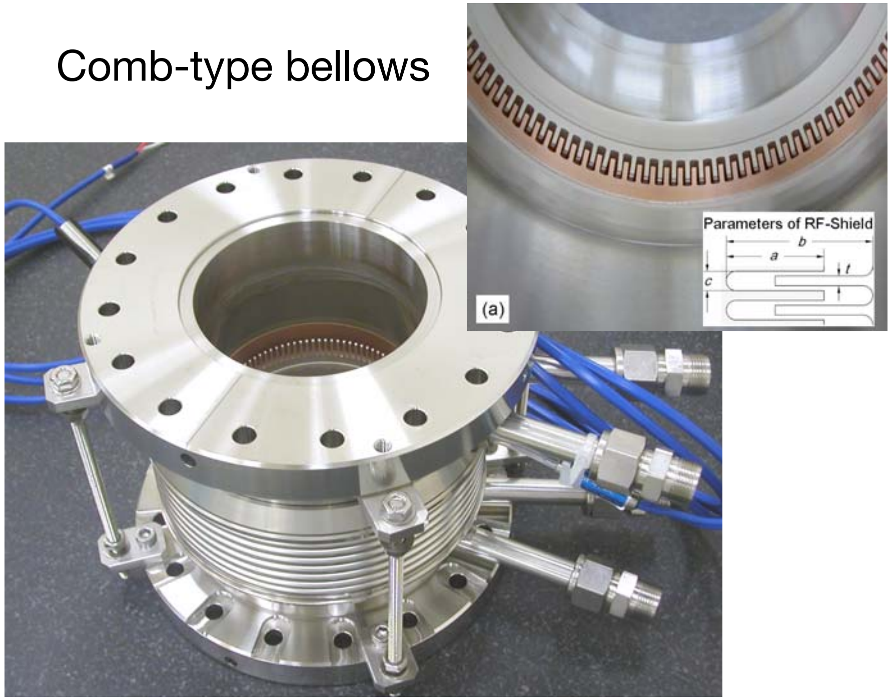
Final focus system (QCS)

Injector linac

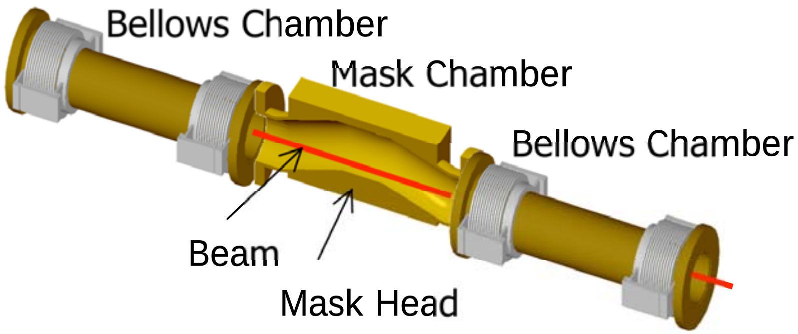
Ante-chamber



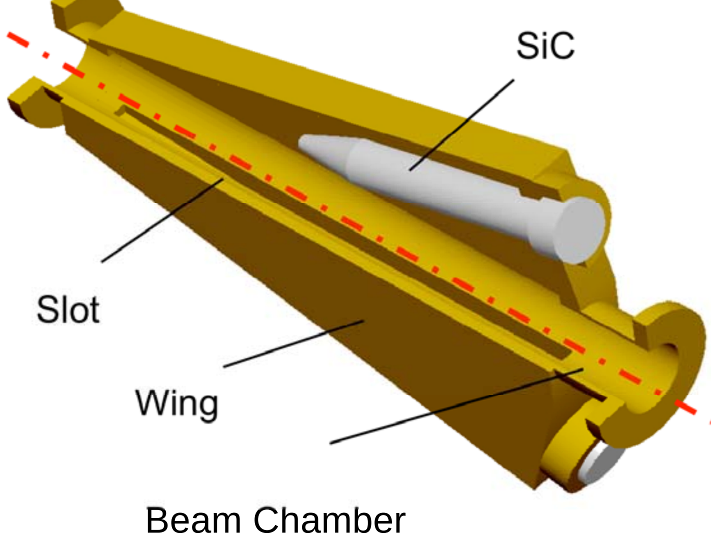
Comb-type bellows



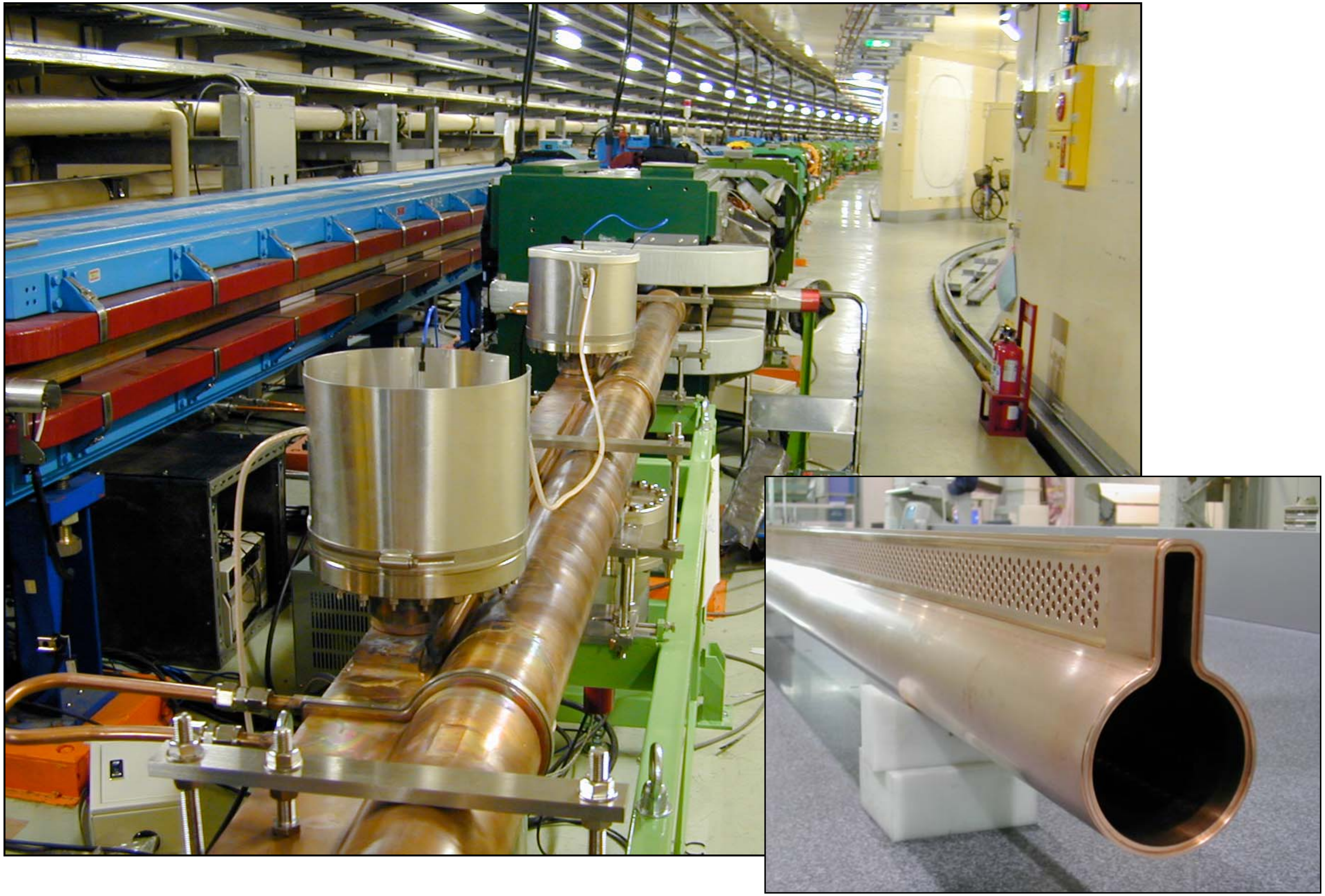
Movable mask



HOM absorber



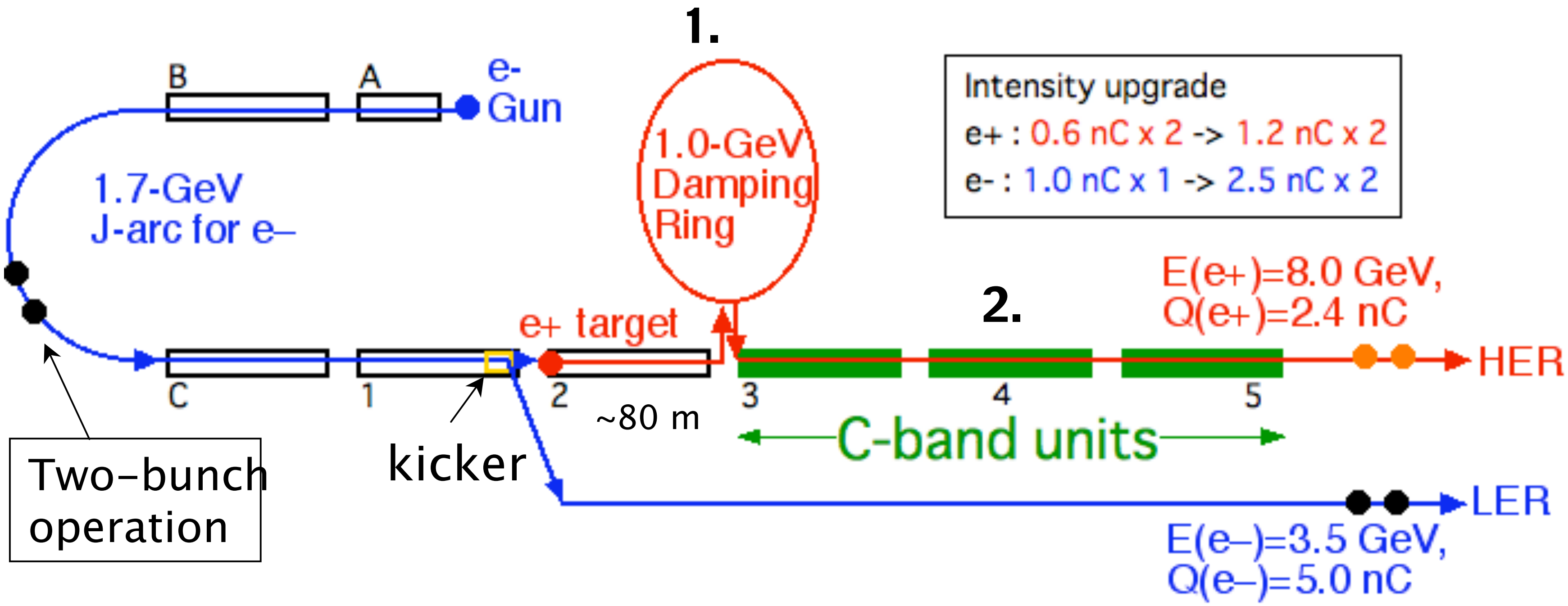
Test of prototype ante-chamber at KEKB(LER)



Upgrade of injector linac

- Exchange of beam energy: efficient injection and cure of electron cloud(if necessary).

8 GeV e- / 3.5 GeV e+ (KEKB)→ 8GeV e+ / 3.5GeV e- (SuperKEKB)

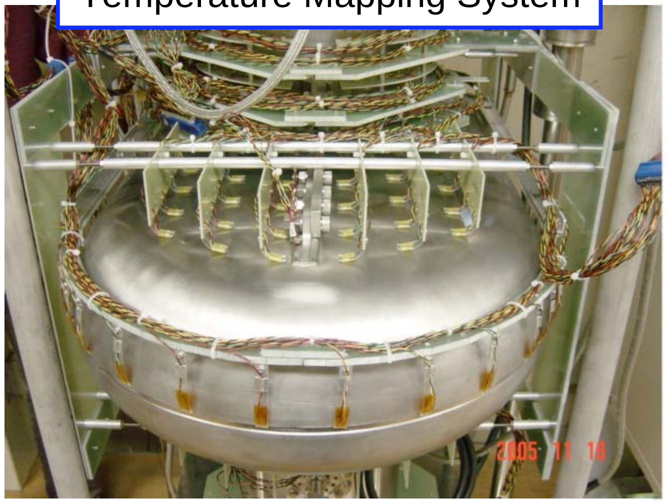


1. Positron damping ring (1 GeV)
2. C-band accelerating structure can make 8 GeV positron beam. (C-band : 40 MeV/m ⇔ S-band : 20 MeV/m)

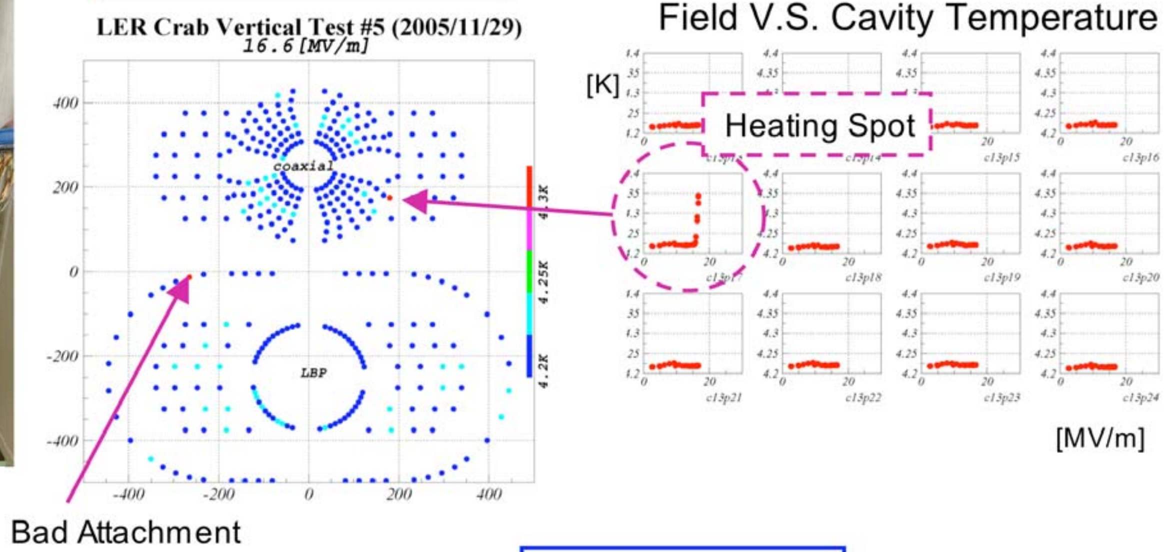

2006.03.03 20:28

LER crab cavity inside inspection

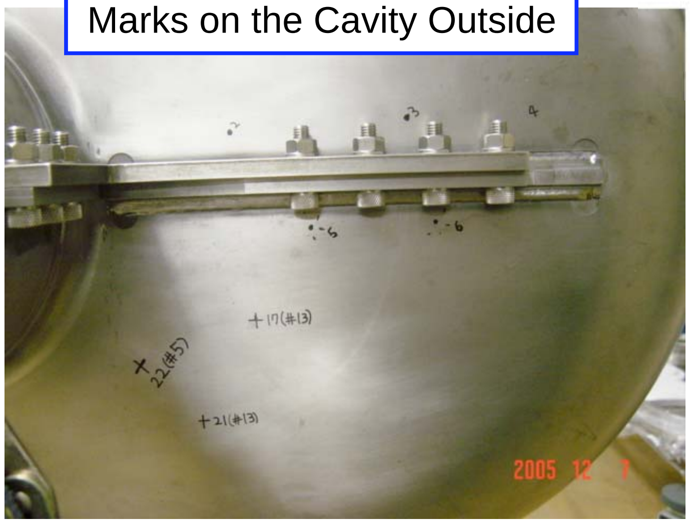
Temperature Mapping System



Temperature Mapping

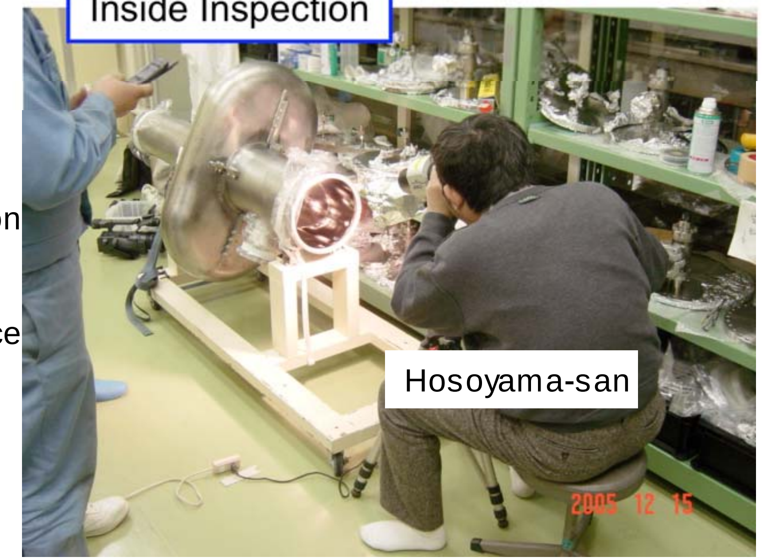


Marks on the Cavity Outside

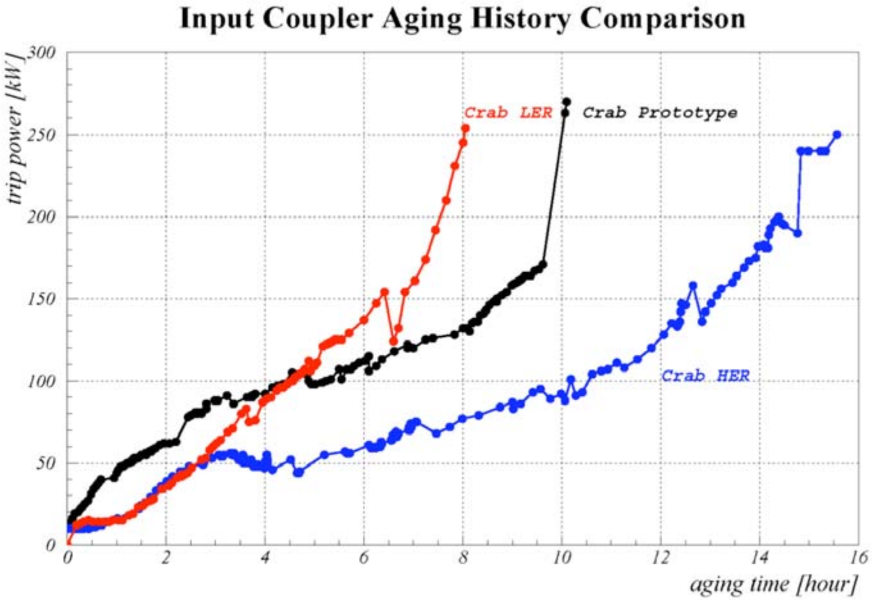


We found the contamination
around the marks.
And we got rid of it !
Then the cavity performance
became much better.

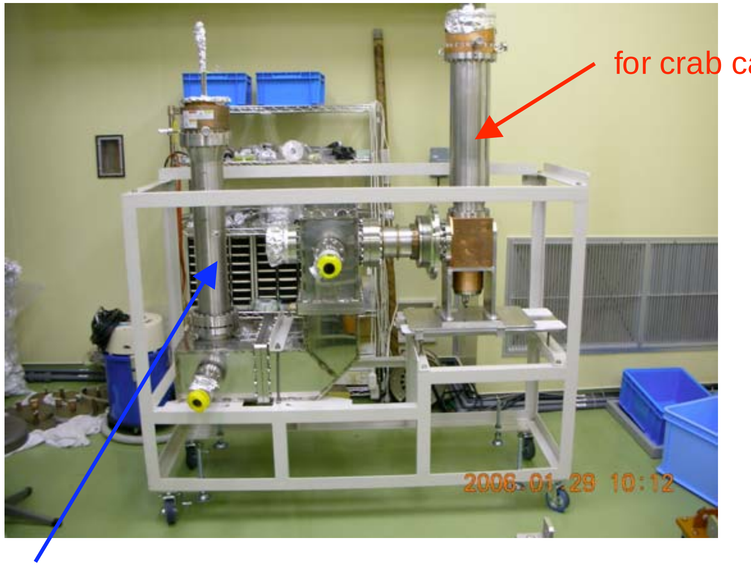
Inside Inspection



Input coupler conditioning

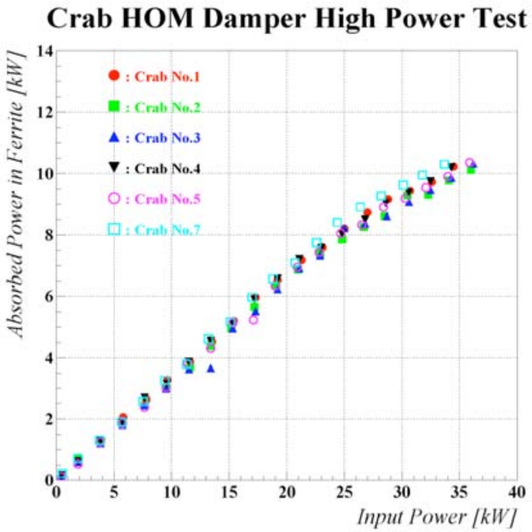


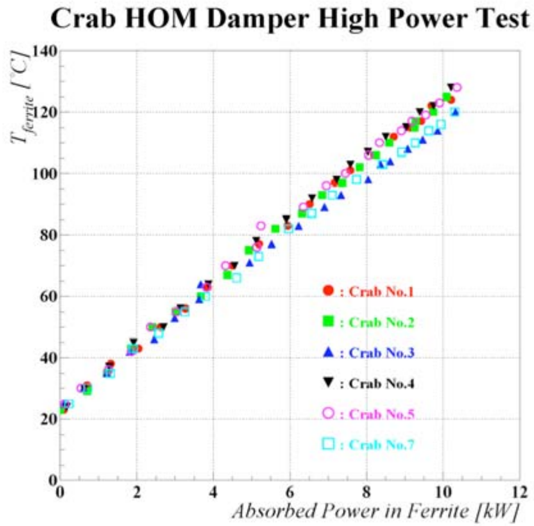
Input coupler conditioning



LER Coupler gets a good performance.
HER Coupler had a little trouble around the t-stub structure where the heating occurred.
The cooling water pipe was attached there to avoid this.

HOM damper high power test

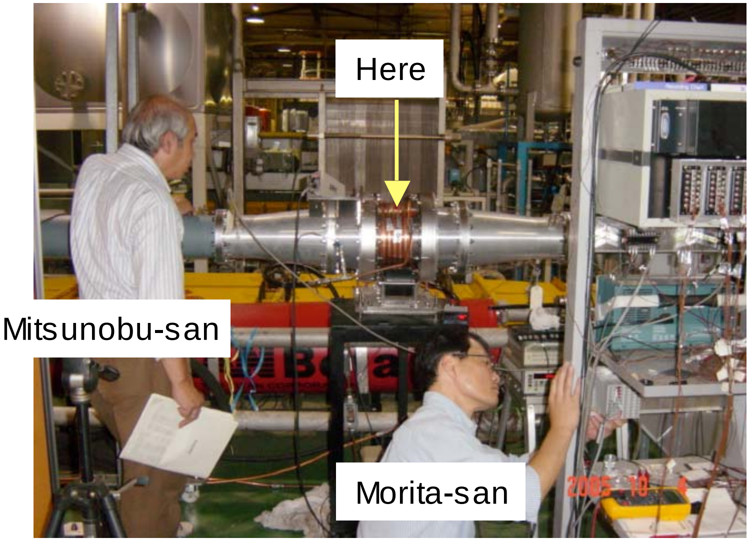




The max. surface temperature was around 130℃.

The absorbed power of 10kW was achieved.

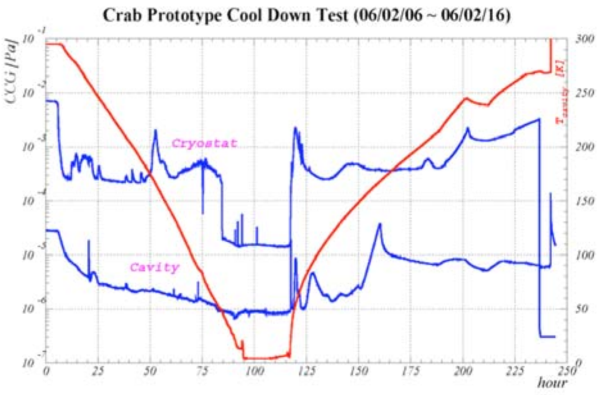
Six dampers had the almost same property.



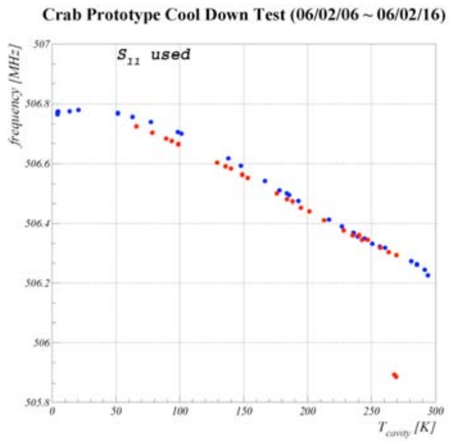
Surface inspection

Cold test of porototype crab cavity

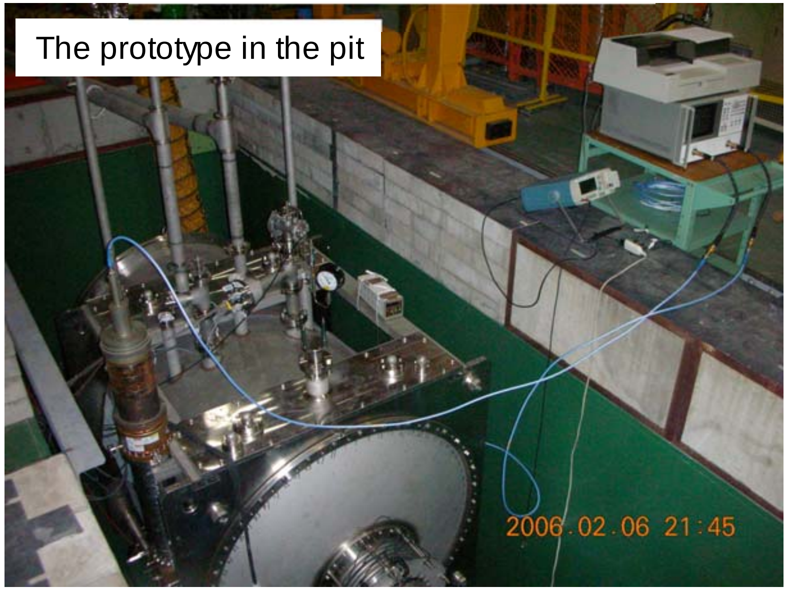
Time variation of the cavity and cryostat vacuum



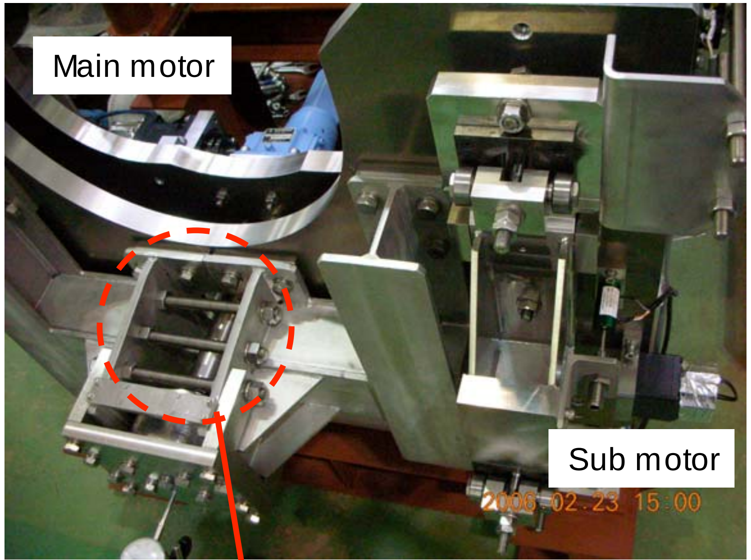
The temperature dependence of the frequency

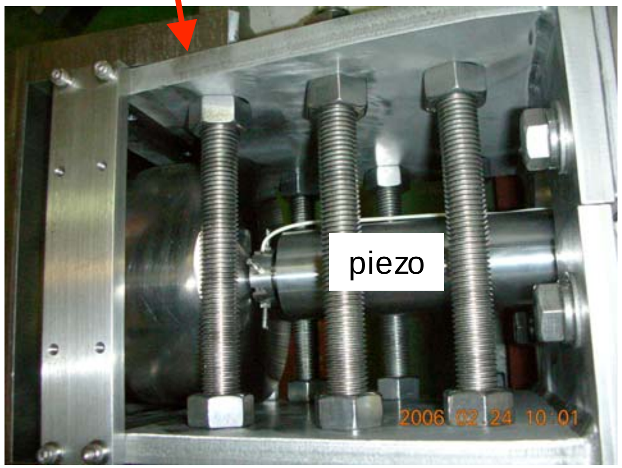


The cold test was done !



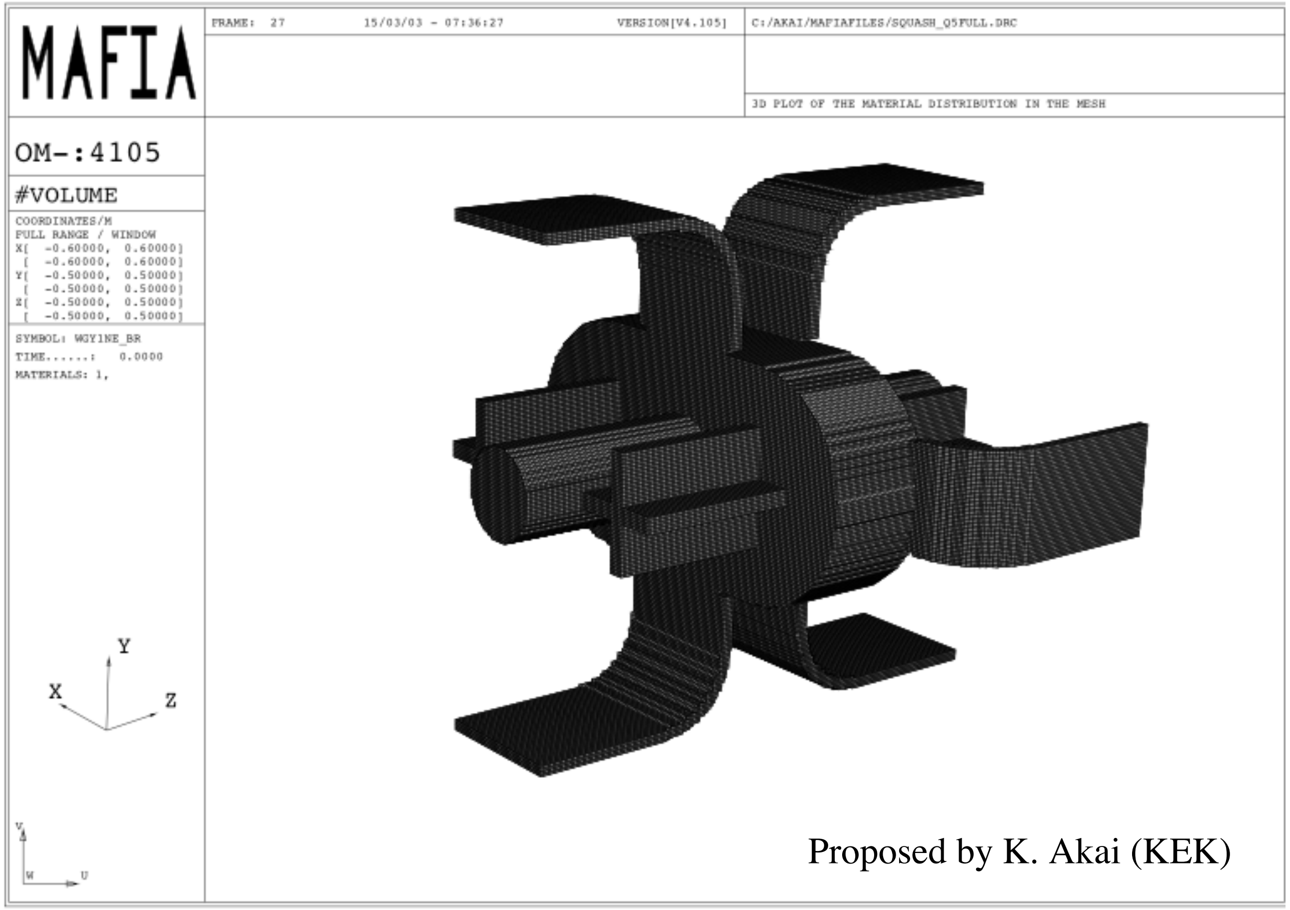
Tuner operation test





The tuner system can be operated without any troubles.

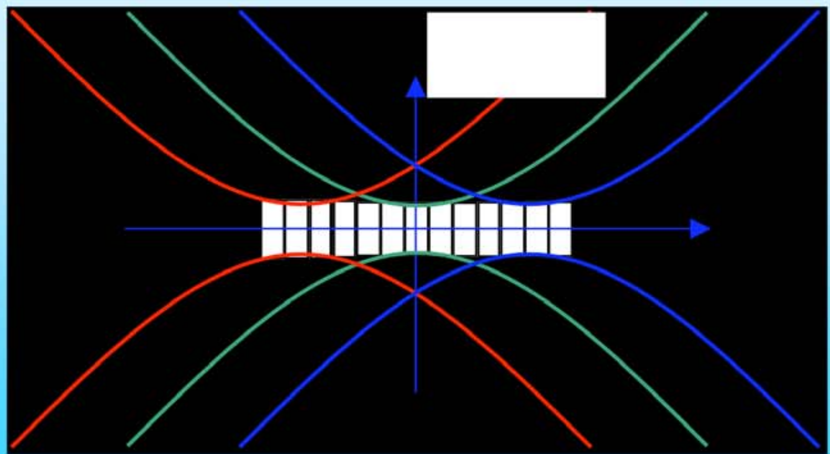
Cell and wave guides of new crab cavity for 10 A

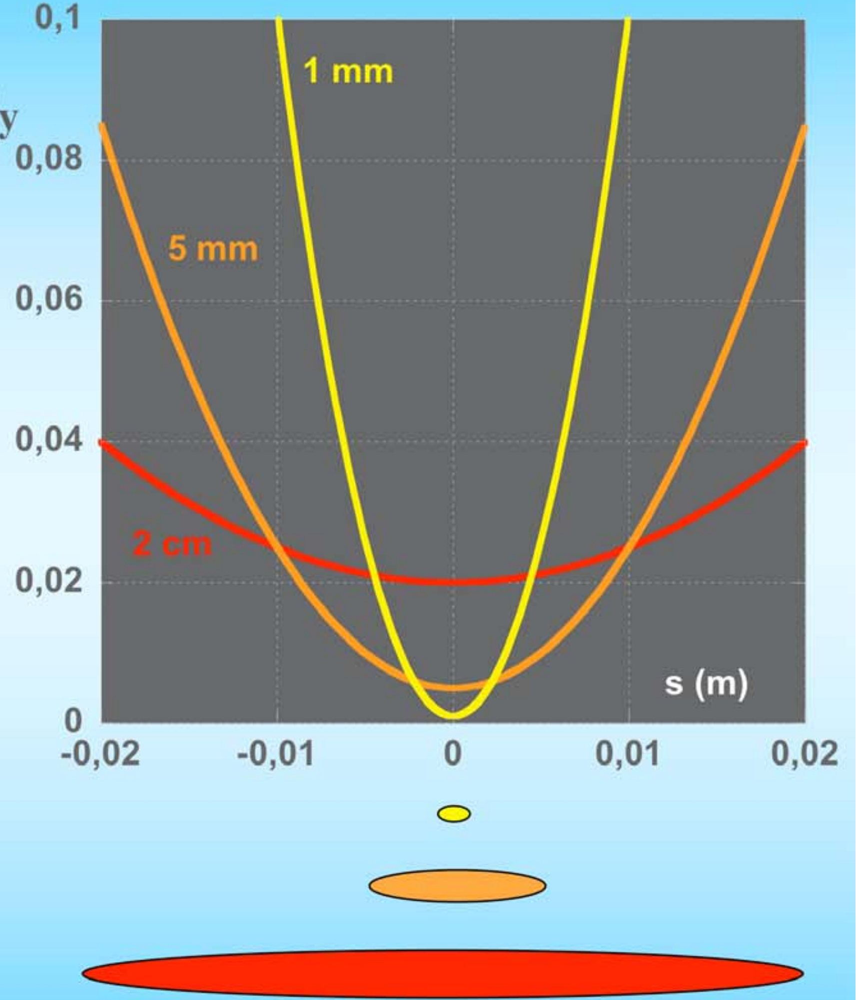


M.E. Biagini, DIF06

"Hourglass" effect

- Gain in L by squeezing the vertical bean size through the b_y only possible if the bunch length is also decreased
- Possible solution: "travelling focus" with RF quadrupole at IP to move waist along bunch length



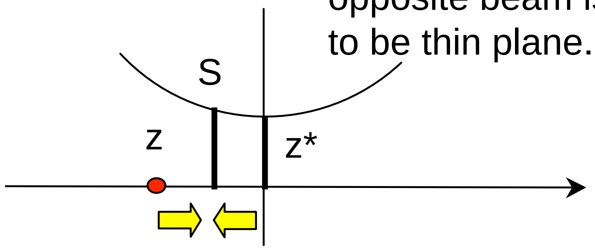


Bunch length

Tracking simulation with beam-beam kick

Location of the collision:

$$S\left(z,z^*\right)=\frac{z-z^*}{2}$$



Coordinate transformation:

$$\vec{x}_{new}=M_D^{-1}\left(S\left(z,z^*\right)\right)M_{BB}\left(S\left(z,z^*\right)\right)M_D\left(S\left(z,z^*\right)\right)\vec{x}_{org}$$

Drift space: M_D

$$\vec{x}_{ex}=\exp\left(-:\frac{p_x^2+p_y^2}{2}S\left(z,z^*\right):\right)\vec{x}_{in} \qquad \vec{x}=\left(x,p_x,y,p_y,z,\delta\right)$$

$$\boxed{\begin{array}{ll} x_2=x_1+p_{x1}S & p_{x2}=p_{x1} \\ y_2=y_1+p_{y1}S & p_{y2}=p_{y1} \\ z_2=z_1 & \delta_2=\delta_1-\left(p_{x1}^2+p_{y1}^2\right)/4 \end{array}}$$

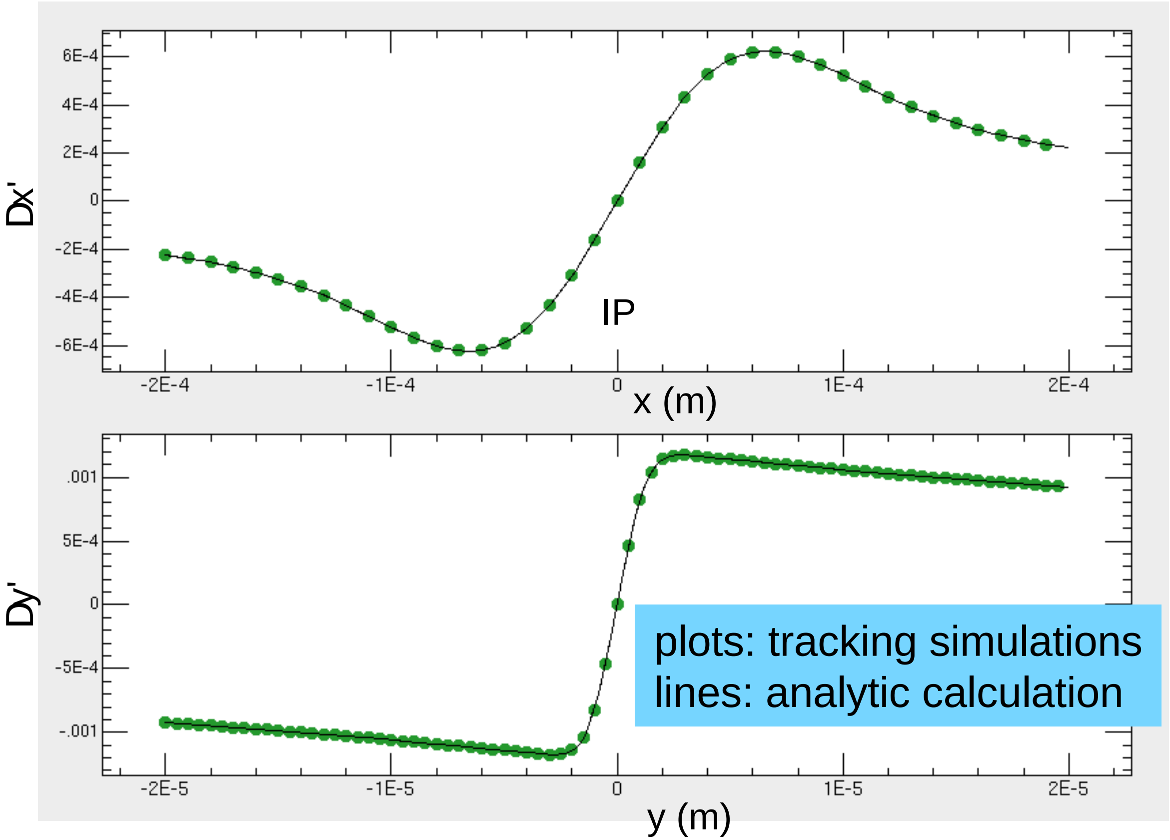
Tracking simulation with beam-beam interactions by SAD

Beam-beam kick:

$$\Delta x' = \frac{N_- r_e}{\gamma_+} F_x(x, y, \sigma_x, \sigma_y) R_{\xi x}(\theta, \beta_y, \sigma_x, \sigma_y, \sigma_z)$$

$$\Delta y' = \frac{N_- r_e}{\gamma_+} F_y(x, y, \sigma_x, \sigma_y) R_{\xi y}(\theta, \beta_y, \sigma_x, \sigma_y, \sigma_z)$$

Beam receives beam-beam kick at IP.



N_-=5.14x10^{10}
(4.1 A, 5018 bunches)

Dynamic beta, dynamic emittance are considered.

s_x = 50 mm
s_y = 1 mm
b_y = 2.4 mm
s_z = 3 mm
q = 0 rad

Tracking simulation with beam-beam kick

Beam size depends on z.

$$\begin{pmatrix}\beta_2\\ \alpha_2\\ \gamma_2\end{pmatrix}\varepsilon = M_{2\leftarrow 1}\begin{pmatrix}\beta_2\\ \alpha_2\\ \gamma_2\end{pmatrix}\varepsilon \qquad \sigma_{x,y} = \sqrt{\varepsilon_{x,y}\beta_{x,y}}$$

Transverse and longitudinal beam-beam kick: M_{BB}

$$\begin{cases} p_x \rightarrow p_x - f_x \\ p_y \rightarrow p_y - f_y \\ \delta \rightarrow \delta - g \end{cases}$$

$$f_x = \frac{N_{-} r_e}{\gamma_+} F_x\left(x, y, \sigma_x, \sigma_y\right) R_{\xi x}\left(\theta, \beta_y, \sigma_x, \sigma_y, \sigma_z\right)$$

$$f_y = \frac{N_{-} r_e}{\gamma_+} F_y\left(x, y, \sigma_x, \sigma_y\right) R_{\xi y}\left(\theta, \beta_y, \sigma_x, \sigma_y, \sigma_z\right)$$

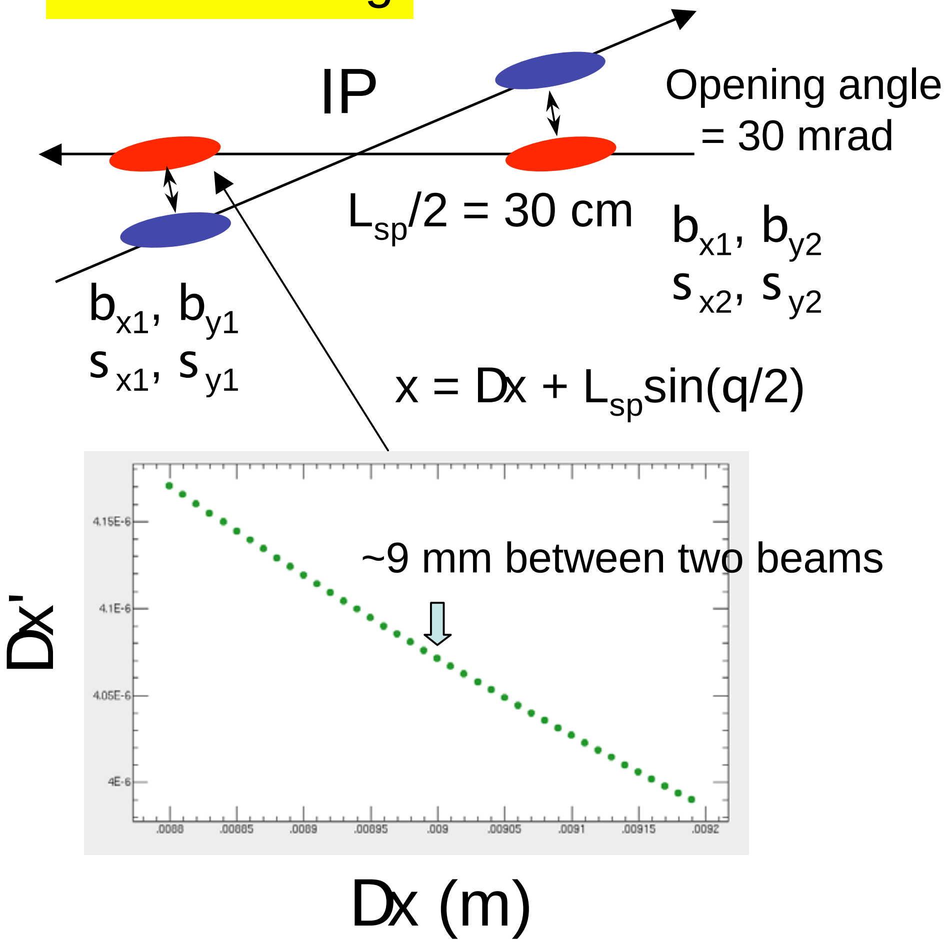
$$g = \frac{N}{2}\left(\frac{d\sigma_x^2}{ds}\frac{\partial U}{\partial \sigma_x^2} + \frac{d\sigma_y^2}{ds}\frac{\partial U}{\partial \sigma_y^2}\right)$$

$$= -\varepsilon_x \alpha_x \left(N\frac{\partial U}{\partial \sigma_x^2}\right) - -\varepsilon_y \alpha_y \left(N\frac{\partial U}{\partial \sigma_y^2}\right)$$

$$\begin{cases} N\dfrac{\partial U}{\partial \sigma_x^2} = -\dfrac{1}{2\left(\sigma_x^2 - \sigma_y^2\right)}\left\{ x f_x + y f_y + \dfrac{2Nr_e}{\gamma}\left[\dfrac{\sigma_y}{\sigma_x}\exp\left(-\dfrac{x^2}{2\sigma_x^2} - \dfrac{y^2}{2\sigma_y^2}\right) - 1\right]\right\} \\ N\dfrac{\partial U}{\partial \sigma_y^2} = +\dfrac{1}{2\left(\sigma_x^2 - \sigma_y^2\right)}\left\{ x f_x + y f_y + \dfrac{2Nr_e}{\gamma}\left[\dfrac{\sigma_x}{\sigma_y}\exp\left(-\dfrac{x^2}{2\sigma_x^2} - \dfrac{y^2}{2\sigma_y^2}\right) - 1\right]\right\} \end{cases}$$

Parasitic collision

Crab crossing



Beam size(includes dynamic effect)
at parasitic collision point

s_{x1} = 782 mm, s_{y1} = 127 mm

Beam-beam kick from parasitic collision

$$\Delta x'_1 = \frac{N_- r_e}{\gamma_+} F_x\left(x_1, y_1, \sigma_{x1}, \sigma_{y1}\right) R_{\xi x}\left(\theta, \beta_{y1}, \sigma_{x1}, \sigma_{y1}, \sigma_z\right)$$

$$\Delta y'_1 = \frac{N_- r_e}{\gamma_+} F_y\left(x_1, y_1, \sigma_{x1}, \sigma_{y1}\right) R_{\xi y}\left(\theta, \beta_{y1}, \sigma_{x1}, \sigma_{y1}, \sigma_z\right)$$