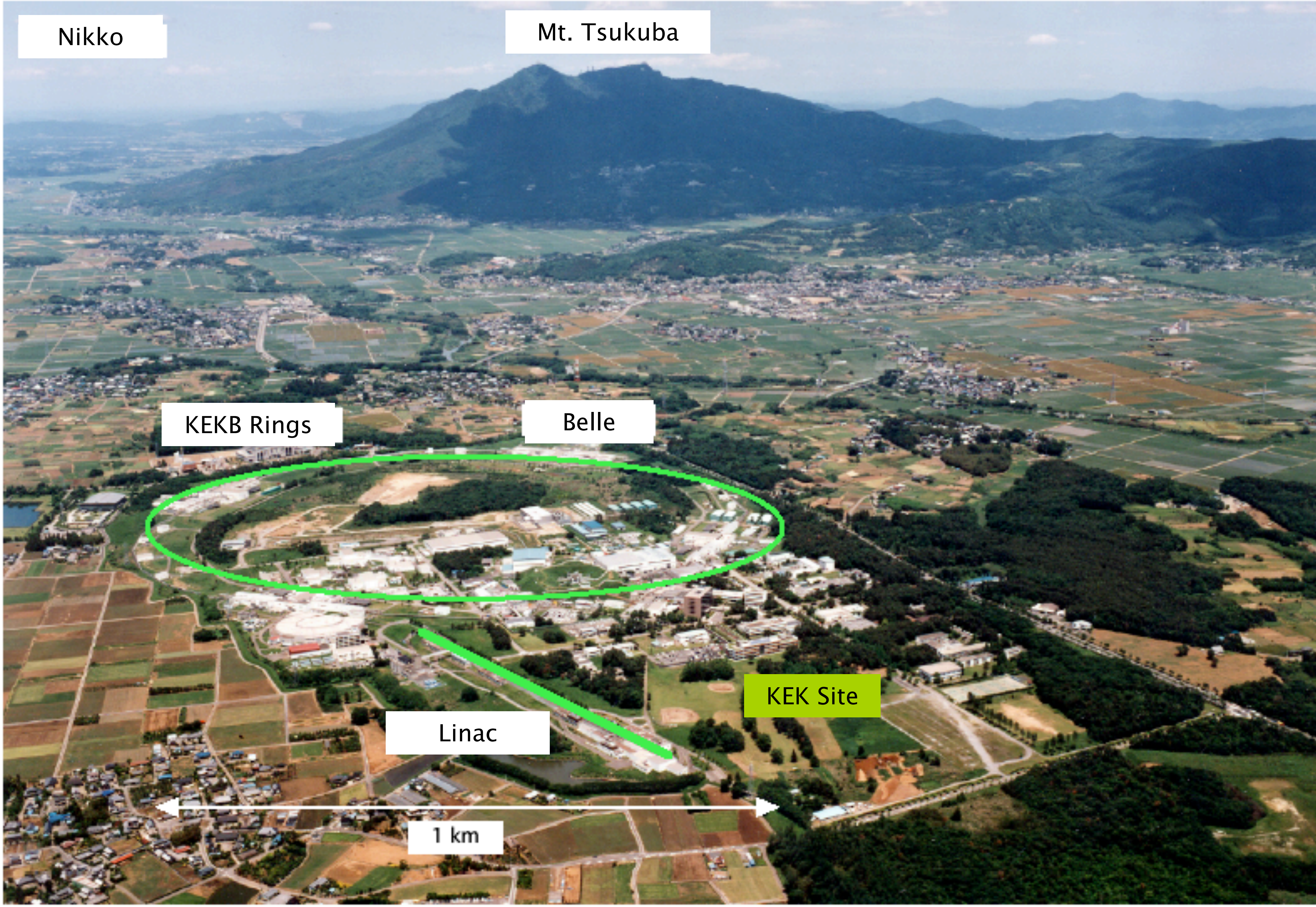
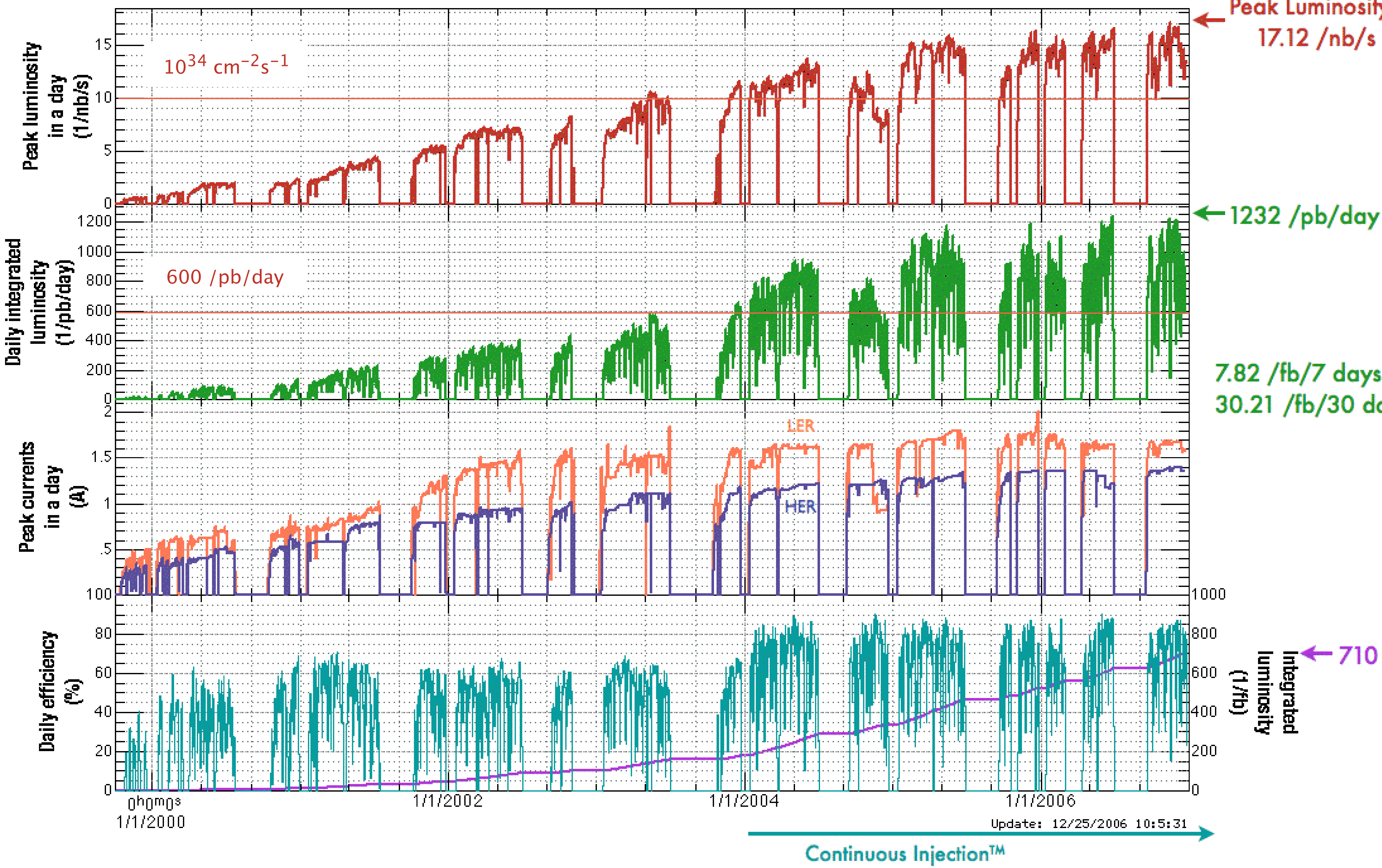
KEKB Upgrade

11 Dec 2007

K. Oide (KEK) @ DESY


Nikko
Mt. Tsukuba
KEKB Rings
Belle
KEK Site
Linac
1 km

Luminosity of KEKB
Oct. 1999 - Dec. 2006



The power of Continuous Injection Mode

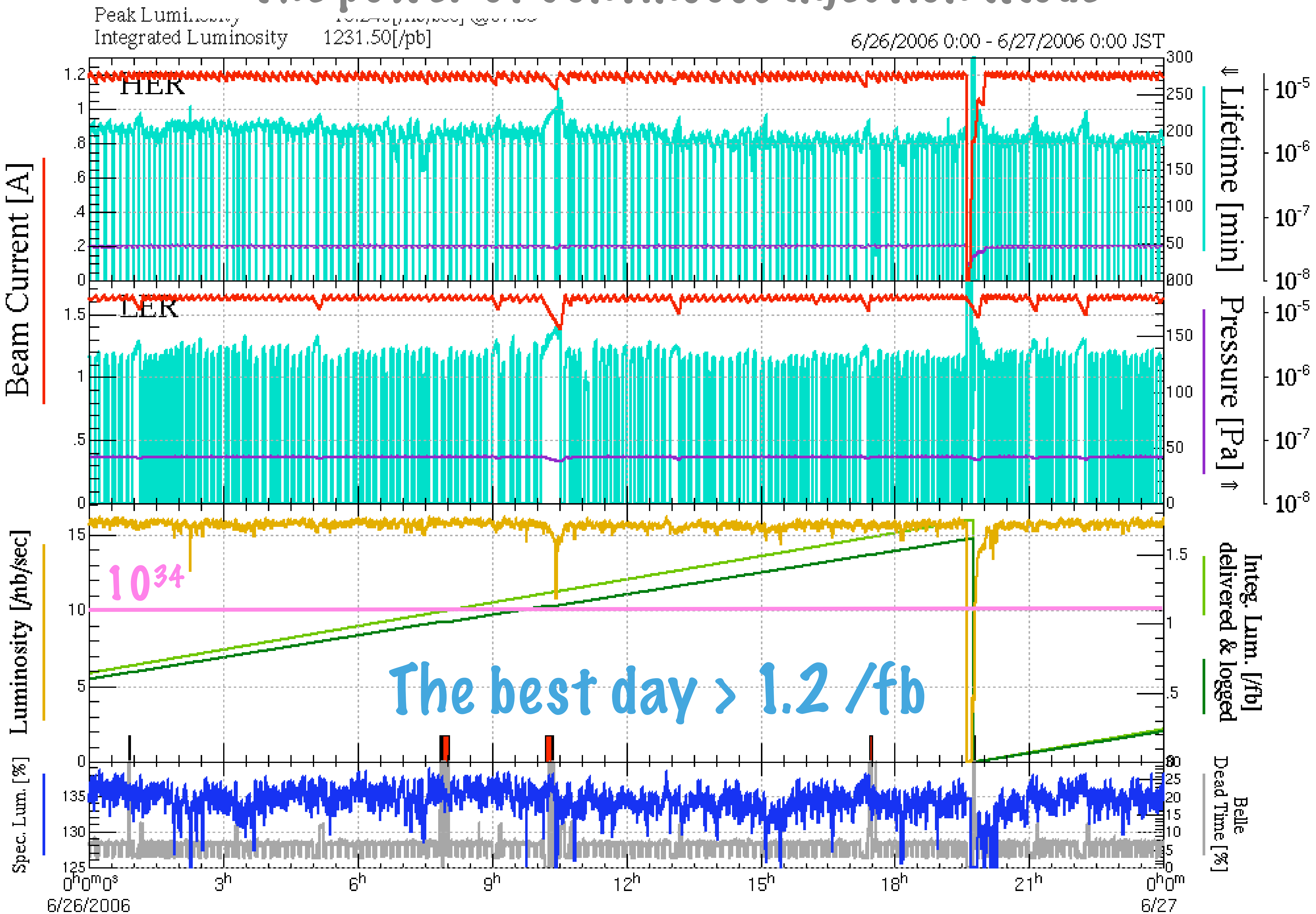


Table 1: Machine parameters of KEKB

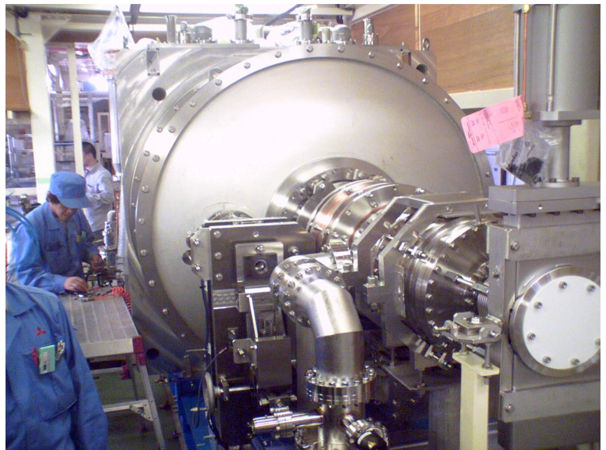
Date	**11/15/2006**		**Design**		
	LER	**HER**	**LER**	**HER**	
Current	1.65	1.33	2.6	1.1	A
Bunches/ring	1389		5000		
Bunch current	1.19	0.96	0.52	0.22	mA
Bunch spacing	1.8–2.4		0.6		m
Emittance ε_x	18	24	18	18	nm
β_x^*	59	56	33	33	cm
β_y^*	0.65	0.59	1.0	1.0	cm
Hor. size @ IP	103	116	77	77	μm
Ver. size @ IP	1.9	1.9	1.9	1.9	μm
Beam-beam ξ_x	0.115	0.075	.039	.039	
Beam-beam ξ_y	0.101	0.056	.052	.052	
Bunch length	7	6	4	4	mm
Luminosity	17.12		10		/nb/s
$\int$Lum./day	1232		~ 600		/pb
$\int$Lum./7 days	7.82		–		/fb
$\int$Lum./30 days	30.21		–		/fb

70% higher than the design

doubled the design

SuperKEKB

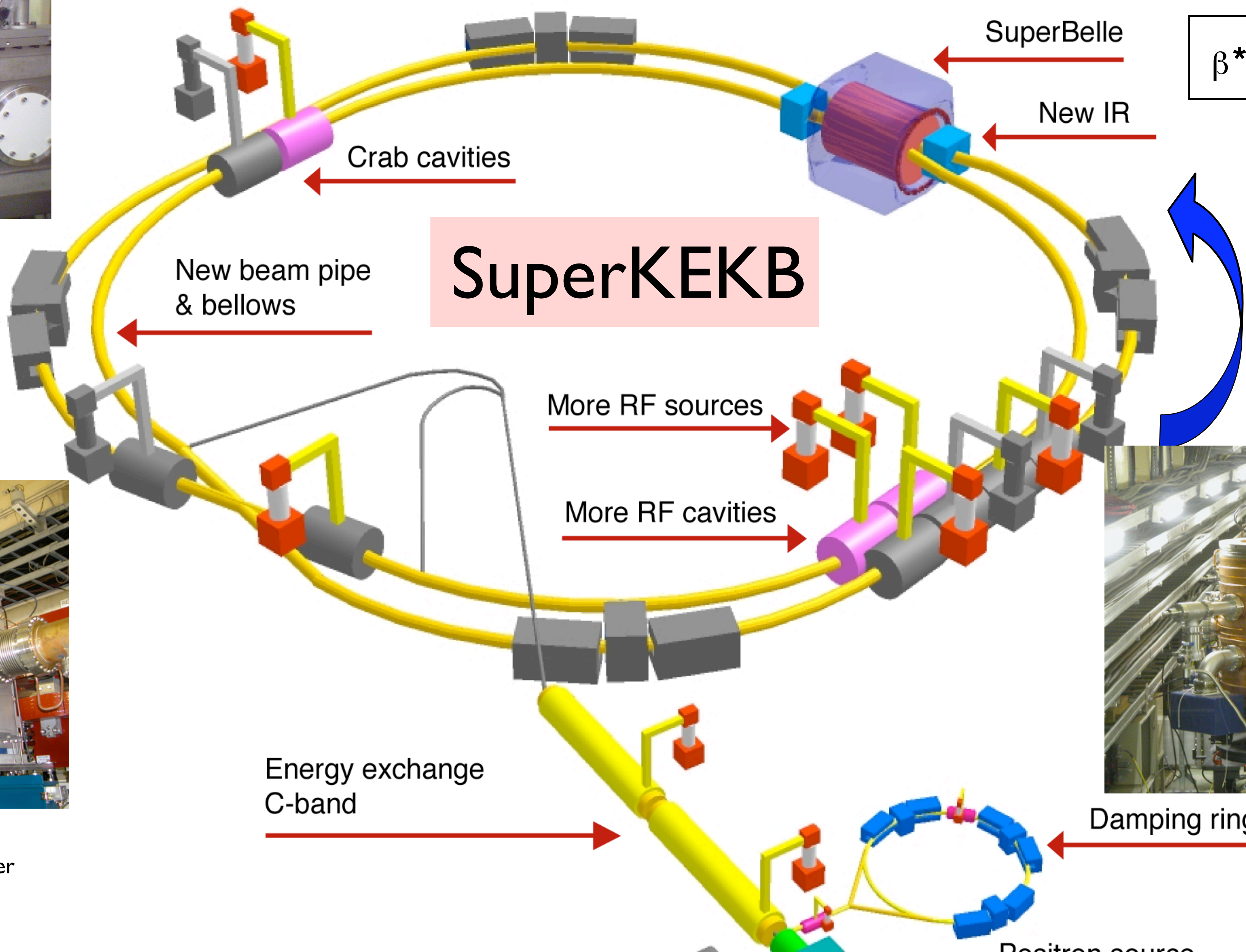
$\beta^*_y = \sigma_z = 3$ mm



Crab cavities will be installed and tested with beam in 2006.

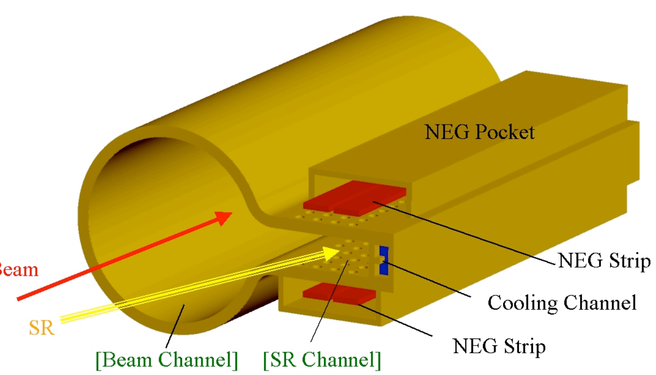
e+ 4.1 A

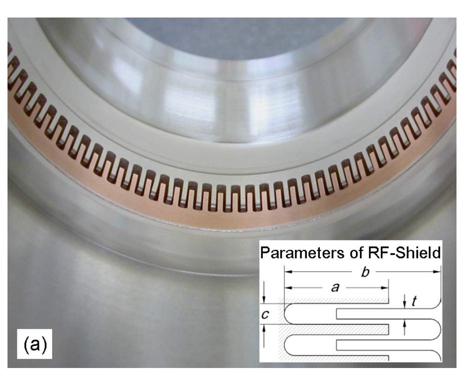
e- 9.4 A



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

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 with higher-current-proof design.

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

will reach 8×10^{35} cm^{-2}s^{-1}.

Three factors to determine luminosity:

Stored current:

1.7 / 1.4 A (e^+/ e^- KEKB)

→ 9.4 /4.1 A (SuperKEKB)

Beam-beam parameter:

0.059 (KEKB)

→ >0.24 (SuperKEKB)

Lorentz factor

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

Classical electron radius

Beam size ratio

Geometrical repipeion factors due to crossing angle and hour-glass effect

Luminosity:

0.17×10^{35} $cm^{-2}s^{-1}$ (KEKB)

8×10^{35} $cm^{-2}s^{-1}$ (SuperKEKB)

Vertical β at the IP:

6.5/5.9 mm (KEKB)

→ 3.0/3.0 mm (SuperKEKB)

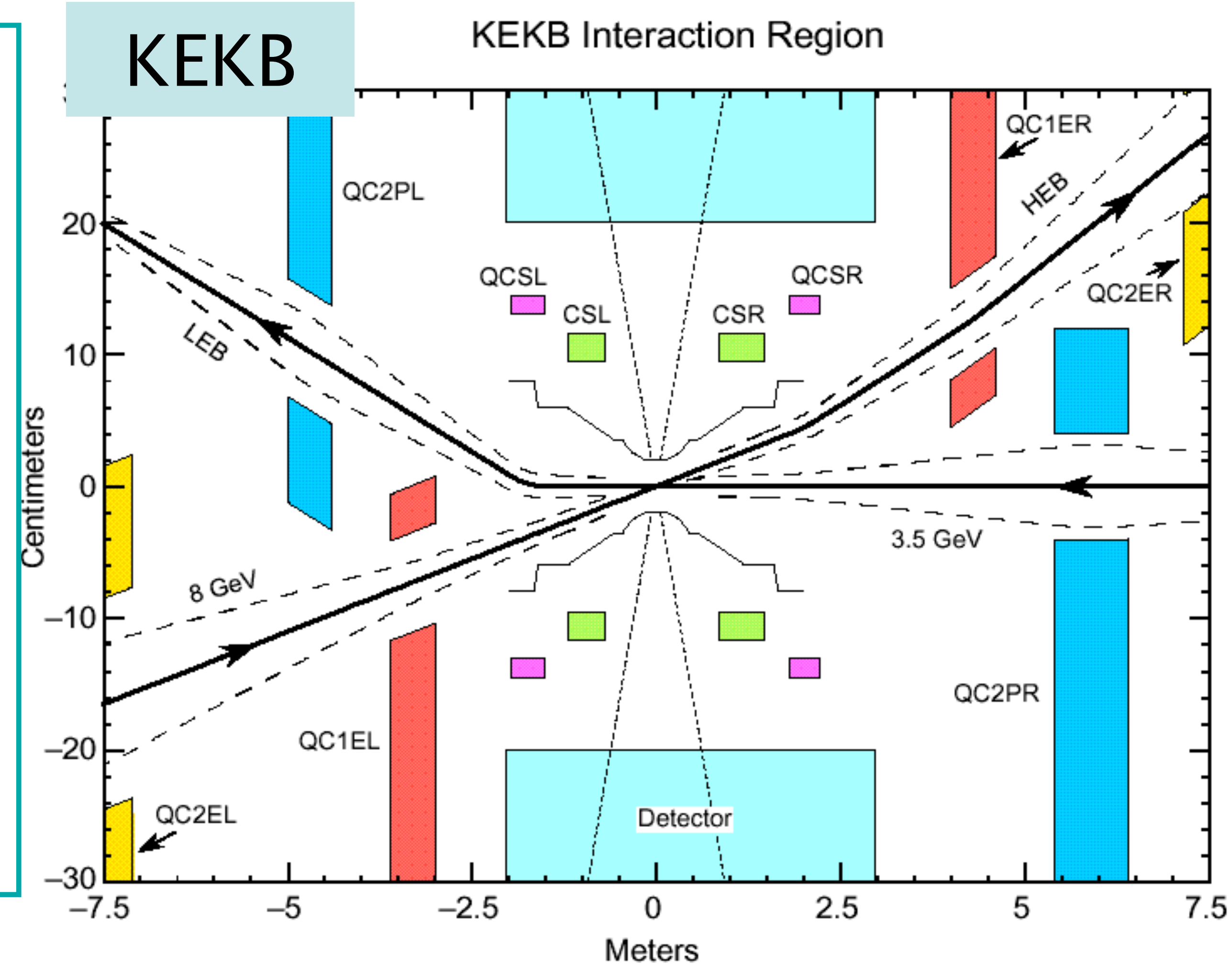
New Parameter Set for 8×10^{35} -- by K. Ohmi

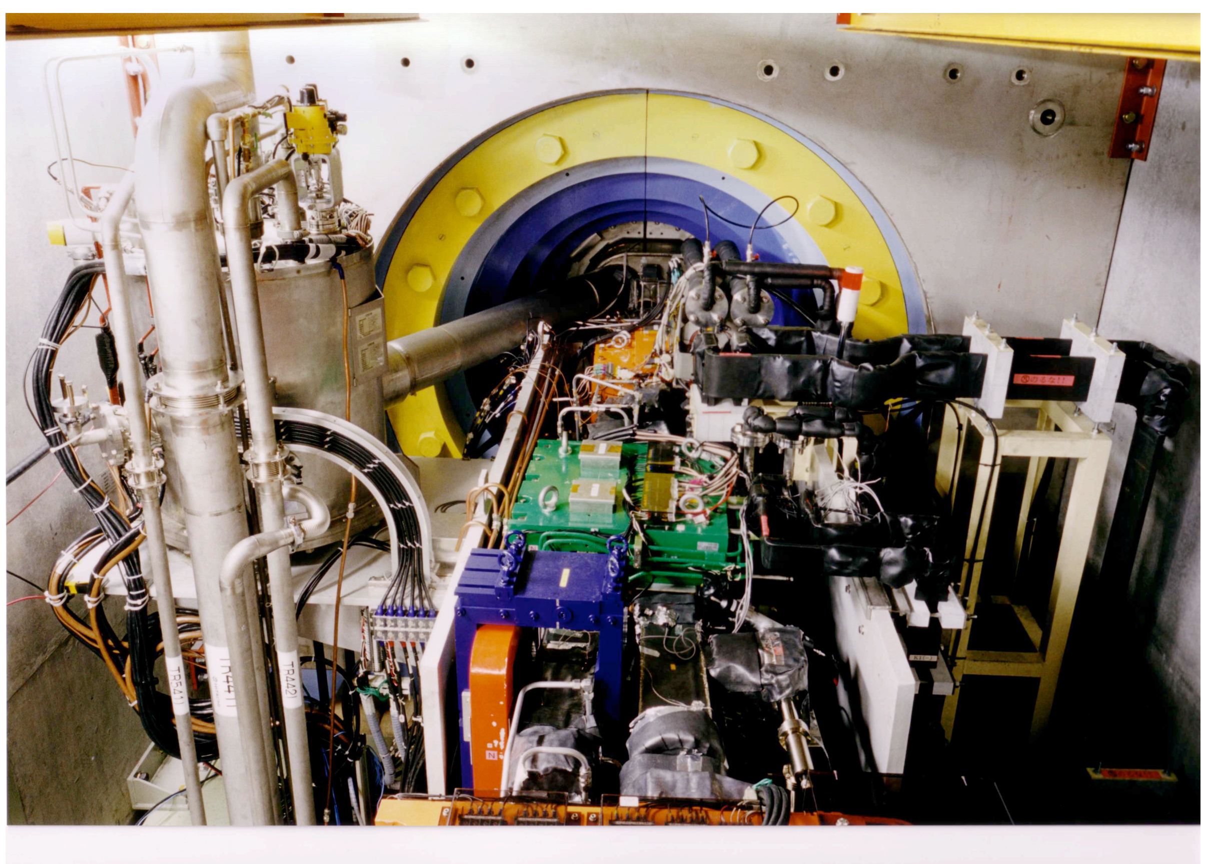
	SuperKEKB	Crab waist			
εx	9.00E−09	6.00E−09	6.00E−09	6.00E−09	6.00E−09
εy	4.50E−11	6.00E−11	6.00E−11	6.00E−11	6.00E−11
βx (mm)	200	100	50	100	50
βy (mm)	3	1	0.5	1	0.5
σz (mm)	3	6	6	4	4
νs	0.025	0.01	0.01	0.01	0.01
ne	5.50E+10	5.50E+10	5.50E+10	3.50E+10	3.50E+10
np	1.26E+11	1.27E+11	1.27E+11	8.00E+10	8.00E+10
φ/2 (mrad)	0	15	15	15	15
ξx	0.397	0.0418	0.022	0.0547	0.0298
ξy	0.794→0.24	0.1985	0.179	0.178	0.154
Lum (W.S.)	8E+35	6.70E+35	1.00E+36	3.95E+35	4.80E+35
Lum (S.S.)	8E35	4.77E35	5.65E36	3.94E35	4.27E35

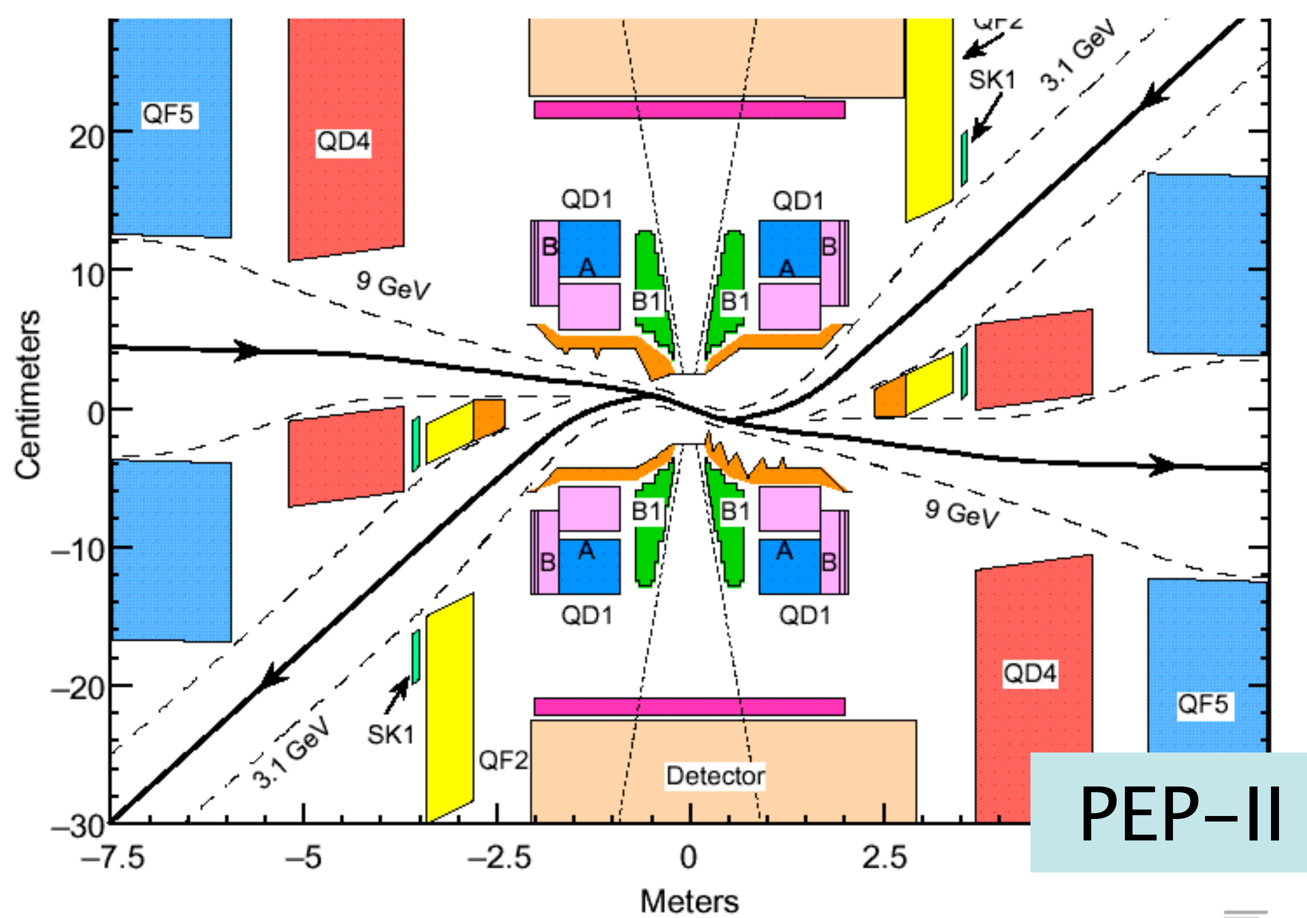
- Good parameters are not yet found with crab waist.

KEKB has 22 mrad horizontal crossing angle at the IP:

- •Easier beam separation
- •Simpler design around the IP.
- •Less number of components.
- •Less synchrotron radiation.
- •Less luminosity-dependent background.
- •Space for compensation solenoid, etc.



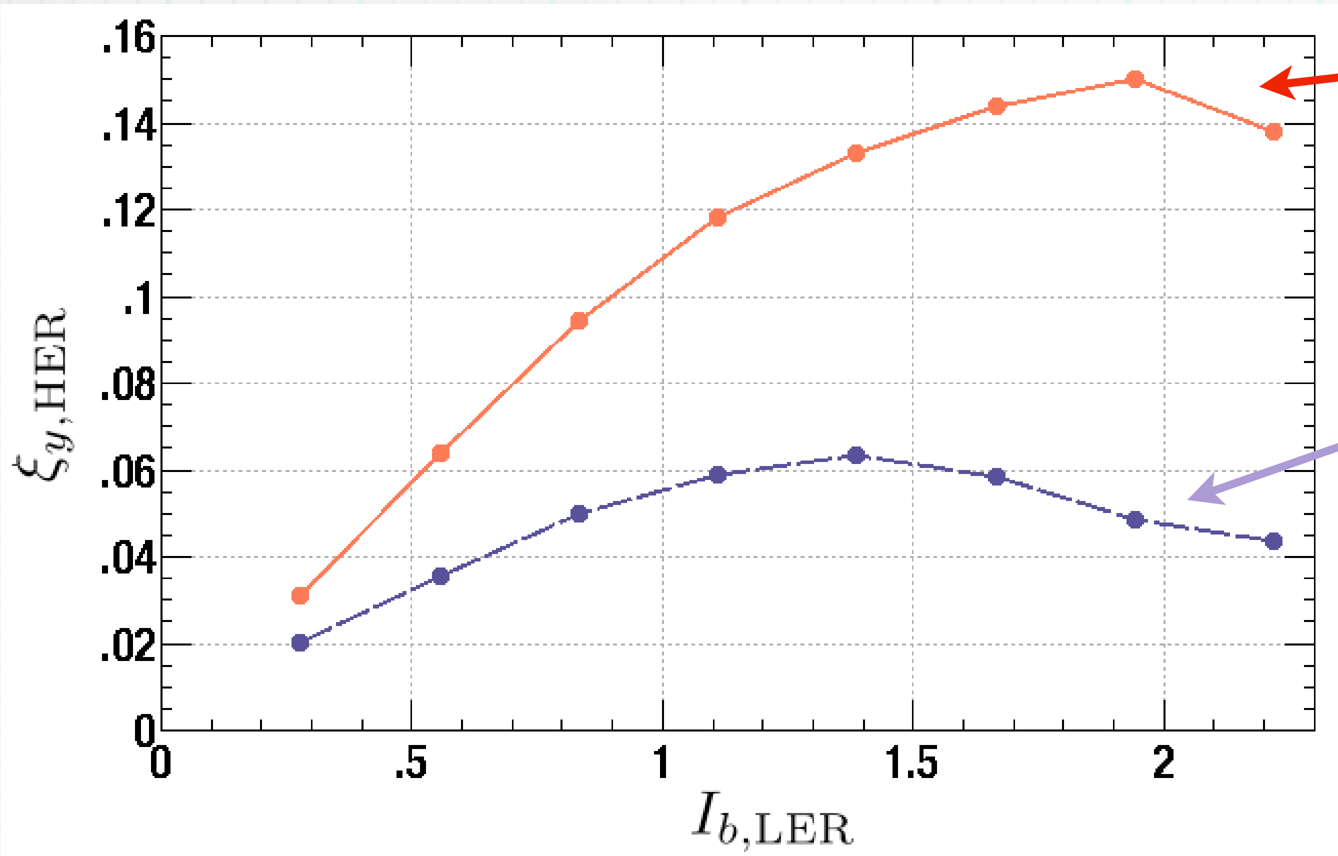




Crab Crossing @ KEKB

- Crab Crossing can boot the beam-beam parameter higher than 0.15 !

K. Ohmi

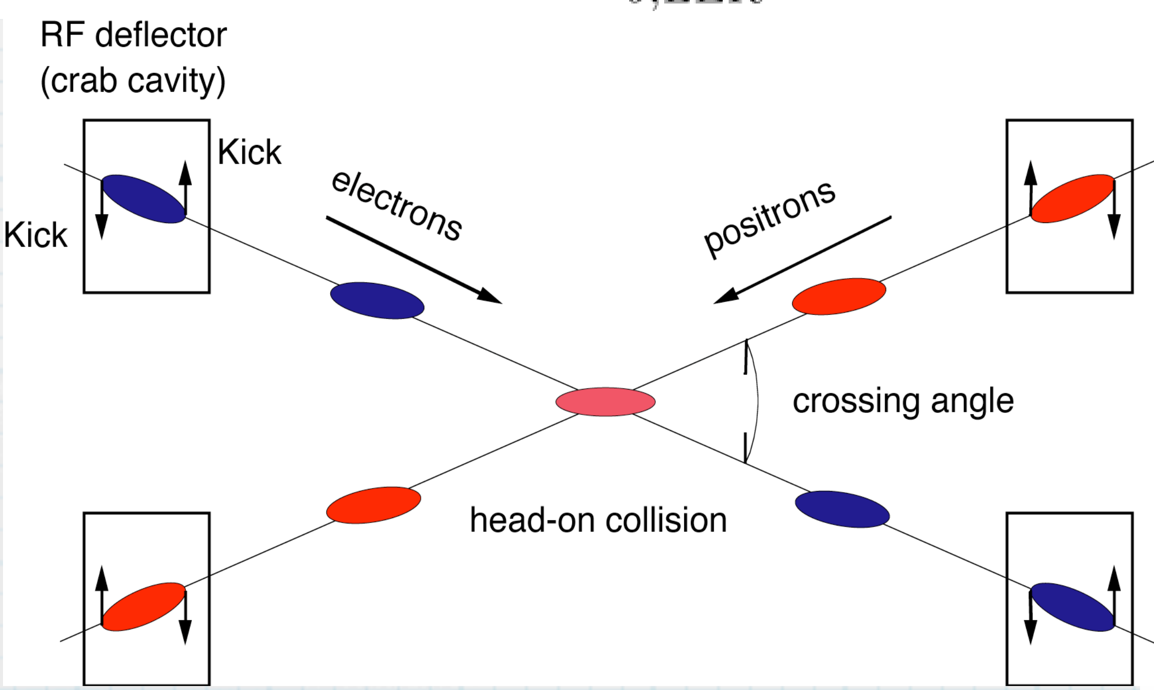


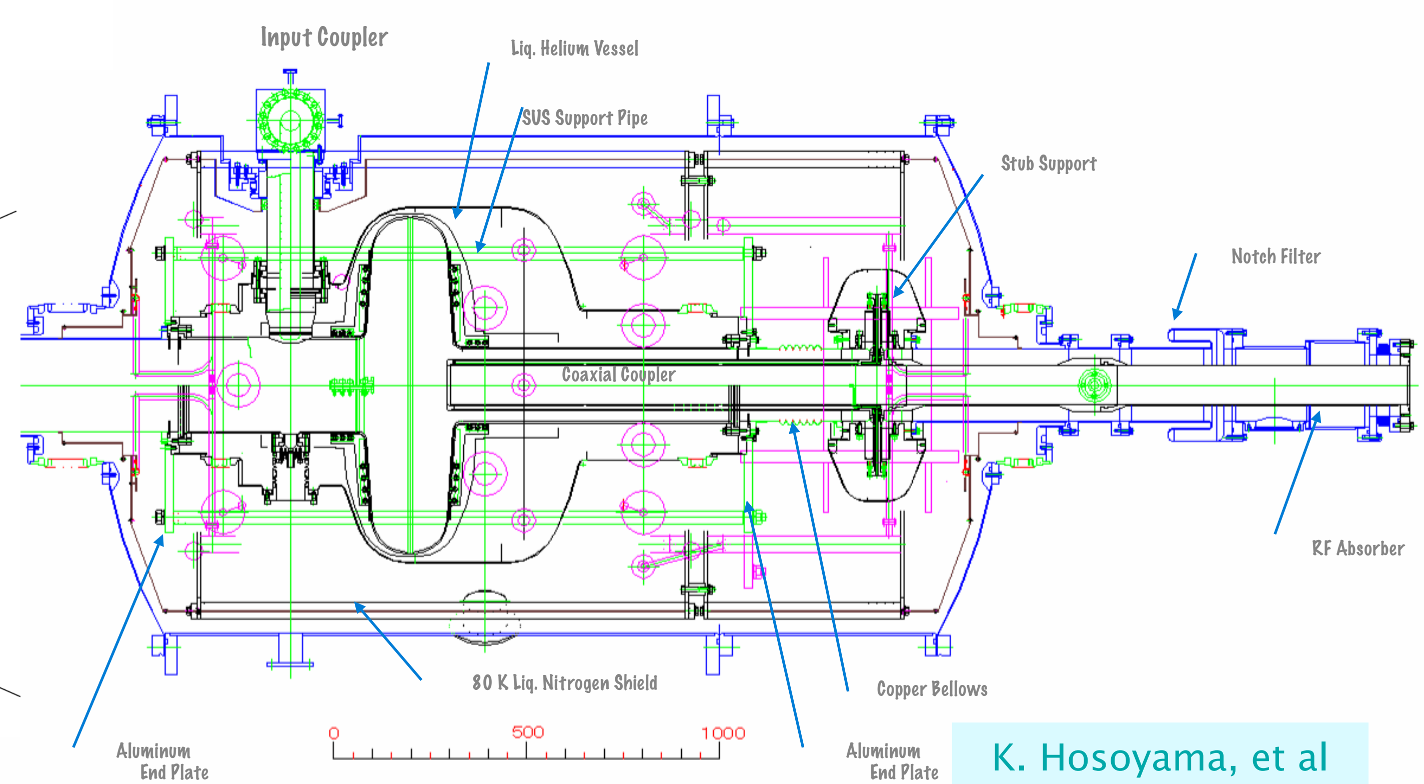
Head-on (crab)

(Strong-strong simulation)

Crossing angle 22 mrad

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

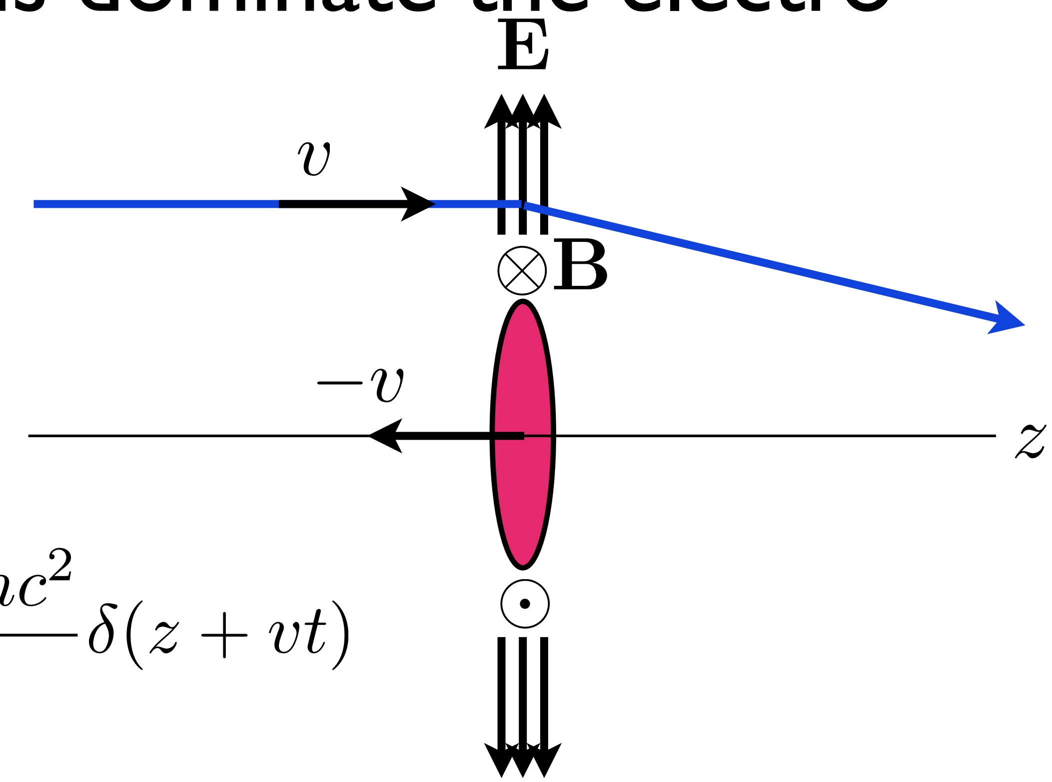




K. Hosoyama, et al

Beam-beam interactions

- When $v \approx c$, the transverse directions dominate the electro-magnetic field produced by a beam.



- If encountering a point charge:

$$E_r = \frac{e}{2\pi\varepsilon_0 r}\delta(z+vt), \qquad B_\varphi = -\frac{v}{c^2}E_r$$

$$F_r = -e(E_r - vB_r) \approx -\frac{e^2}{\pi\varepsilon_0 r}\delta(z+vt) = -\frac{4r_e mc^2}{r}\delta(z+vt)$$

- The momentum kick received from the encountering charge:

$$\Delta p_r = \int_{-\infty}^{\infty} F_{r,z=vt}dt \quad = \quad \int_{-\infty}^{\infty} -\frac{4r_e mc^2}{r}\delta(2vt)dt \approx -\frac{2r_e mc}{r}$$

$$\Delta\left(\frac{p_r}{\gamma mc}\right) \quad = \quad -\frac{2r_e}{\gamma r}$$

The received momentum is prop to the 2D electro-static field.

Beam-beam interactions(2)

- If the encountering beam has distribution:

$$f_{x,y} = \Delta\left(\frac{p_{x,y}}{\gamma mc}\right) = -\partial_{x,y}\phi$$

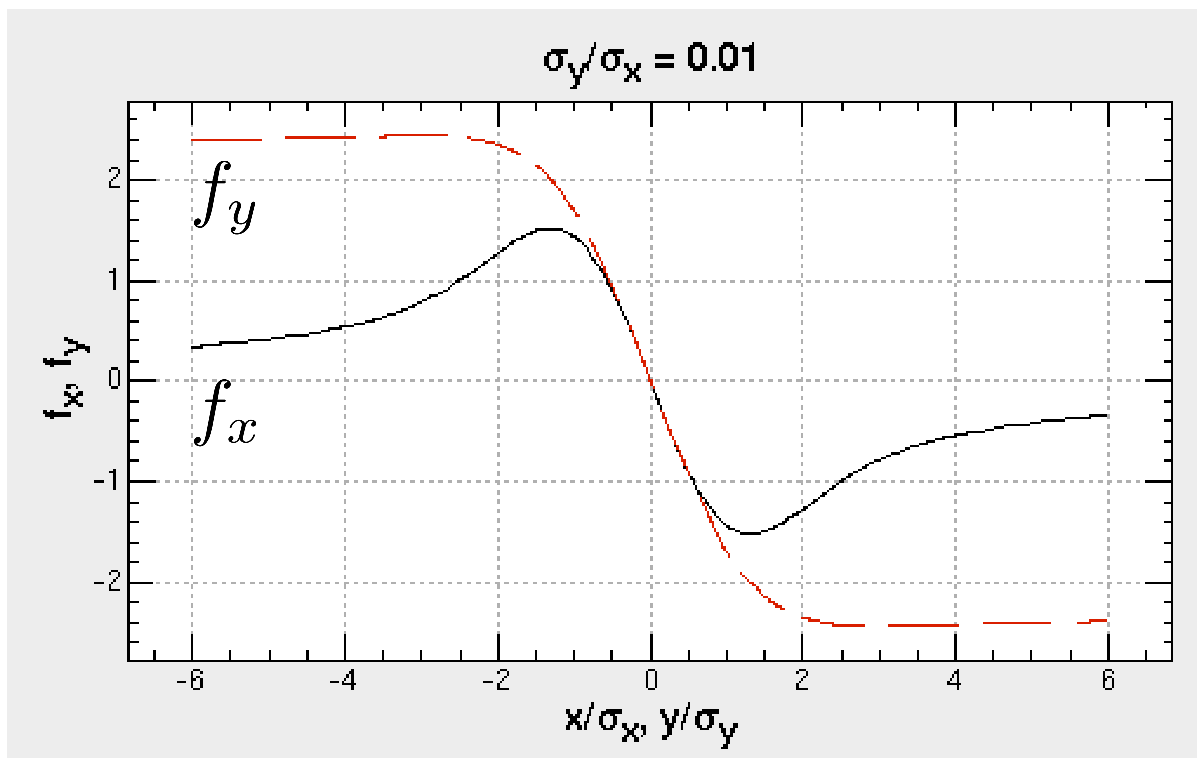
$$\phi = \int \frac{r_e}{\gamma} \log\left((x-x')^2 + (y-y')^2\right)\rho(x',y')dx'dy'$$

- When the beam is Gaussian:

$$f_x + if_y = -\frac{Nr_e}{\gamma}\sqrt{\frac{2\pi}{\sigma_x^2-\sigma_y^2}}\left[w\left(\frac{x+iy}{\sqrt{2(\sigma_x^2-\sigma_y^2)}}\right) - \exp\left(-\frac{x^2}{2\sigma_x^2}-\frac{y^2}{2\sigma_y^2}\right)w\left(\frac{\frac{\sigma_y}{\sigma_x}x + i\frac{\sigma_x}{\sigma_y}y}{\sqrt{2(\sigma_x^2-\sigma_y^2)}}\right)\right]$$

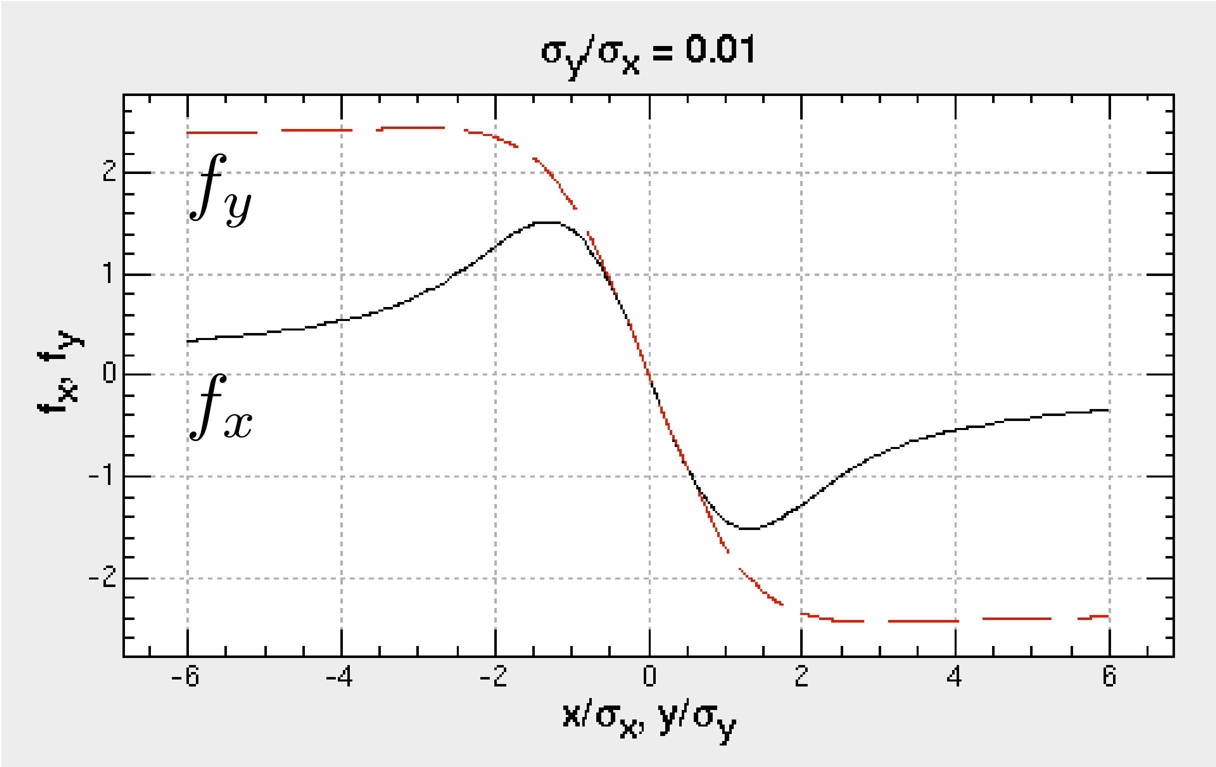
$$w(z) \equiv \exp(-z^2)\left\{1-\mathrm{erf}(-iz)\right\}$$

(complex error function)



Beam-beam interactions(3)

- Near the origin $(|x/\sigma_x|, |y/\sigma_y| \leq 1)$, the forces are proportional to displacements.



- Strength of the converging lens:

$$k_{x,y} = \frac{2Nr_e}{\gamma\sigma_{x,y}(\sigma_x + \sigma_y)}$$

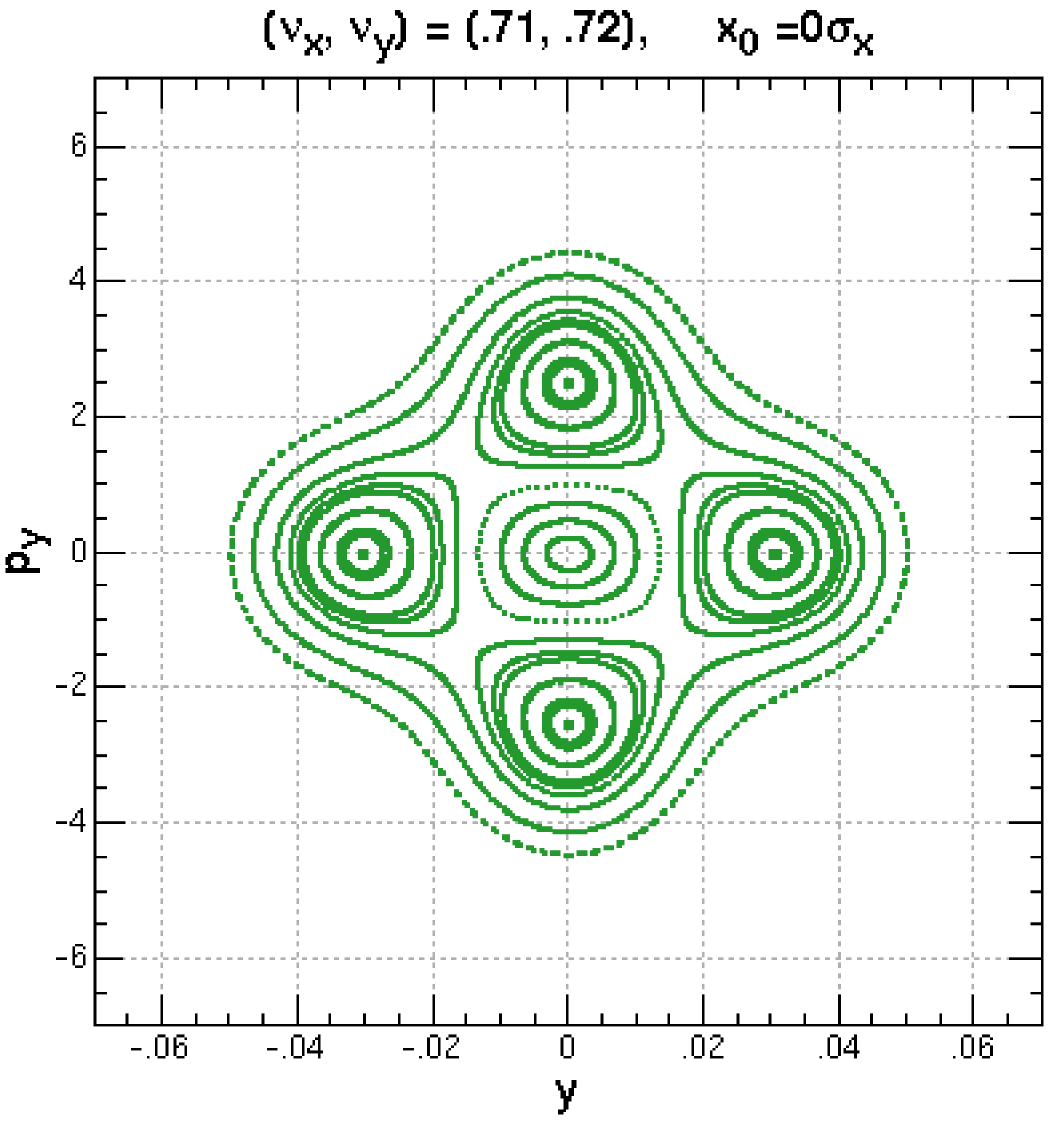
- Beam-beam tune-shift parameters:

$$\xi_{x,y} = \frac{k_{x,y}\beta^*_{x,y}}{4\pi} = \frac{Nr_e}{2\pi\gamma}\frac{\beta^*_{x,y}}{\sigma_{x,y}(\sigma_x + \sigma_y)}$$

represent the magnitude of the beam-beam interaction.

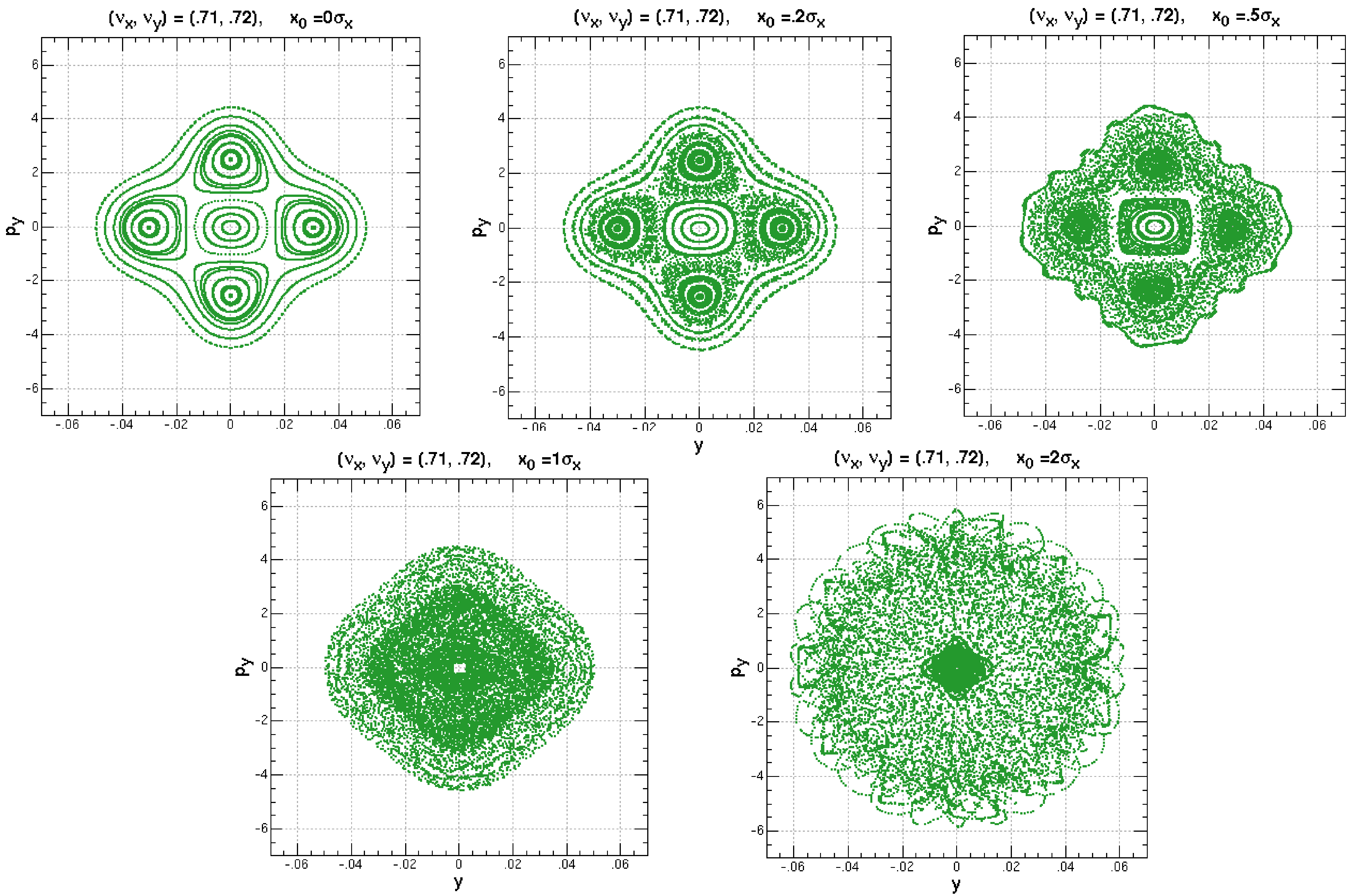
Beam-beam interactions(4)

- In the case of nonlinear motion of one degree of freedom depending on time (or orbit path length s), chaos, if generated, is confined within near-integrable surfaces (KAM surface).



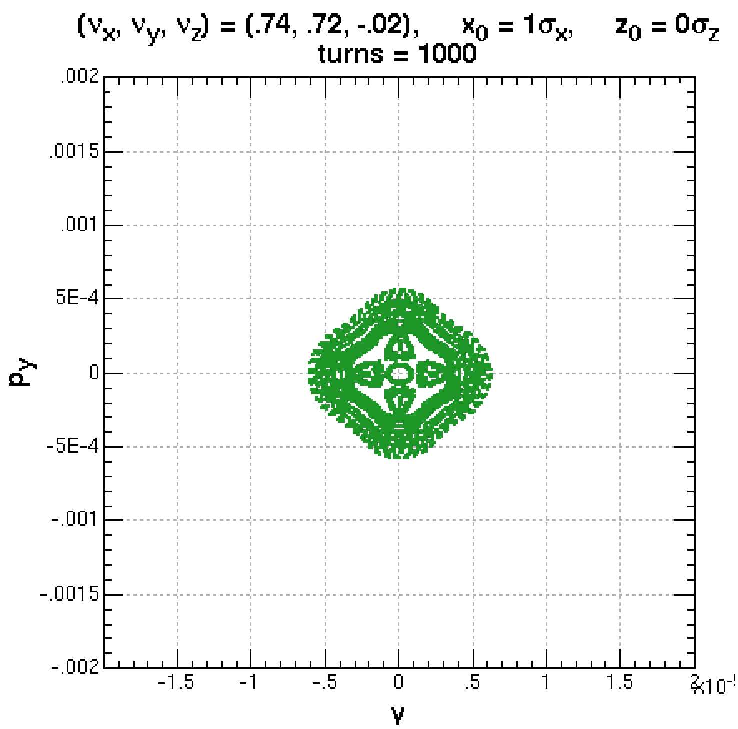
Beam-beam interactions(5)

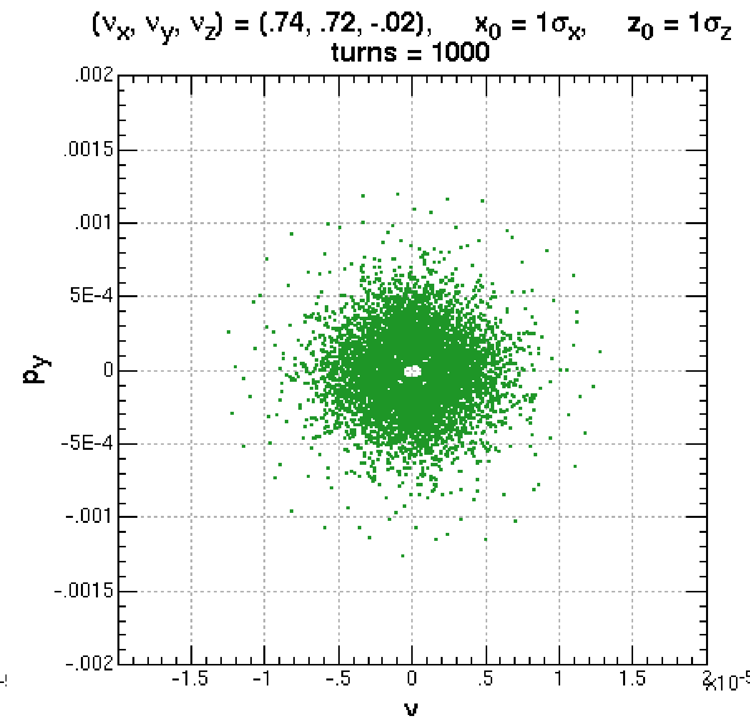
- The KAM surfaces are destroyed if the amplitudes of other degrees of freedom increase:



Beam-beam interactions(6)

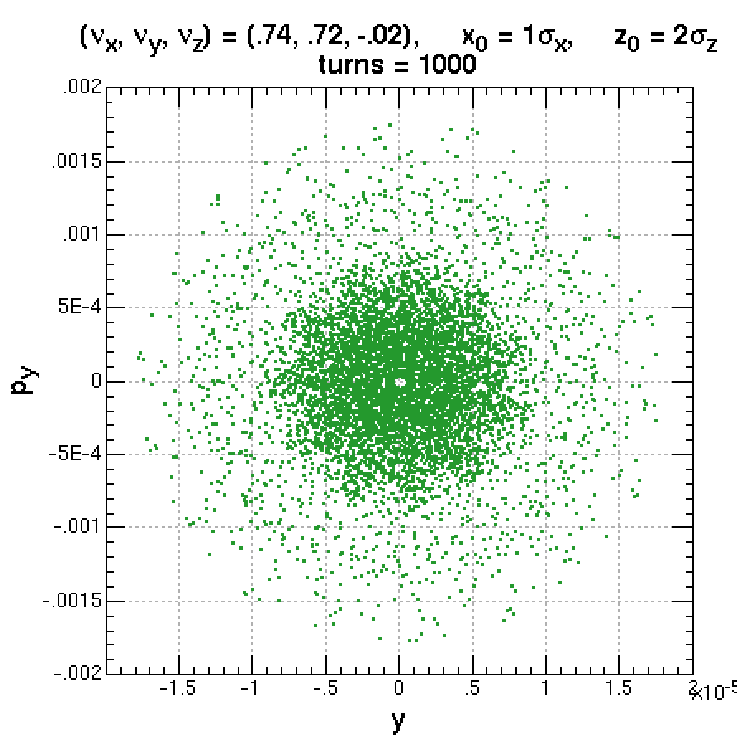
- The longitudinal position of a particle (arrival time) changes, the collision point is modulated: synchrotron-betatron coupling。

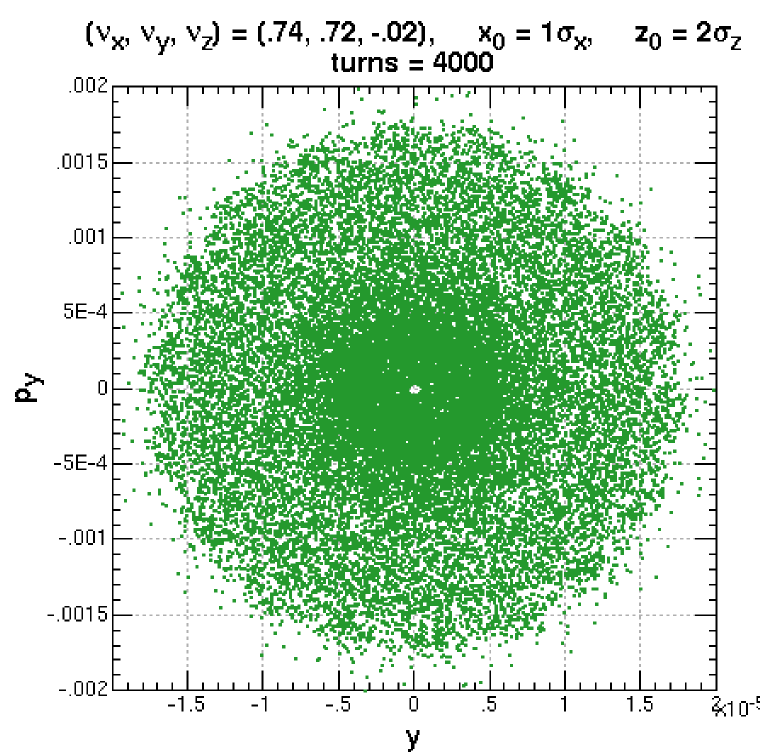


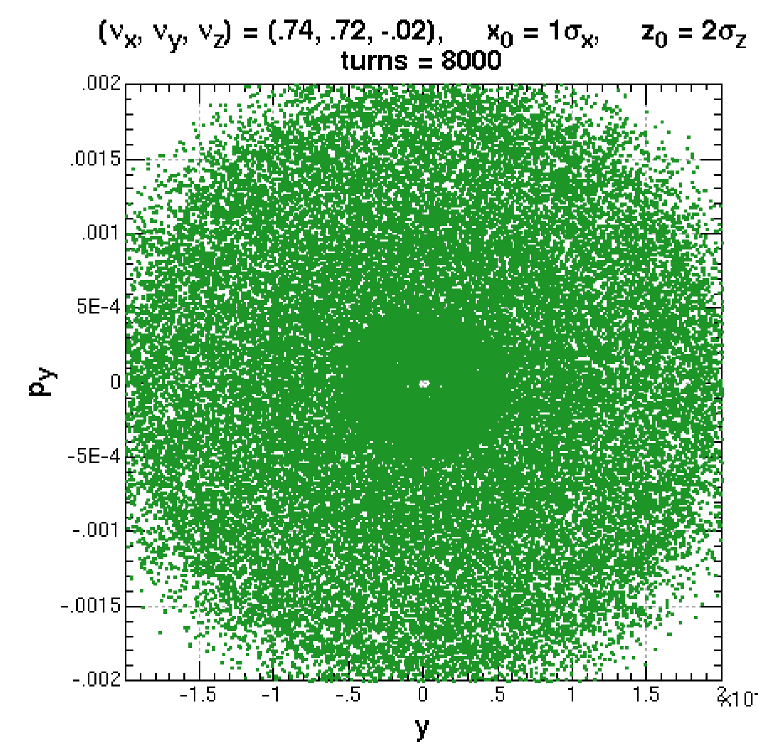


$$\sigma_x/100 = \sigma_y = 1\mu\mathrm{m}$$
$$\beta_x^*/100 = \beta_y^* = 1\mathrm{cm}$$
$$\sigma_z = 5\mathrm{mm}, \sigma_\delta = 0.1\%$$
$$\xi_x = \xi_y = 0.05$$

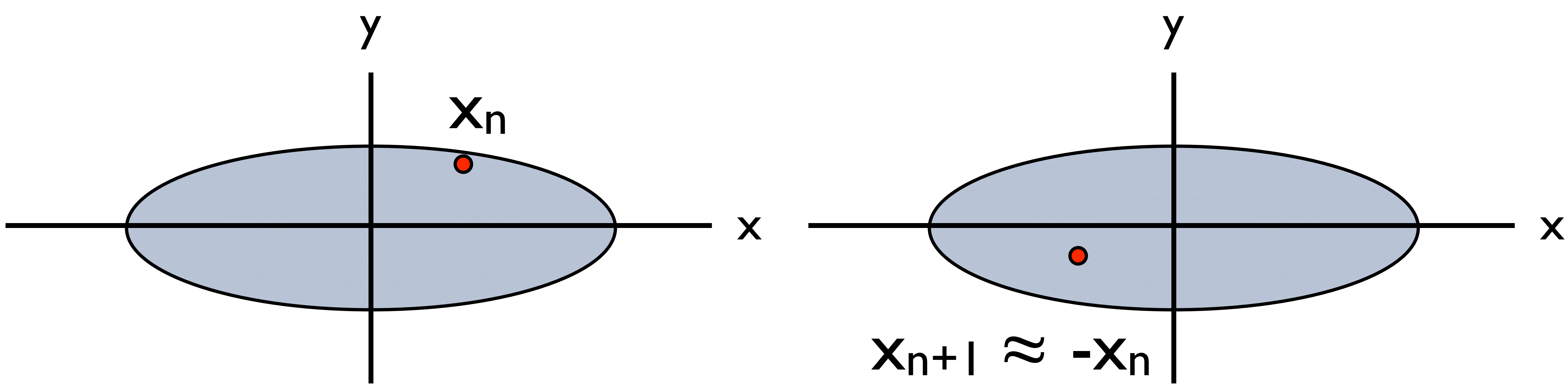
Diffusion of Amplitudes







Head-on + hor. half integer tune ≈ 1D + synchrotron motion



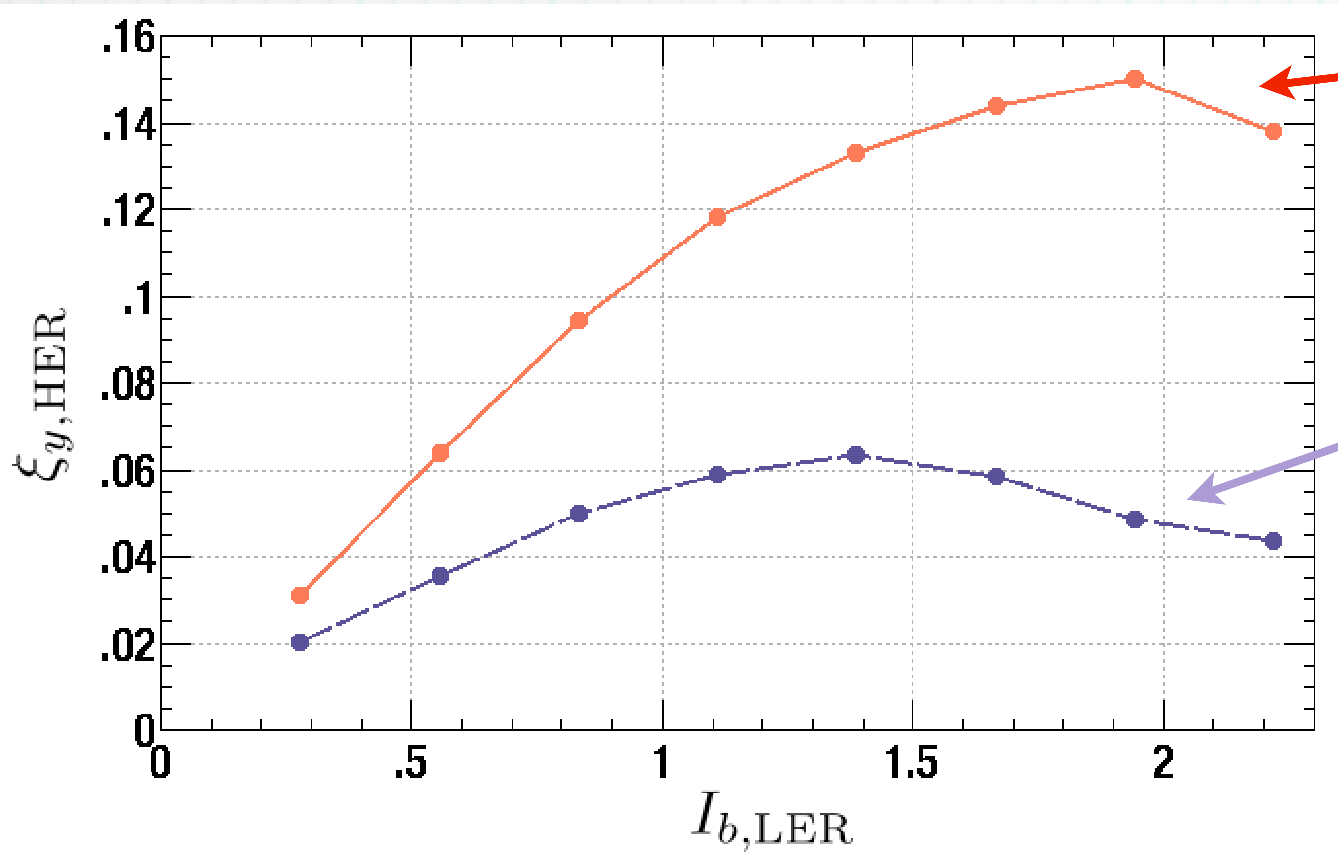
head-on: beam distribution is symmetric in x.

The beam-beam force becomes nearly independent on x at horizontal half integer and with head-on collision
(Ohmi & Perevedentsev)

Crab Crossing @ KEKB

- Crab Crossing can boot the beam-beam parameter higher than 0.15 !

K. Ohmi



Head-on (crab)

(Strong-strong simulation)

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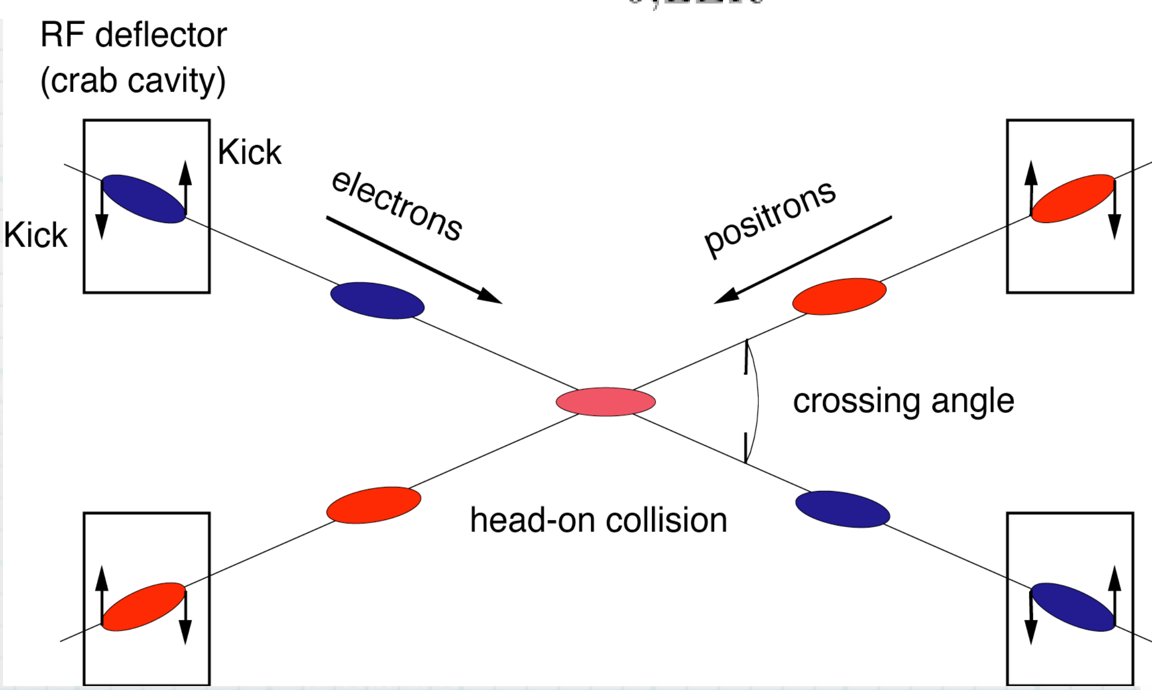

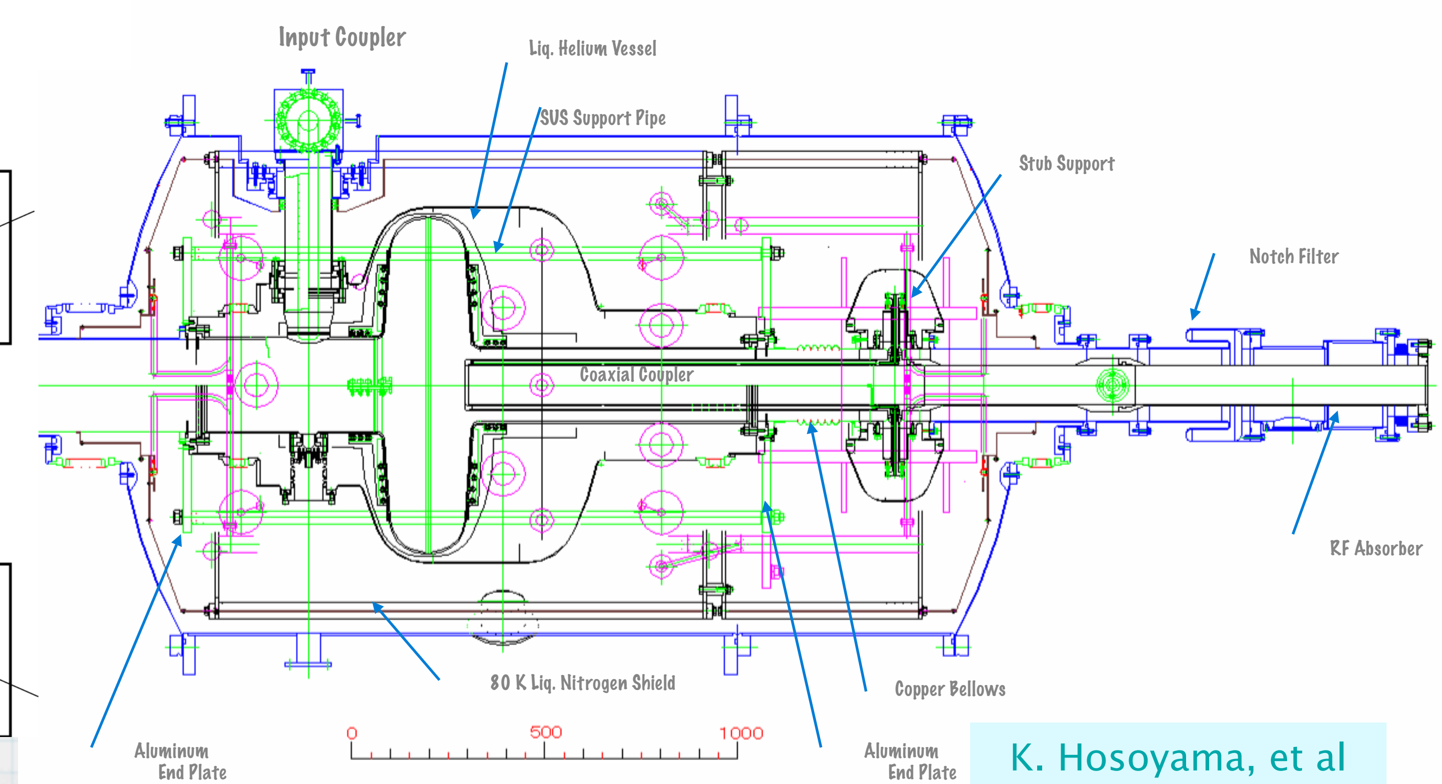

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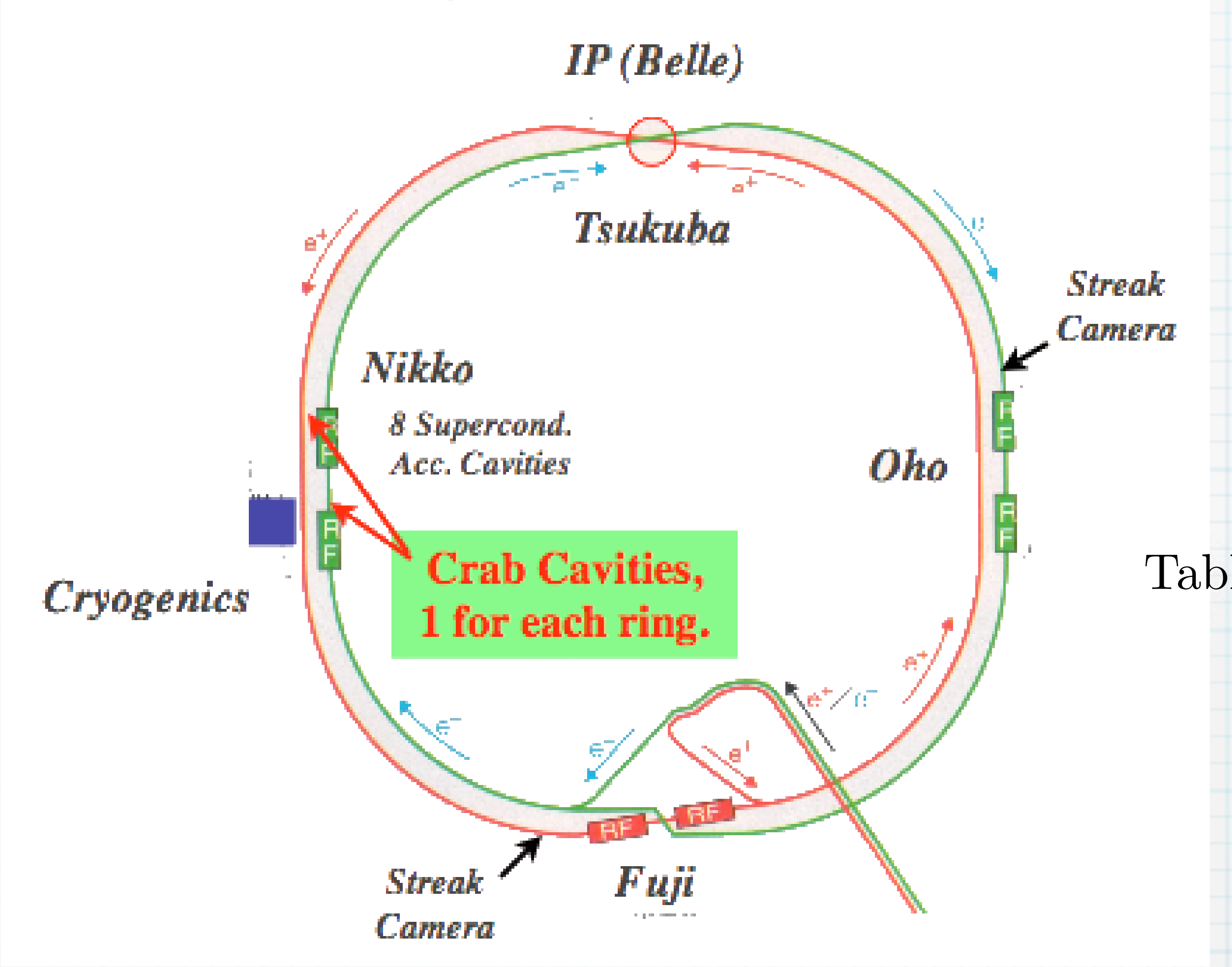
Single Crab Cavity Scheme



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

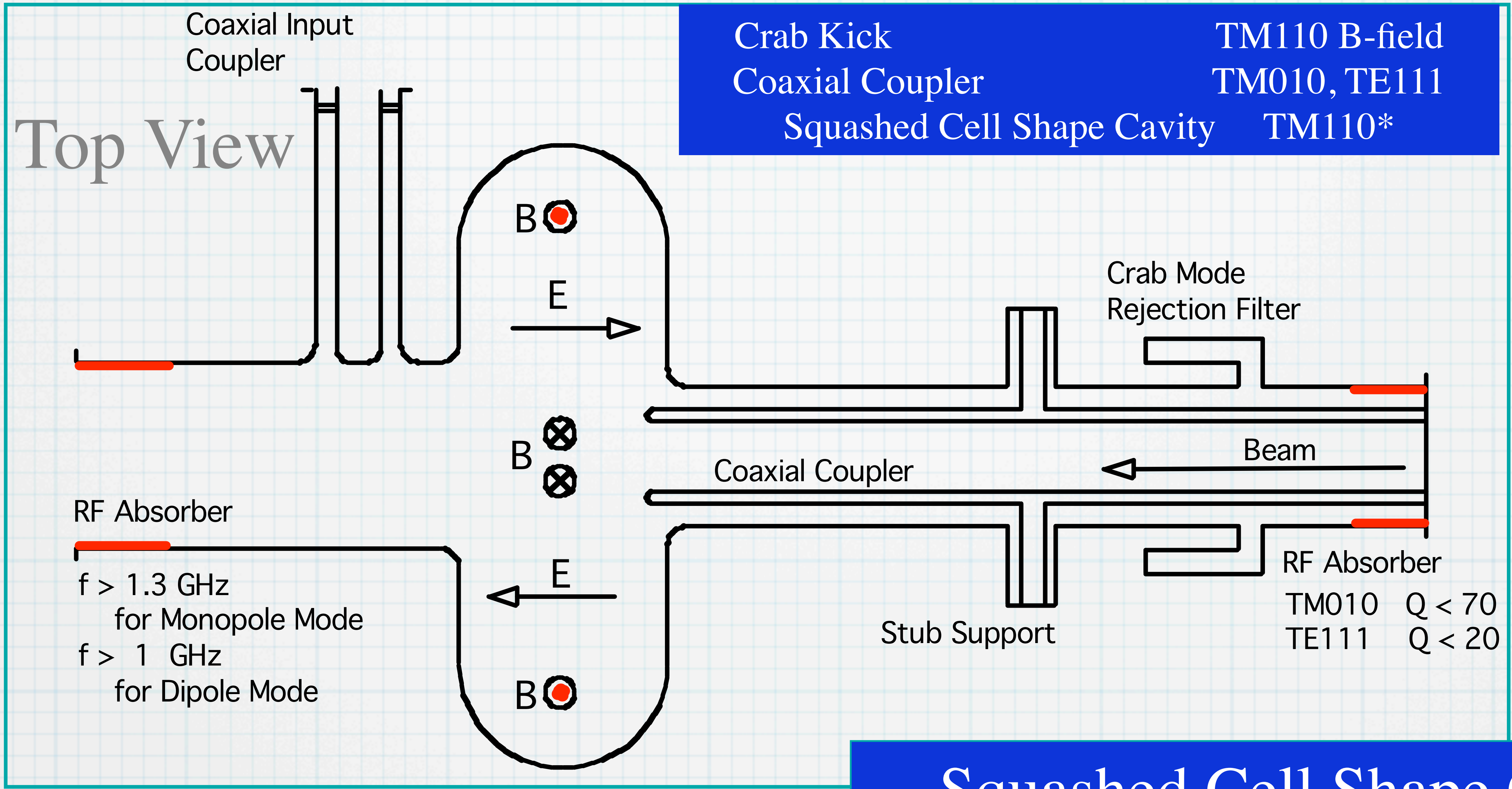
$$\frac{\theta_x}{2} = \frac{\sqrt{\beta_x^C \beta_x^*}\cos(\psi_x^C - \mu_x/2)}{2\sin(\mu_x/2)} \frac{V_C \omega_{\rm rf}}{Ec}$$

Table 1: Typical parameters for the crab crossing.

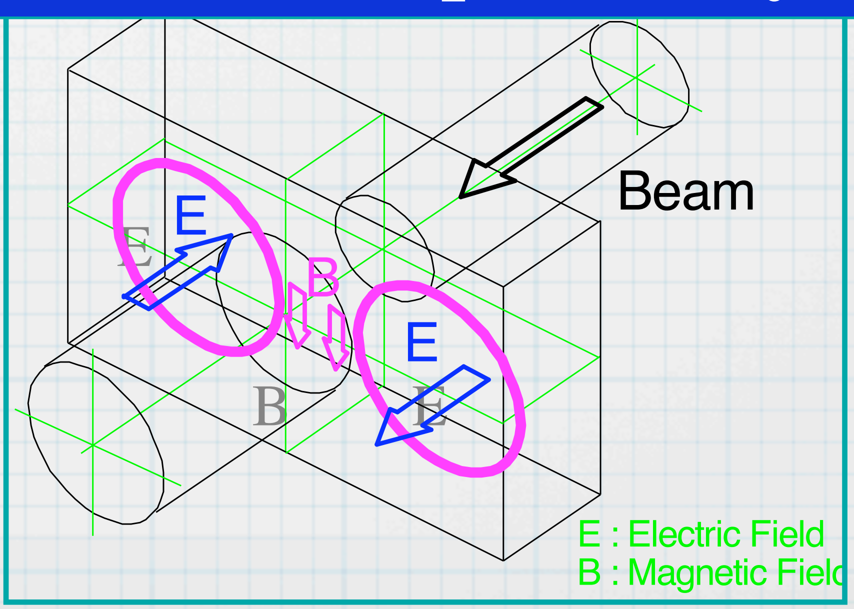
Ring	LER	HER	
θ_x	22		mrad
β_x^*	80	80	cm
β_x^C	73	162	m
$\mu_x/2\pi$	0.505	0.511	
$\psi_x^C/2\pi$	~ 0.25	~ 0.25	
V_C	0.95	1.45	V
$\omega_{\rm rf}/2\pi$	509		MHz

- 1 crab cavity per ring.
- saves the cost of the cavity and cryogenics.
- avoids synchrotron radiation hitting the cavity.

Concept of the KEKB Crab Cavity



Squashed Cell Shape Cavity

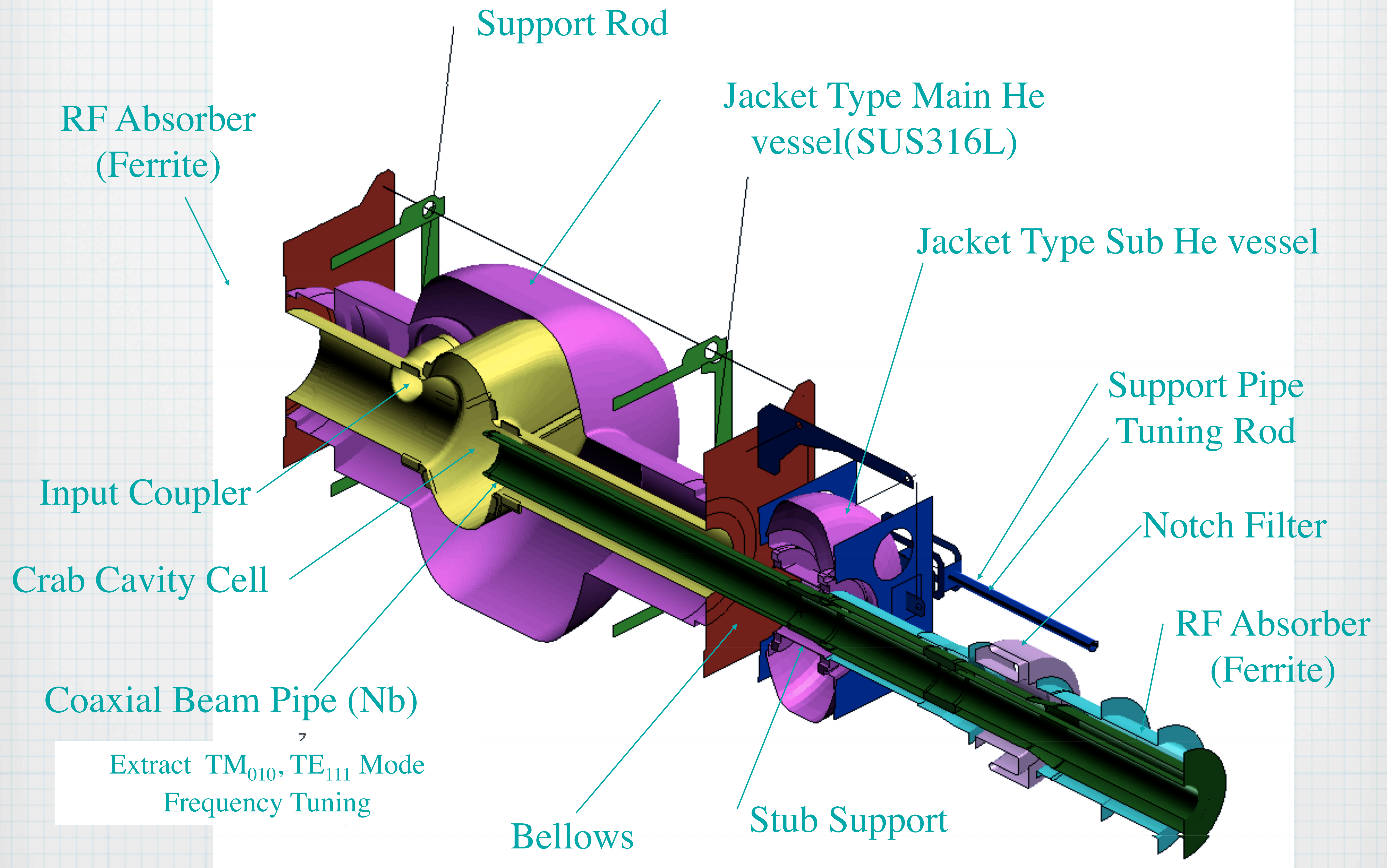


The squashed cell shape cavity scheme was studied extensively by K. Akai at Cornell in 1991 and 1992 for CESR-B under KEK-Cornell collaboration.

We adopted this design as "base design"!

Crab Cavity & Coaxial Coupler in Cryomodule

K. Hosoyama et al

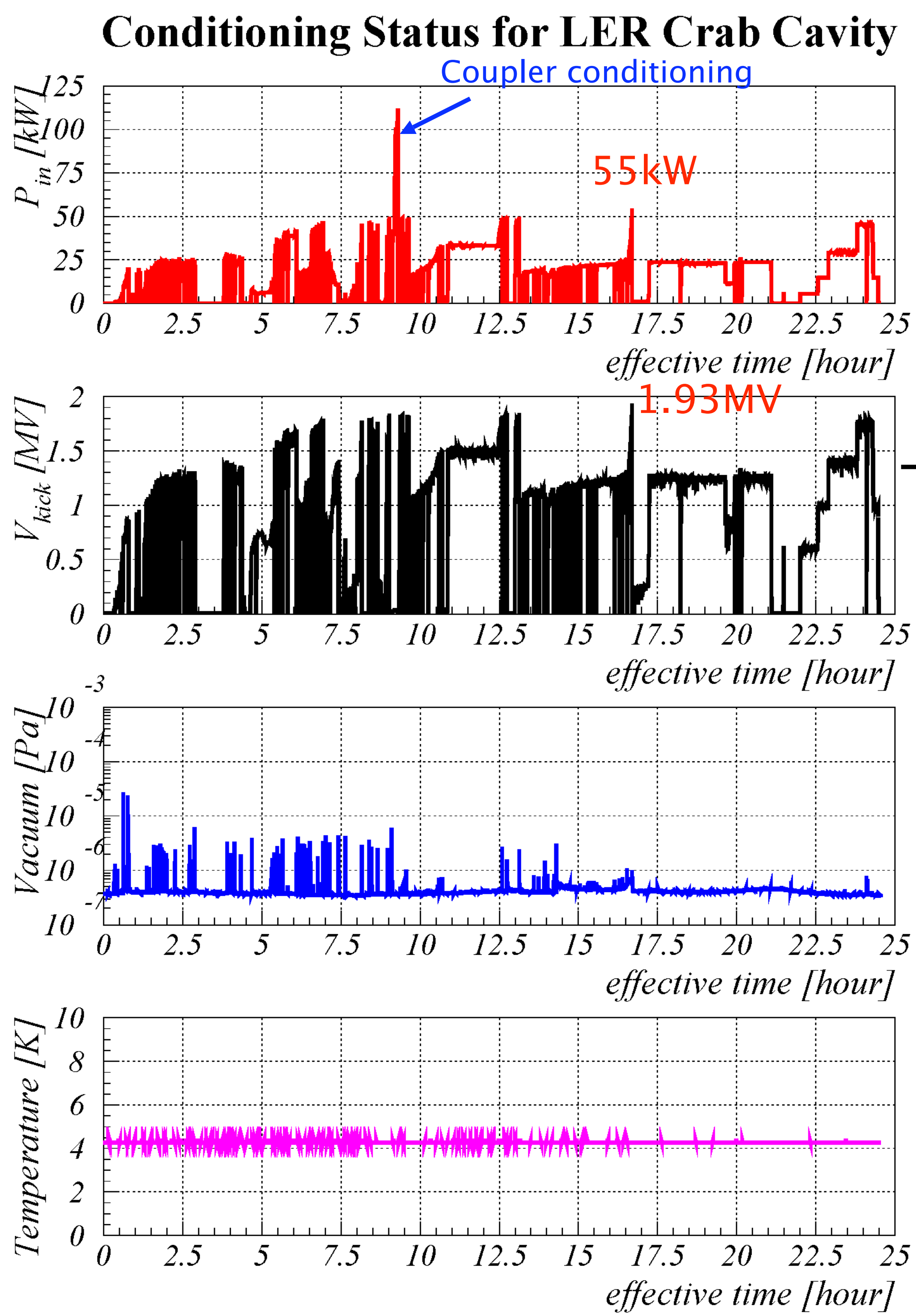


Extract TM_{010}, TE_{111} Mode
Frequency Tuning

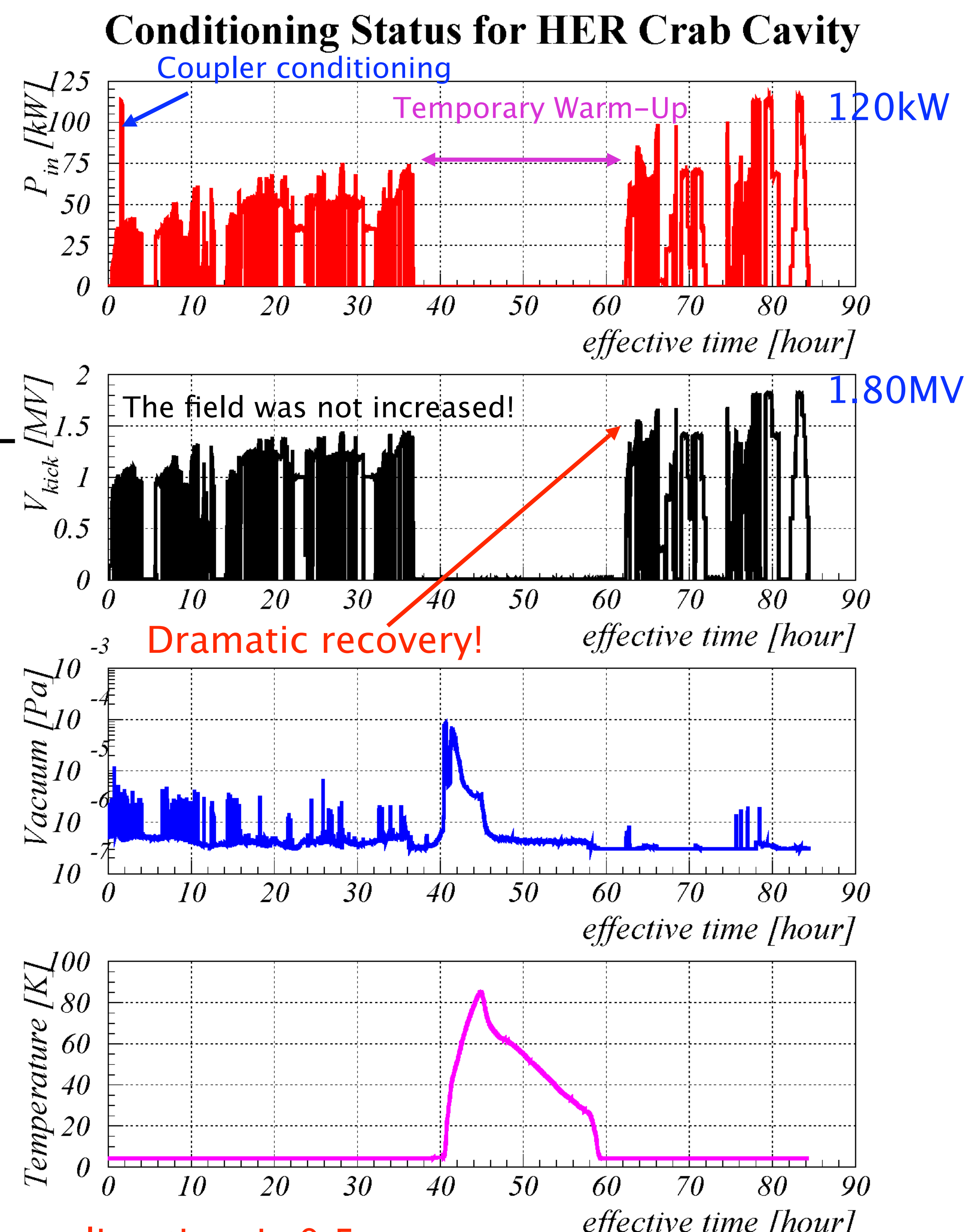
RF Conditioning in Horizontal Tests

LER

HER



Goal
1.4 MV



The sampling time is 0.5sec.

Finally two crab cavity was installed in KEKB, one for each ring in January 2007.

HER (e-, 8 GeV)

LER (e+, 3.5 GeV)

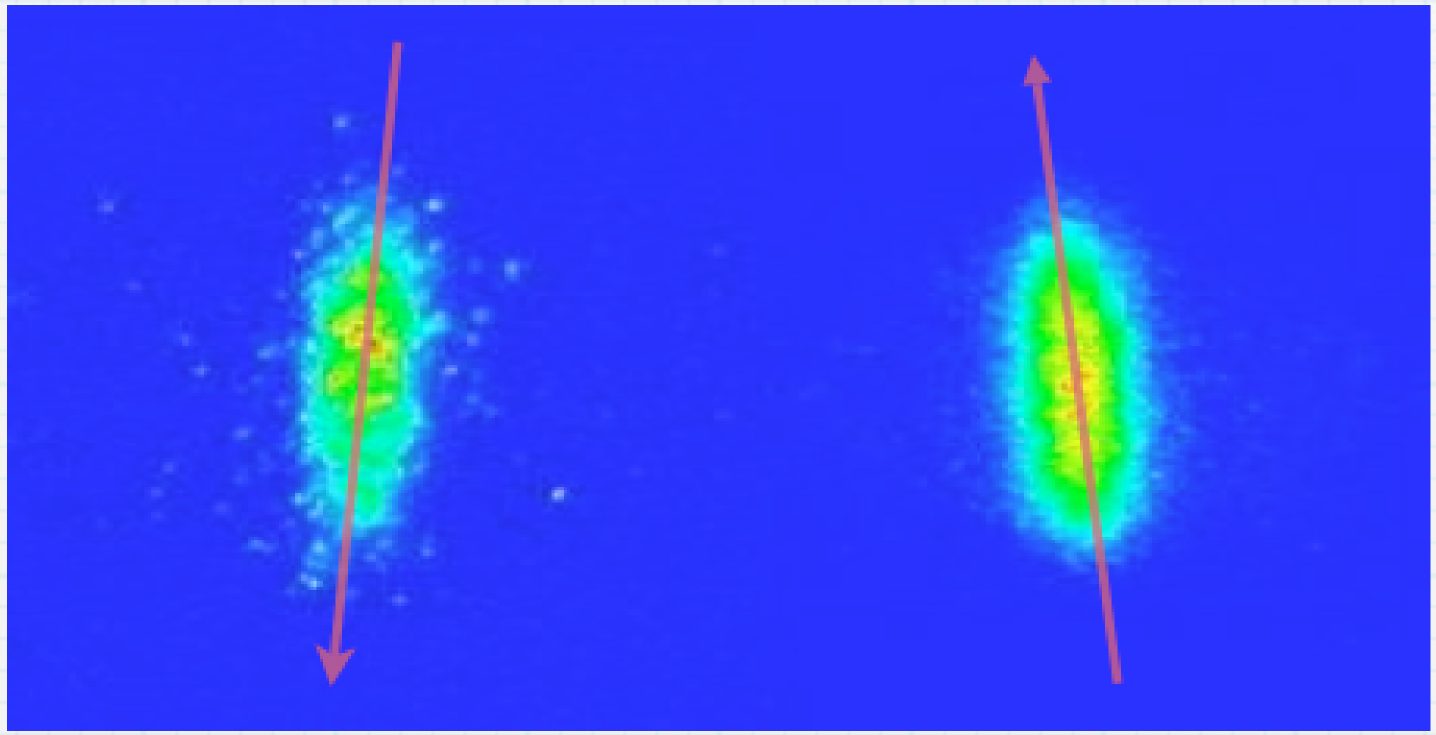
Beams has indeed tilted!

- Observation with Streak Cameras (H. Ikeda et al, FRPMN035)

inside of
the rings

outside of
the rings

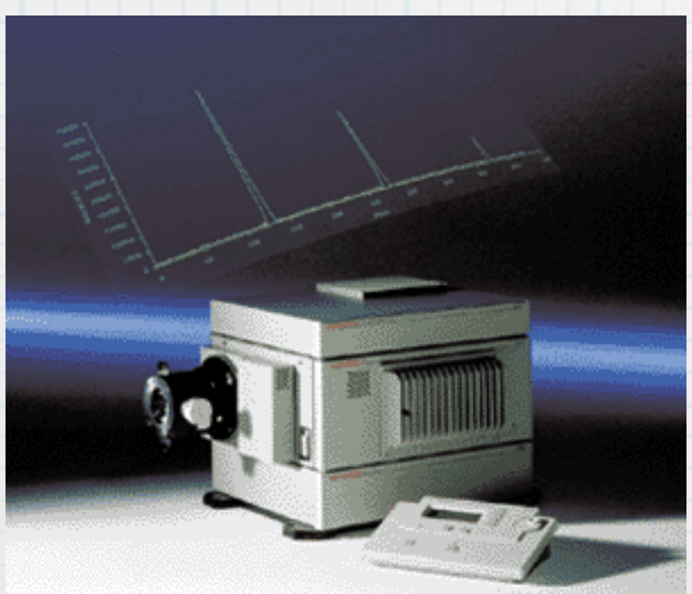
longitudinal



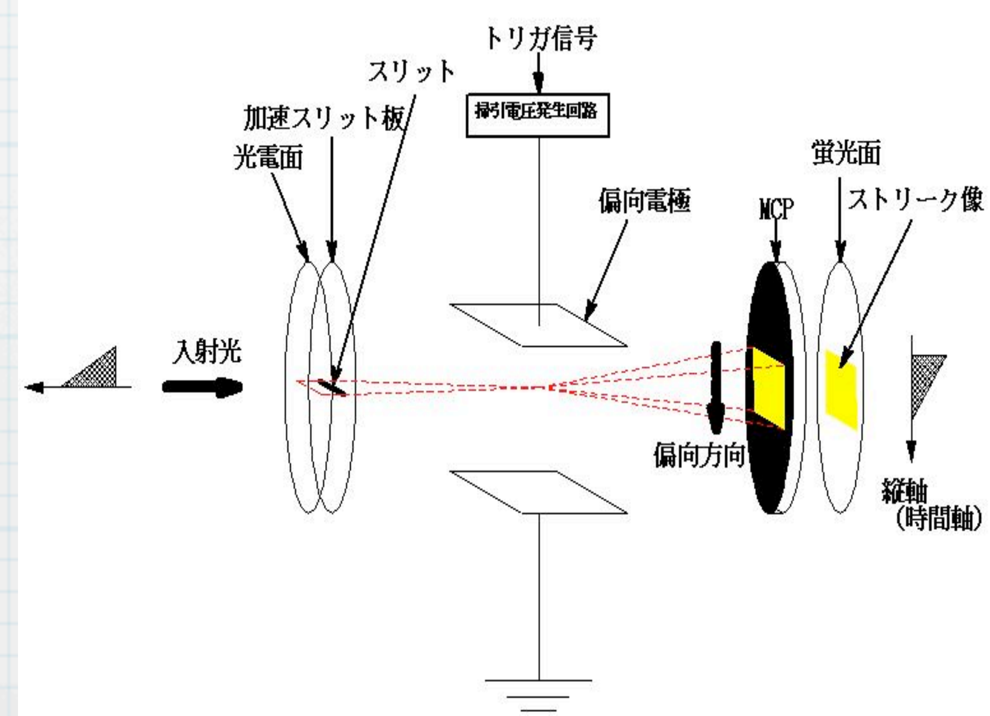
LER

HER

horizontal



The streak camera



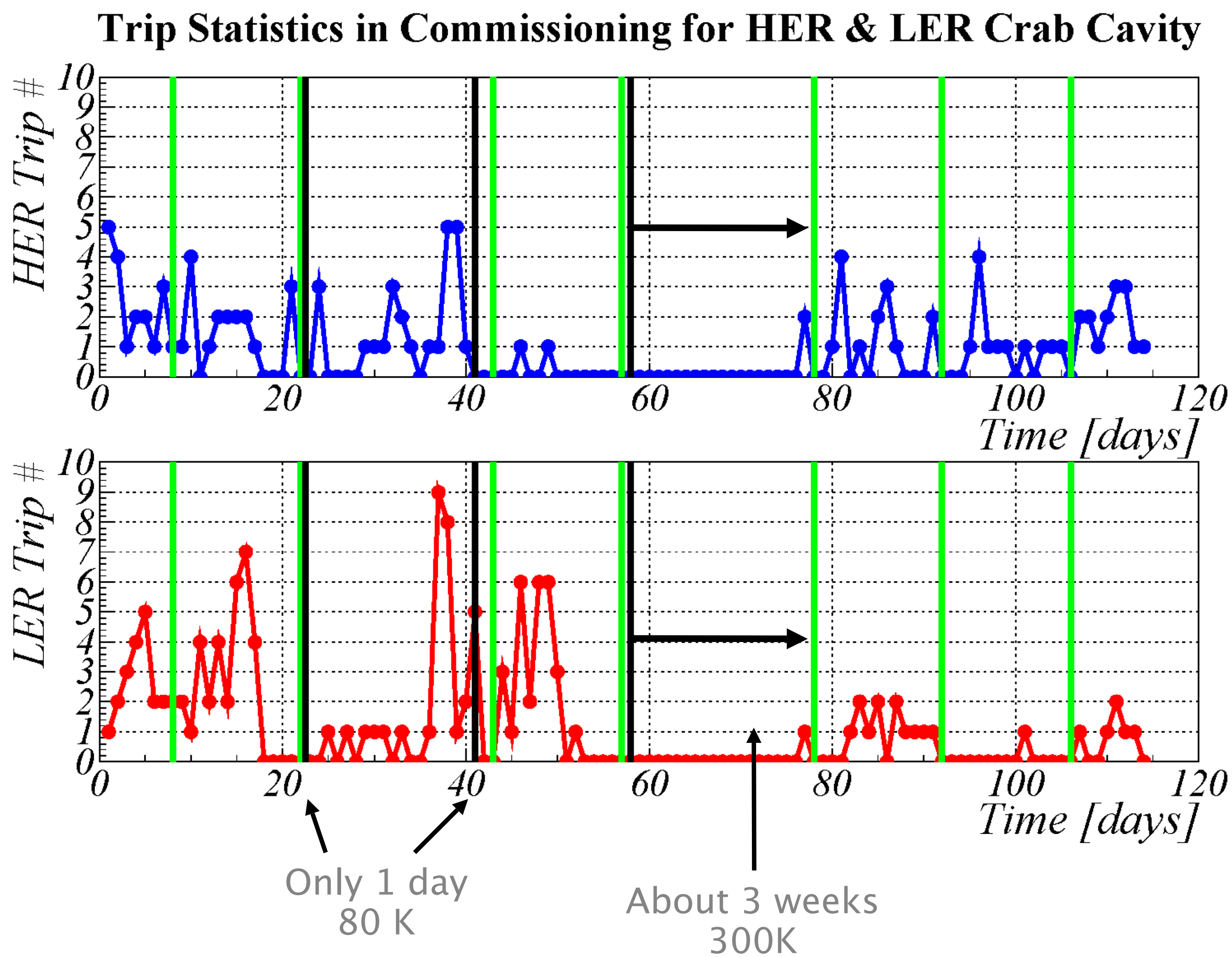
Crab Crossing Started at KEKB

First time in the world!

- A number of checks have confirmed the effective head-on collision:
  - streak camera
  - crab-phase scan
  - sign change and scan of crab voltage
  - horizontal beam-beam kick
  - vertical crabbing
- The highest vertical beam-beam tune-shift parameter is about 0.088 so far, which is higher than the geometrical gain due to head-on by 15%.
- Due to the low-current operation with longer bunch spacing (98 ns), the effect from electron cloud has been negligible.
- There are a few issues are speculated for the reason why the luminosity is lower than the prediction, but not yet confirmed.

Number of trips per cavity per ring.

From March/1 to June/22 (114days)



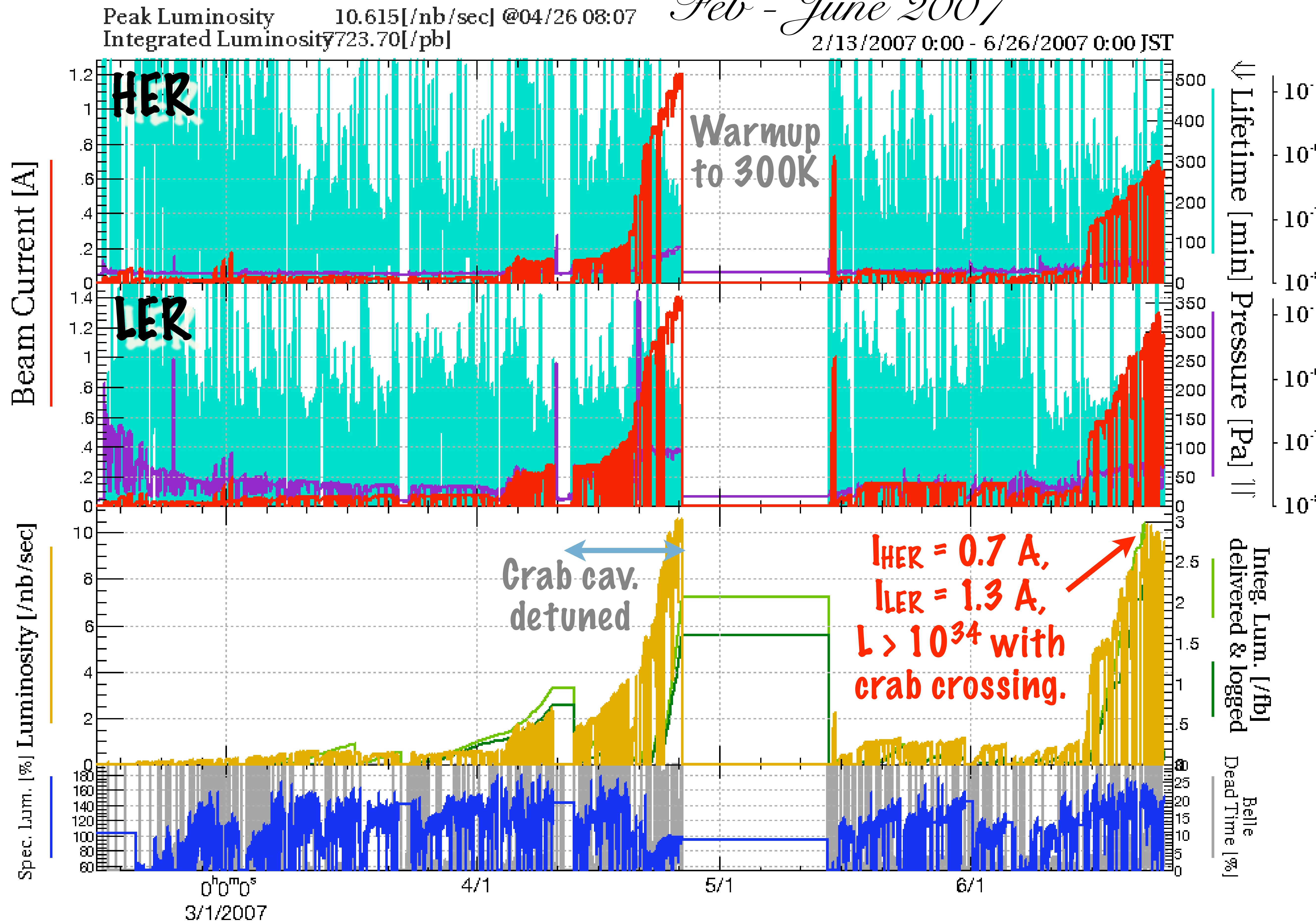
Green line shows the maintenance day.
Black line shows the warm-up period.

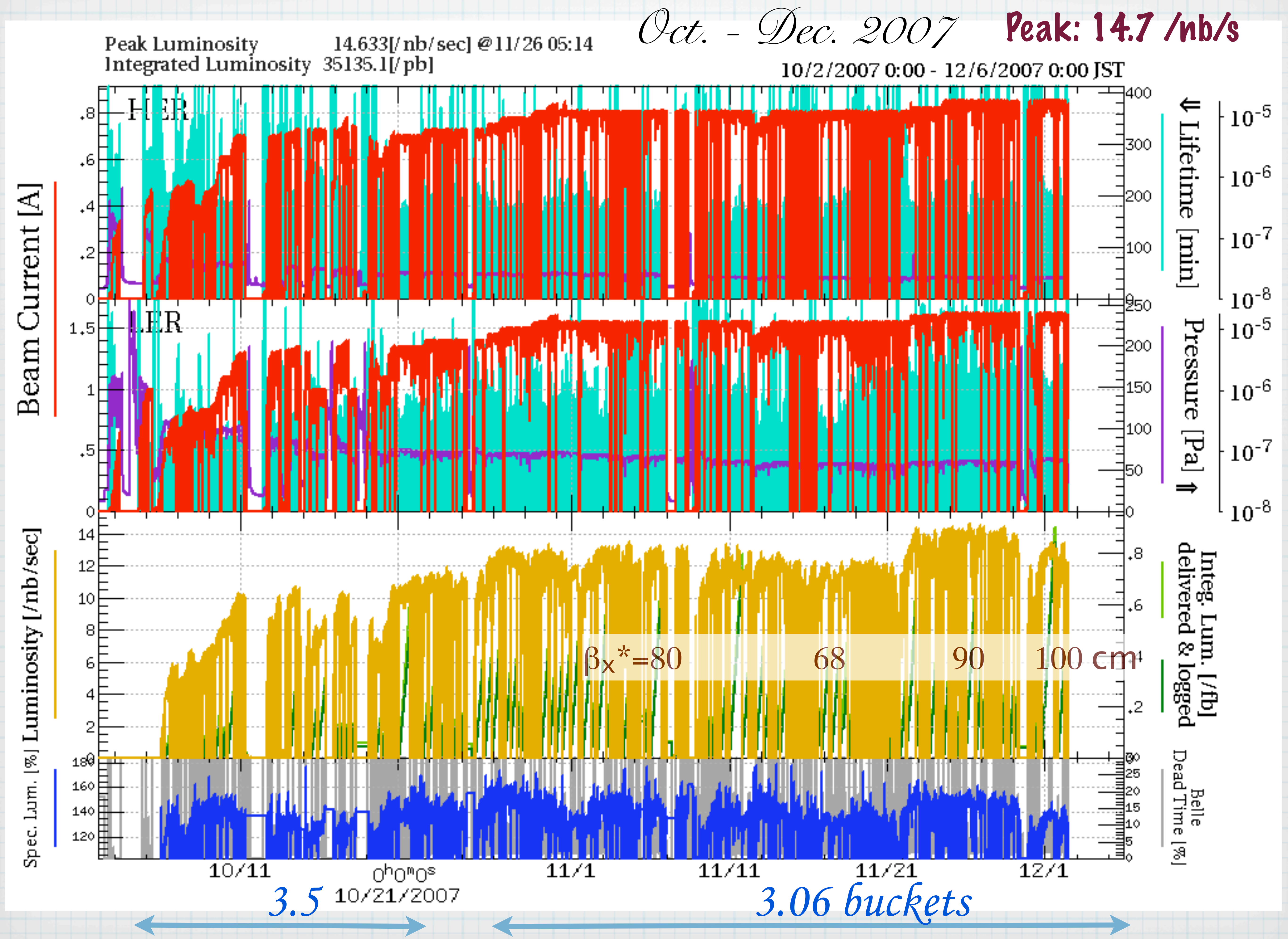
Trip Statistics

	LER	HER
March	58	43
April	55	21
May	13	16
June	7	27
Total	133	107

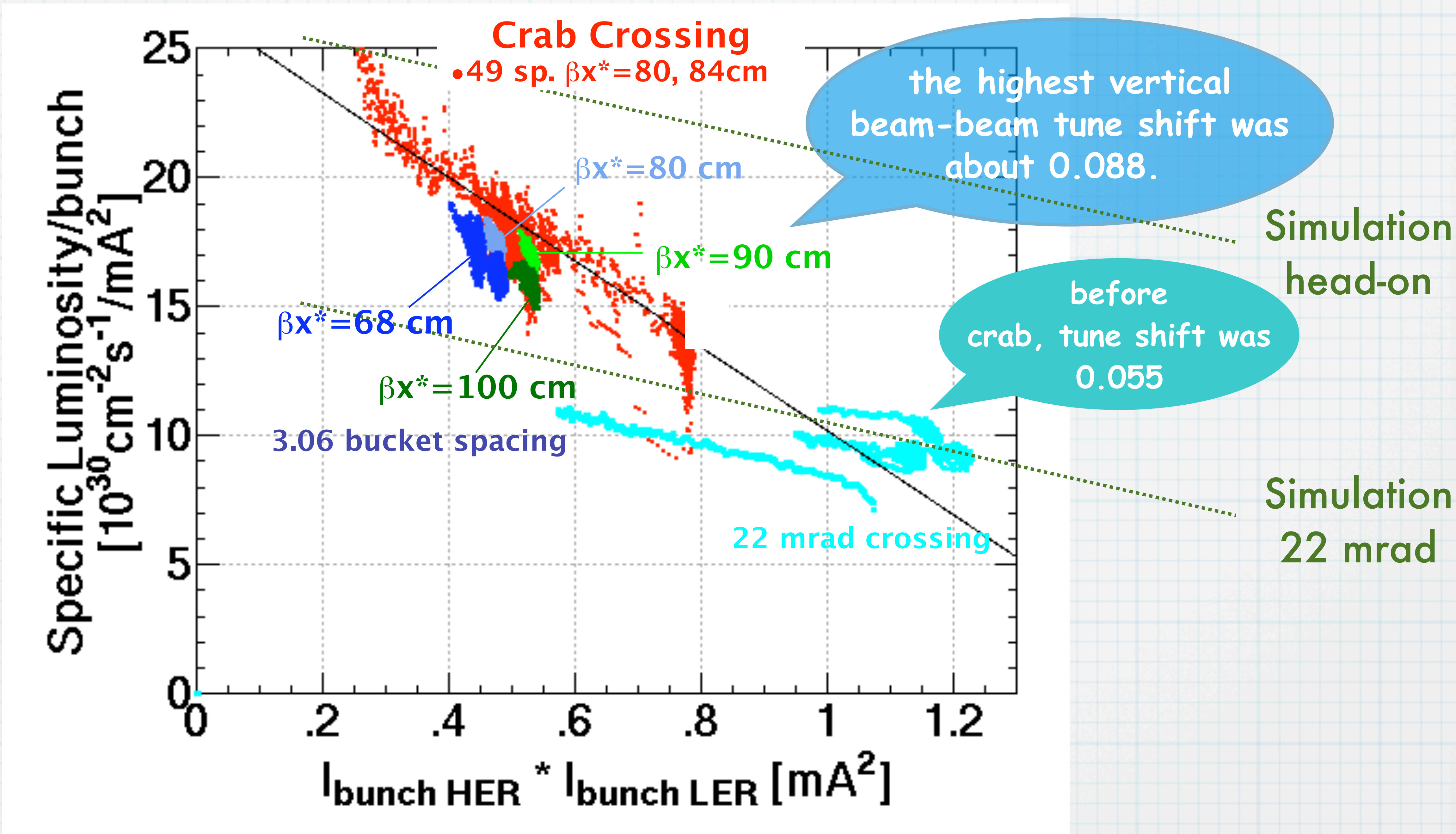
Y. Yamamoto

Feb - June 2007



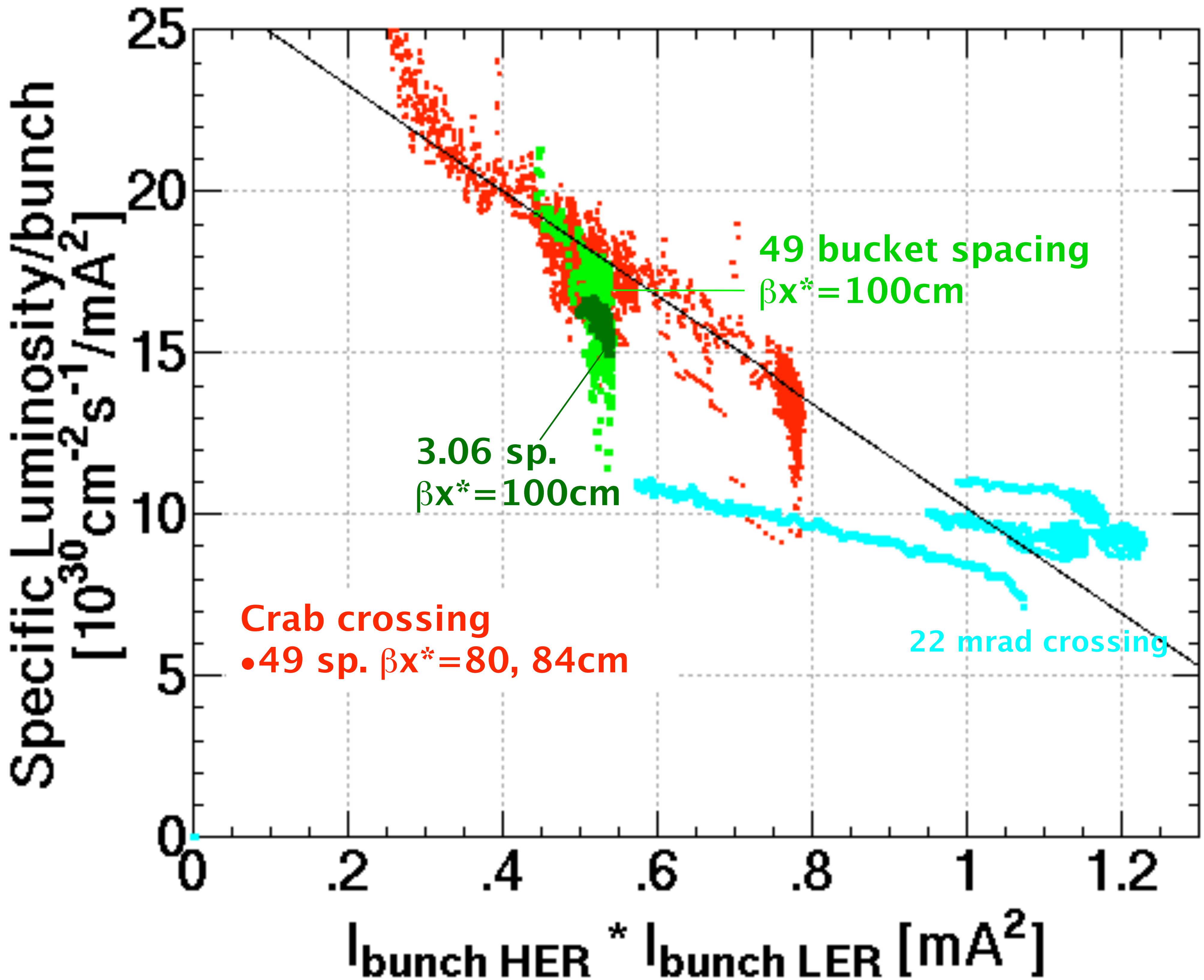

Oct. - Dec. 2007
Peak: 14.7 /nb/s
Peak Luminosity 14.633[/nb/sec] @11/26 05:14
Integrated Luminosity 35135.1[/pb]
10/2/2007 0:00 - 12/6/2007 0:00 JST
HER
LER
Beam Current [A]
⇓ Lifetime [min]
Pressure [Pa] ⇑
Luminosity [/nb/sec]
Integ. Lum. [/fb] delivered & logged
Spec. Lum. [%]
Belle Dead Time [%]
βx*=80
68
90
100 cm
10/11
10/21/2007
11/1
11/11
11/21
12/1
3.5
3.06 buckets

Specific Luminosity



- A number of measurements indicate effective head-on collision.
- The vertical tune shift became higher than 0.088. Before crab, it was 0.055.
- The specific luminosity / bunch was improved more than the geometrical gain.
- Need more time to achieve the goal (X2 specific luminosity).

Specific Luminosity



Three factors to determine luminosity:

Stored current:

1.7 / 1.4 A (e^+/ e^- KEKB)

→ 9.4 /4.1 A (SuperKEKB)

Beam-beam parameter:

0.059 (KEKB)

→ >0.24 (SuperKEKB)

Lorentz factor

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

Classical electron radius

Beam size ratio

Geometrical repipeion factors due to crossing angle and hour-glass effect

Luminosity:

0.17 $\times 10^{35}$ cm^{-2}s^{-1} (KEKB)

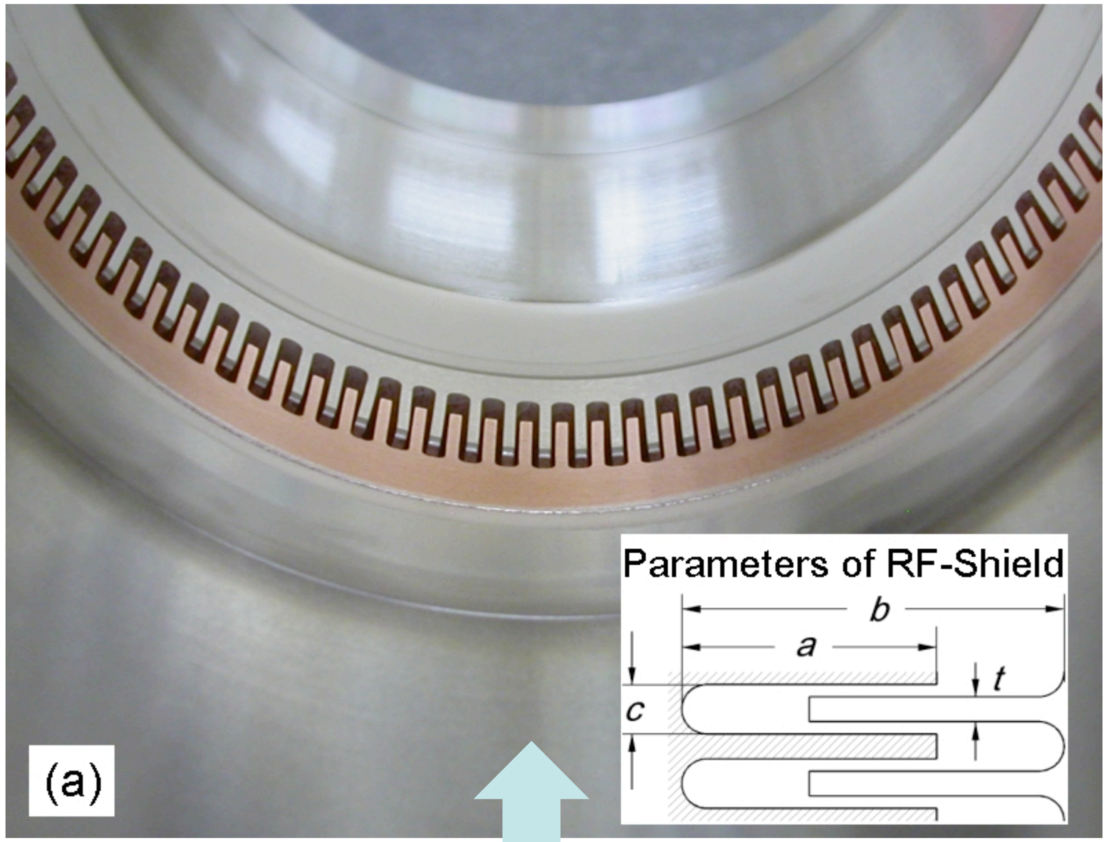
8×10^{35} cm^{-2}s^{-1} (SuperKEKB)

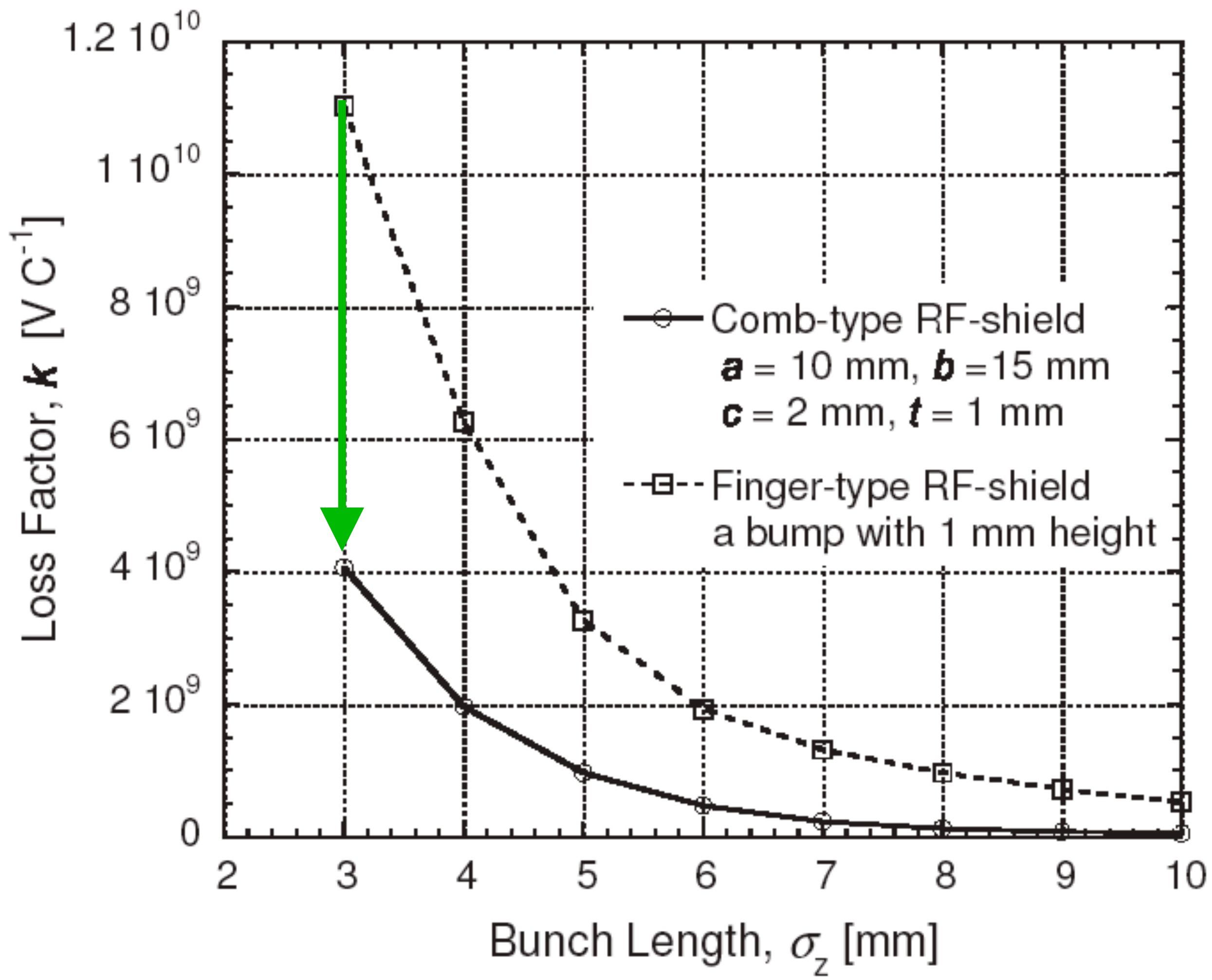
Vertical β at the IP:

6.5/5.9 mm (KEKB)

→ 3.0/3.0 mm (SuperKEKB)

Vacuum components:
Bellows chamber with comb type RF-shield





- High thermal strength
- Low impedance
- No sliding contact on the surface facing the beam

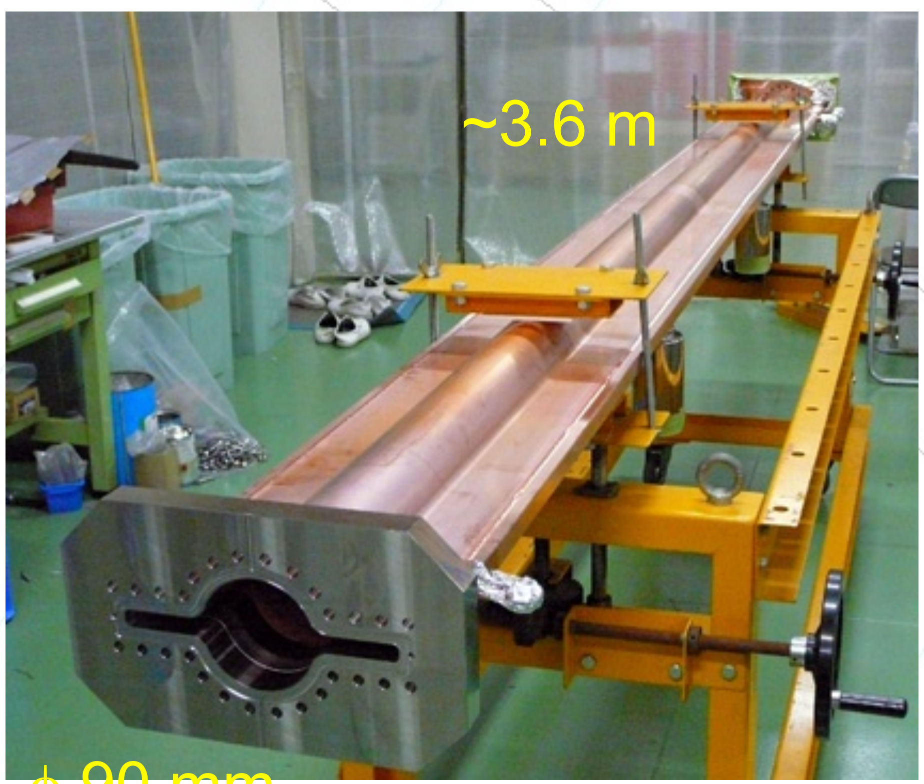
Comb-type bellows were installed in the LER (2004).

Y. Suetsugu, et al

Beam pipe with antechamber Manufacturing

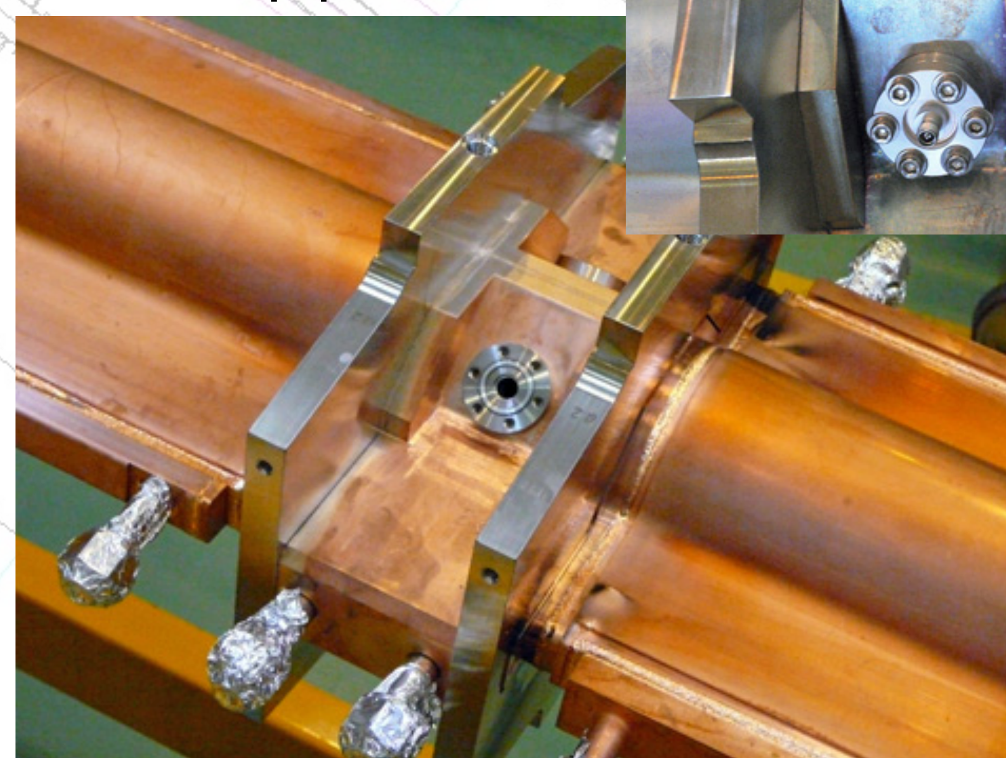
- Cold drawn copper pipe, and welded by EB.
- MO-type flange (stain-less steel).
- BPM electrode was connected by ICF flange.
- No mapping before installation;
  Gain mapping will be done by BBA

Straight pipe

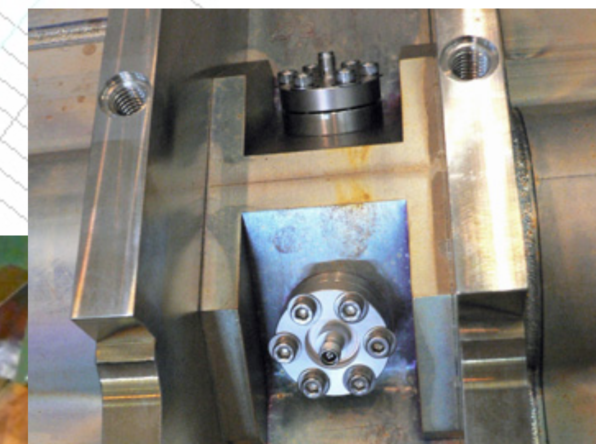


ϕ 90 mm

Q-pipe



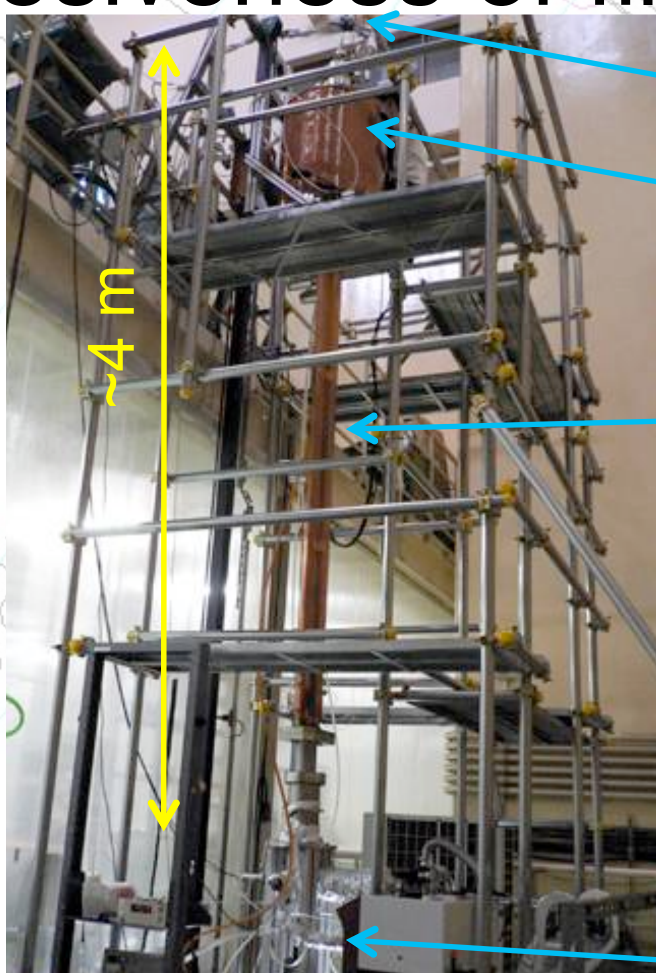
BPM

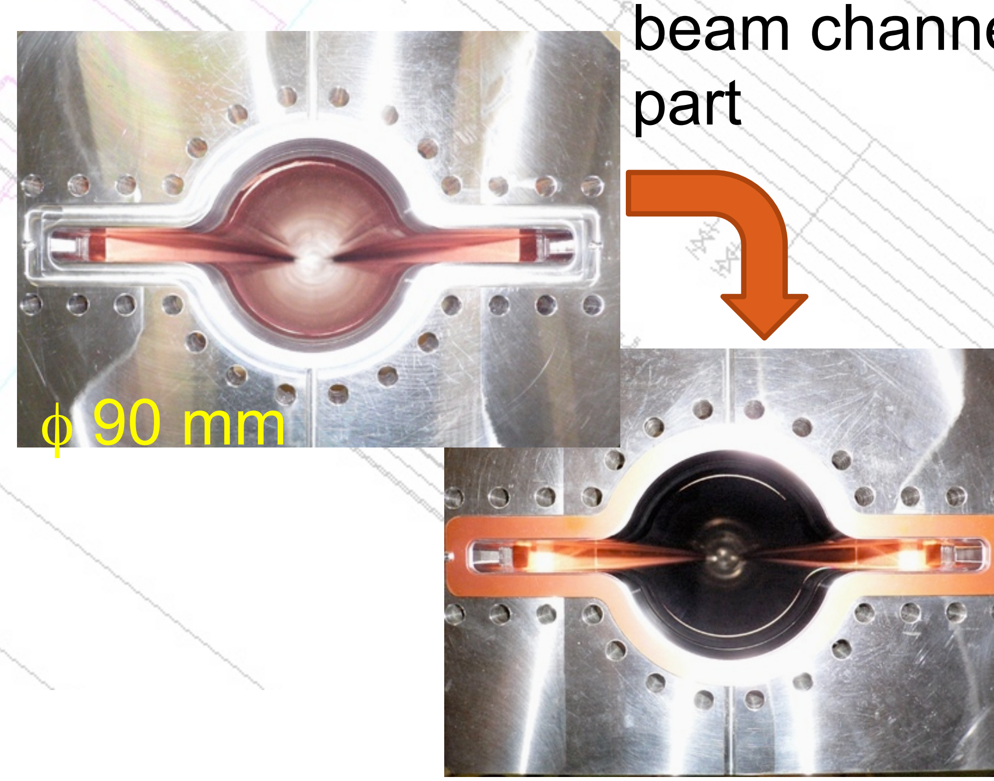


Y. Suetsugu

Beam pipe with antechamber TiN coating

- TiN was coated in KEK (K. Shibata et al.)
- Coating system available for ~4 m pipe was set up.
- Thickness is ~200 nm, which is determined from adhesiveness of film and δ_{max} (~0.84).



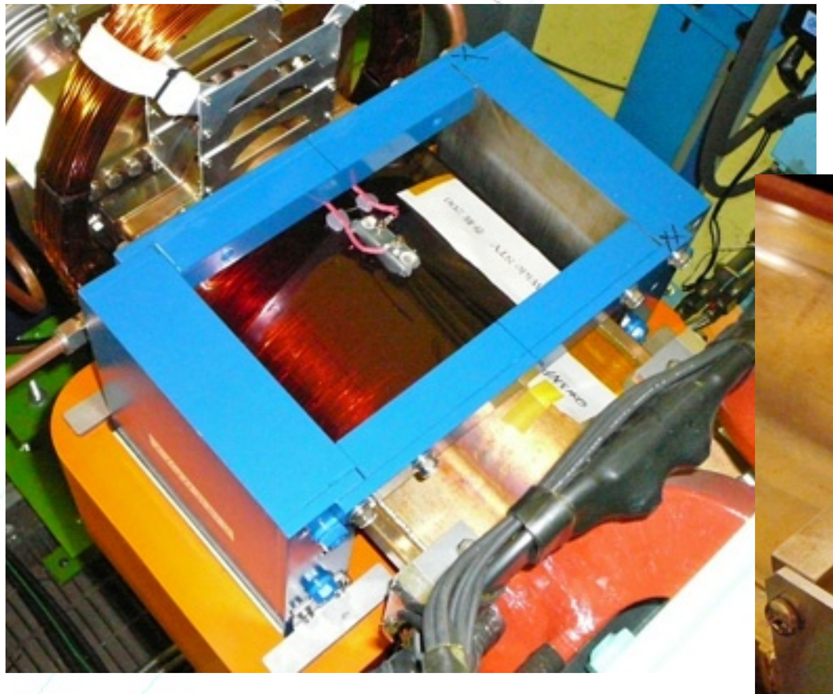


Y. Suetsugu

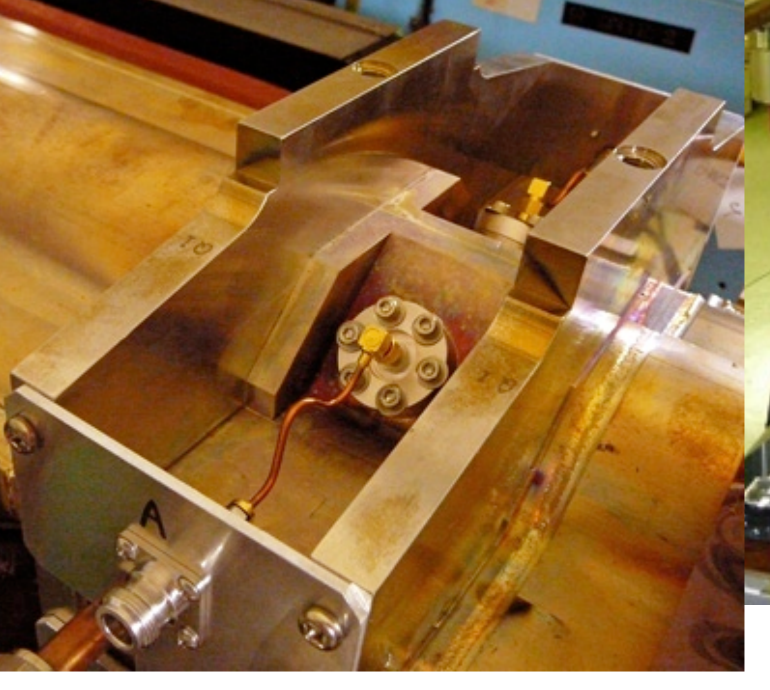
Beam pipe with antechamber BPM and magnet

- New wide vertical steering magnets were prepared to fit wide pipes (~280 mm gap).
- BPM system is the same as that of KEKB.
- Solenoids were wound at drift space.

Wide vertical steering magnet



BPM system



Solenoid at drift space

Y. Suetsugu

In-situ Measurement System of Secondary Electron Yields at Positron Ring of the KEKB

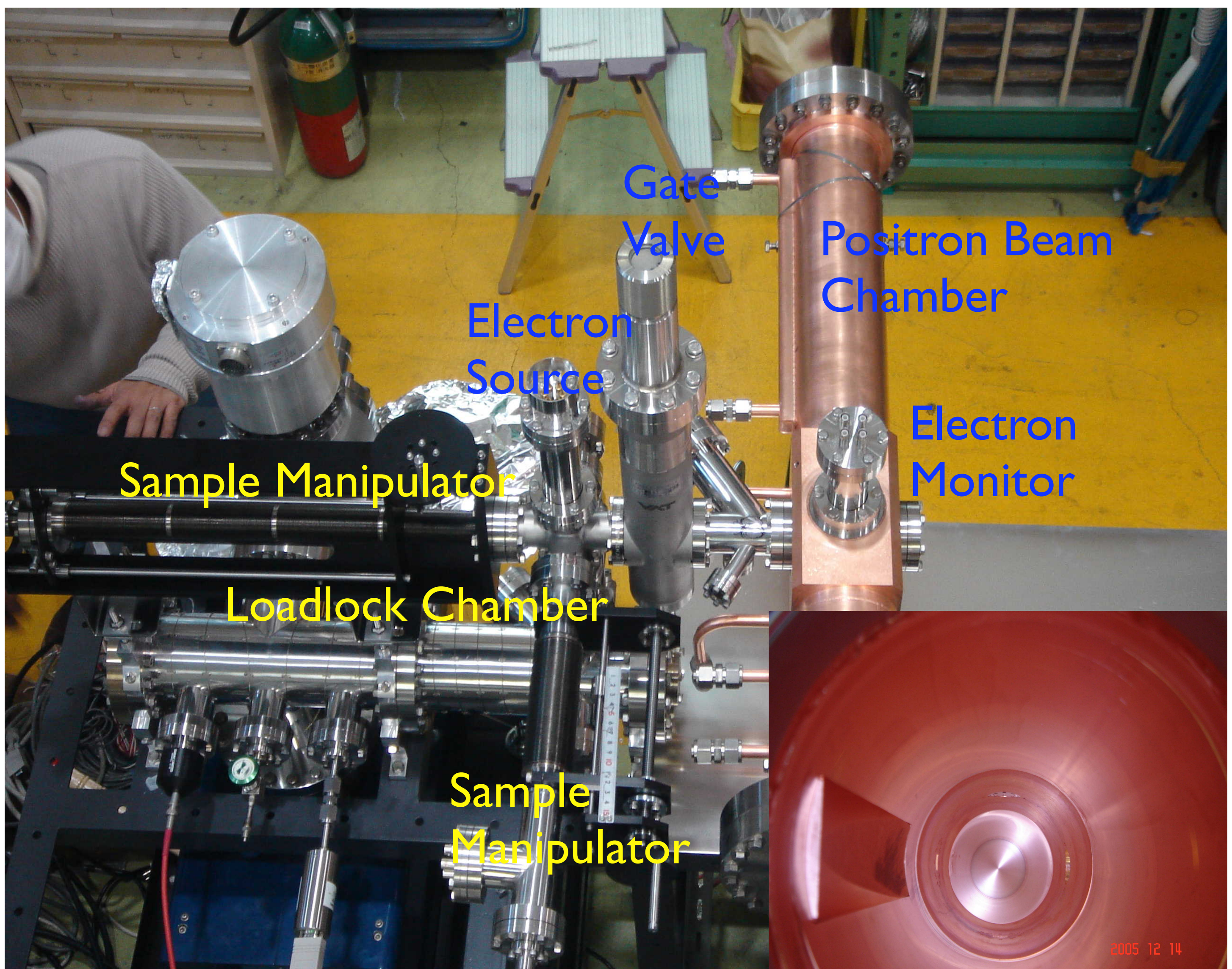
<Features>

★ In-situ Measurements of Secondary Electron Yields at Surfaces Exposed to Positron Beam of the KEKB

★ Primary Electron Beam : 50eV~5KeV, Beam Scan Capability

★ Quick Sample Exchanging Capability with Loadlock Chamber (N.A. @CERN)

★ Electron Activity Monitoring Close to Sample @ Beam Chamber



<Achievement and Plan>

◆ PY2005 :

1. designing and manufacturing of the system
2. installation of a copper beam chamber in a straight section at the KEKB.
3. a measurement system is being tested in a lab..
4. the whole setup will be installed onto the chamber and the measurement will get started.

◆ PY2006 :

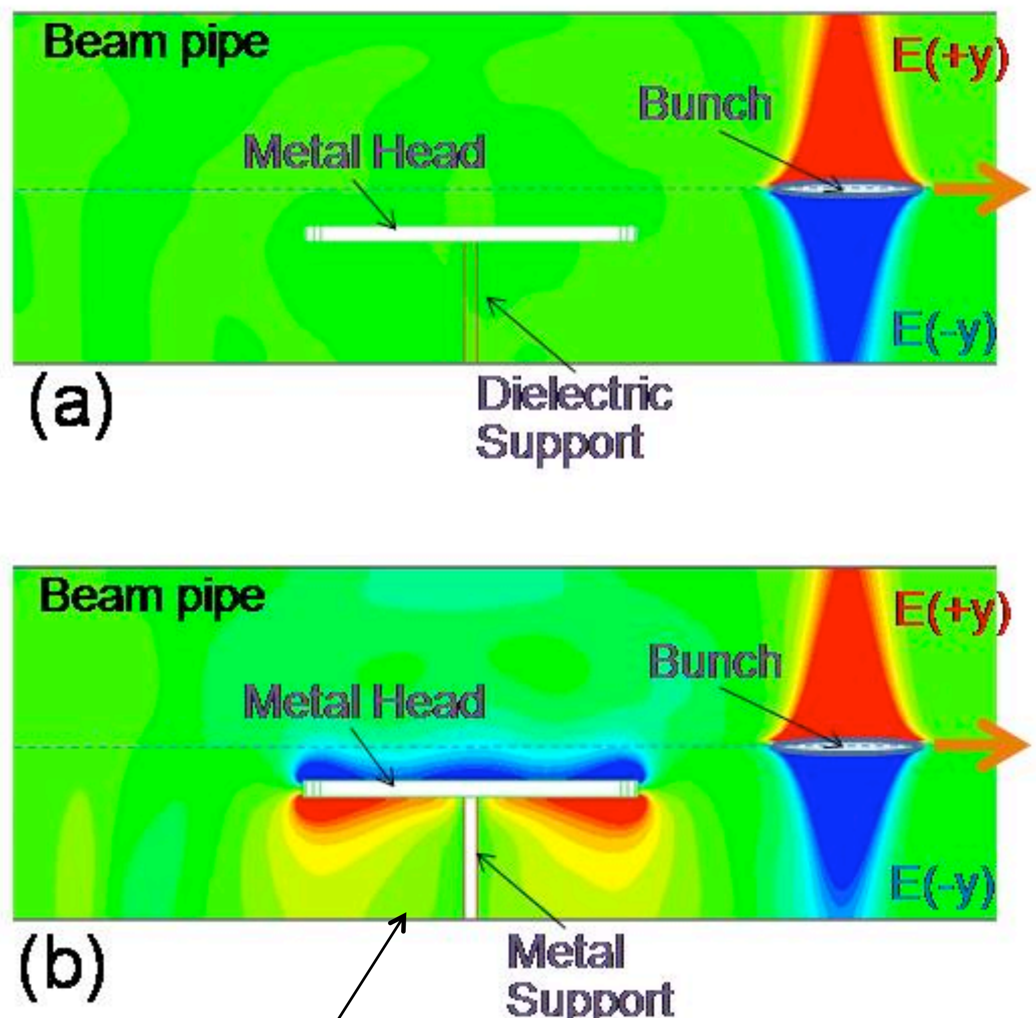
1. a series of the experiments
2. installation of a setup for short & long term exposure capability
3. installation of a setup for gas puffing capability (H_2, CO etc)
4. installation of a residual gas analyzer

S. Katoh

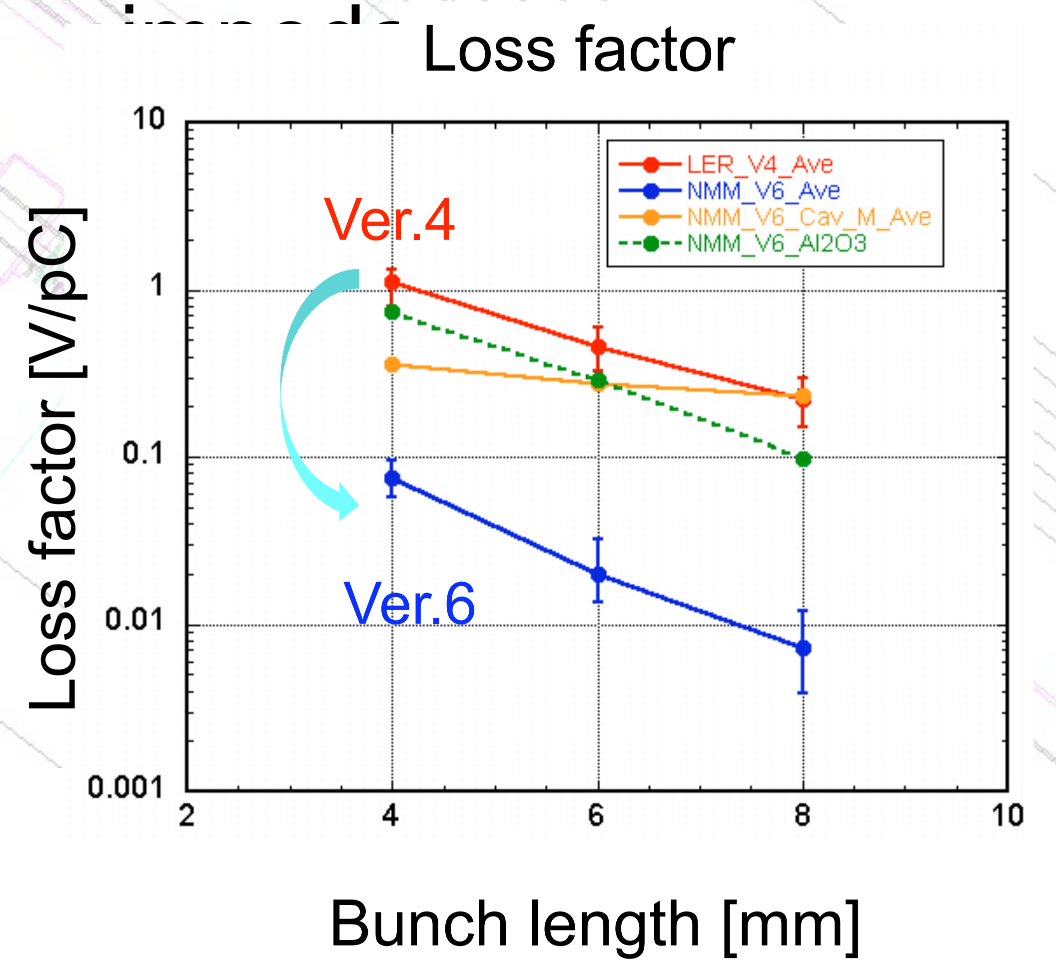
Movable Mask Ver.6 Concept

- Proposal :Metal head supported by dielectric material

  - Little interference with beam
  - Small



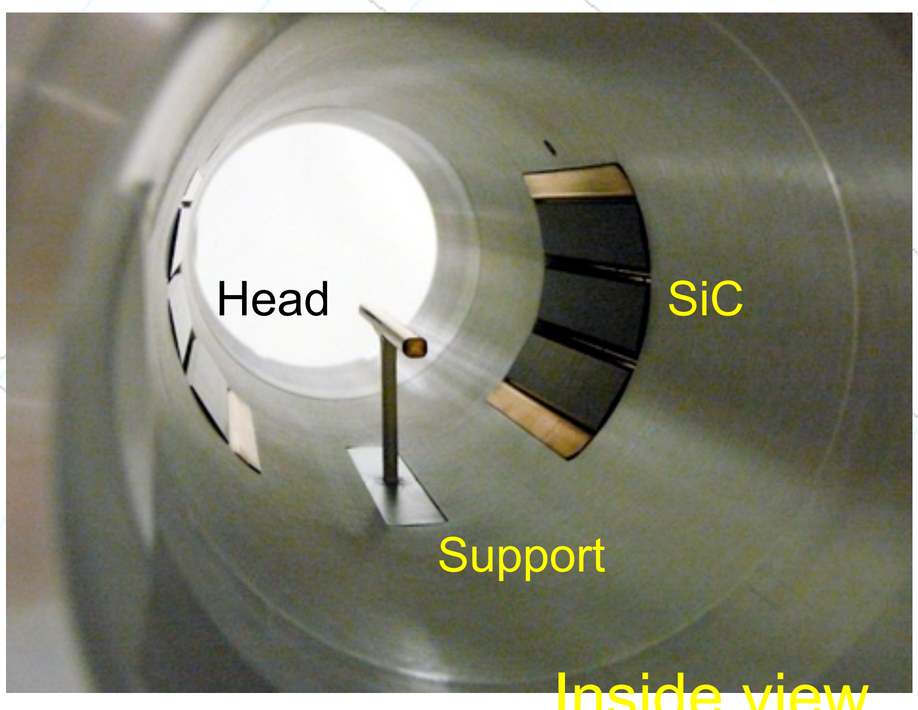
Trapped mode



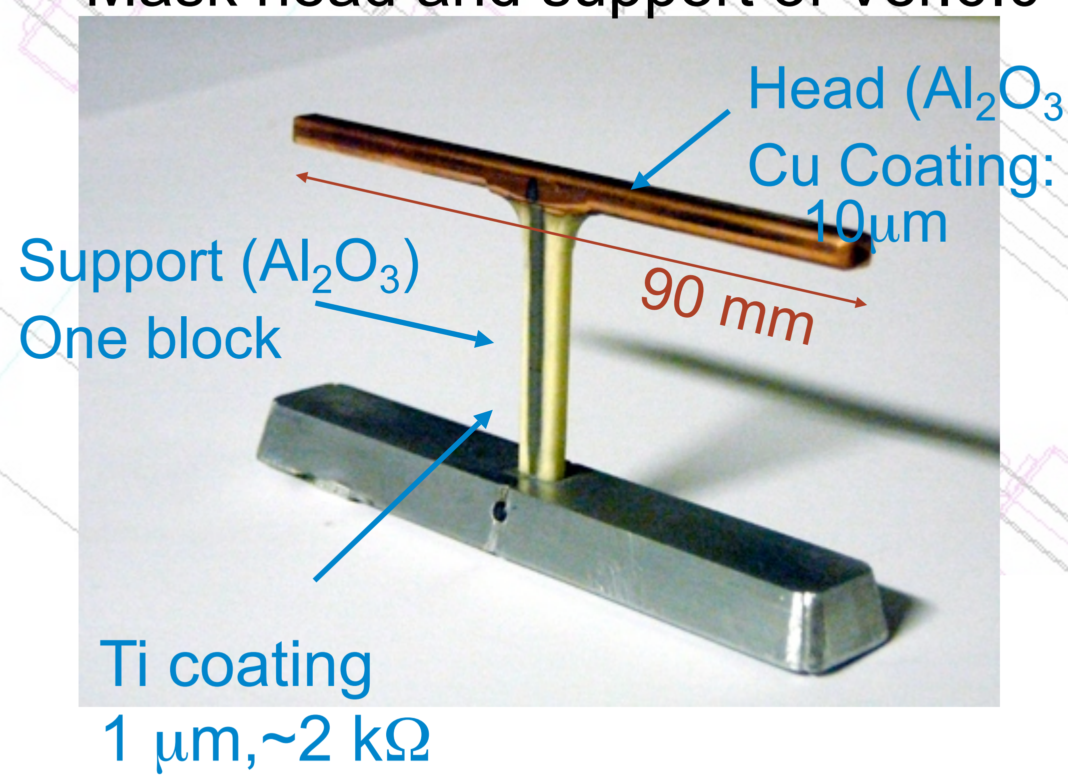
Movable Mask Ver.6
The first test model (Ver. 6.0)

- In 2006, Ver.6.0 was manufactured.
- Head : Al_2O_3 Coated with copper
- Support : Al_2O_3 (Ti coating at one side)
  - Head and support was shaped as a unit.
- HOM absorber: SiC (Inside of chamber)
- Installed into LER for proof of concept.

Inside view of mask chamber



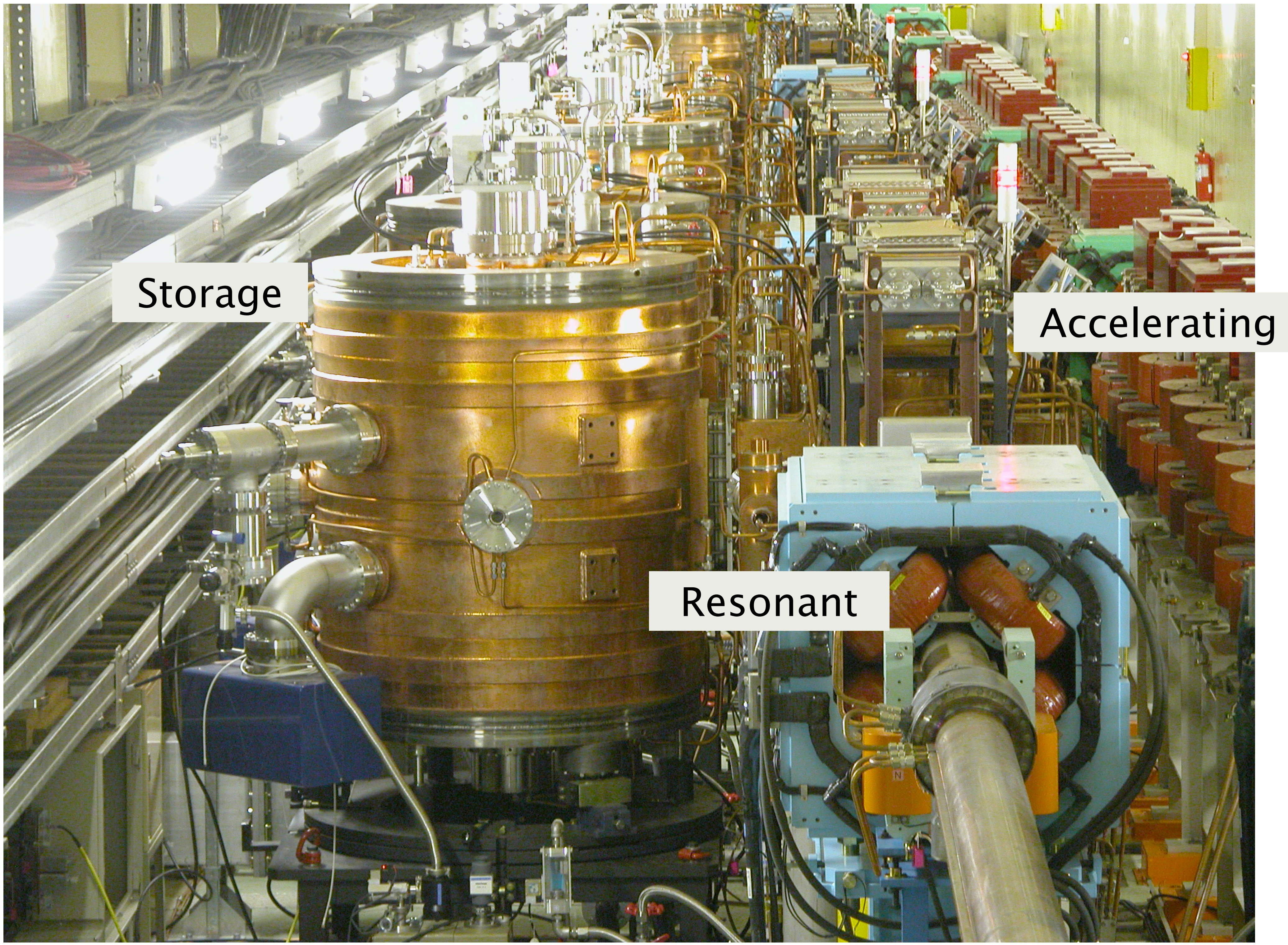
Mask head and support of Ver.6.0



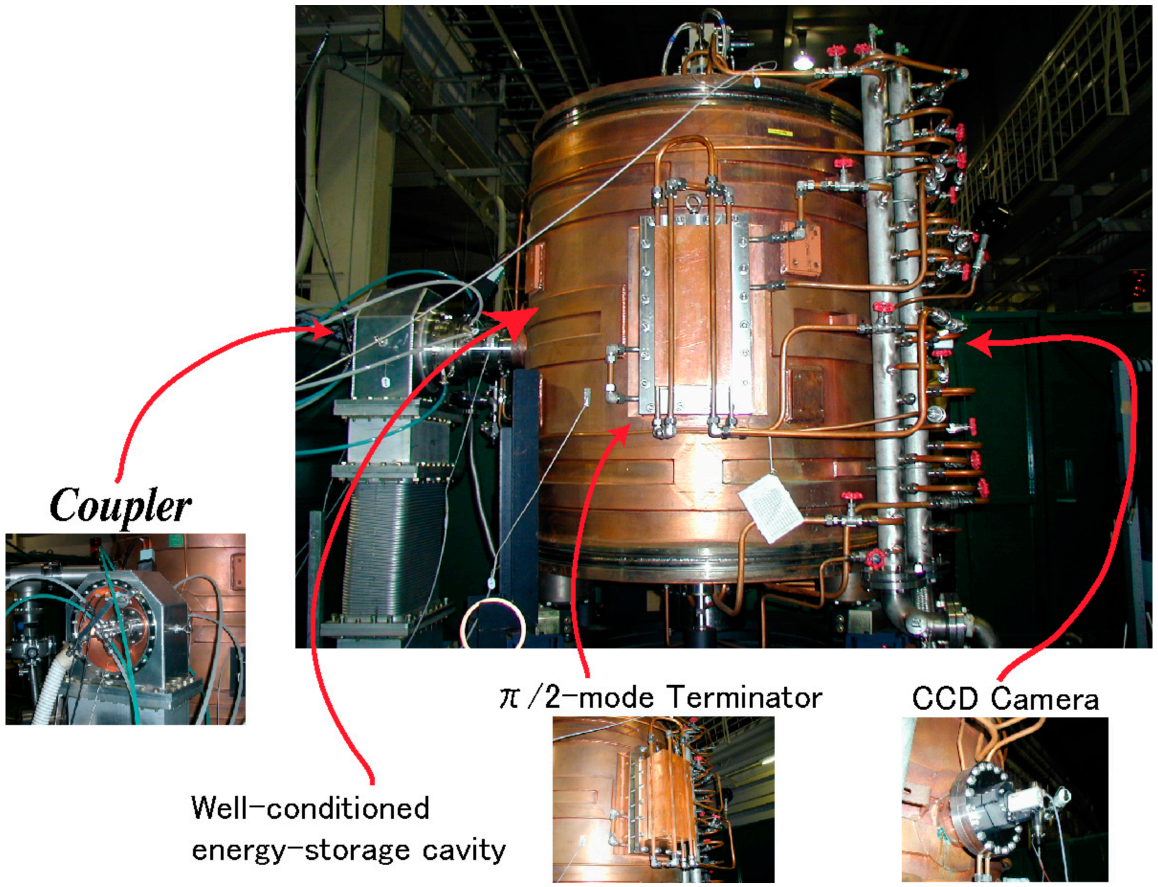
The ARES Cavity

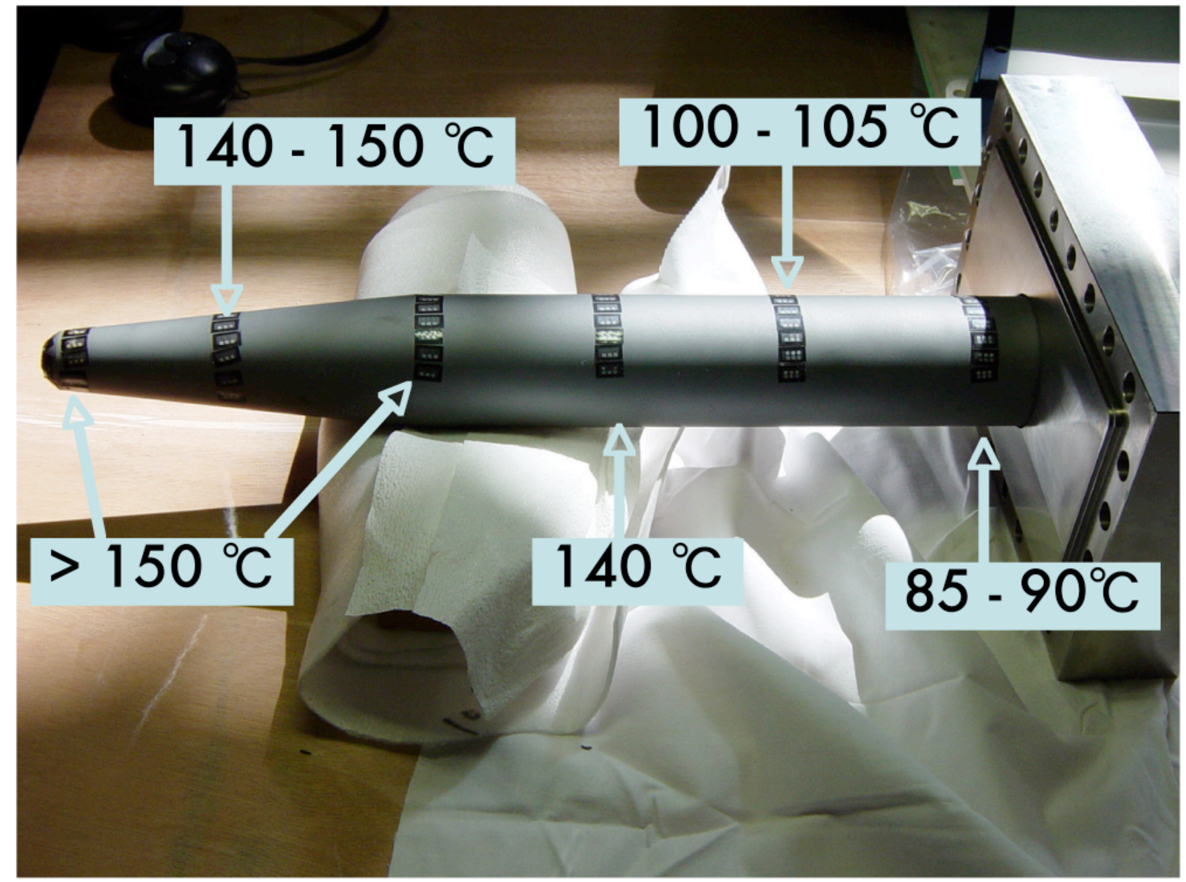
Accelerator Resonatly-coupled Energy Storage

- Passive stabilization with huge stored energy.
- Eliminate unnecessary modes by coupling of 3 cavities.
- Higher order mode dampers and absorbers.
- No need for longitudinal bunch-by-bunch feedback.



High power RF R&D





- Upgrade of ARES with higher energy storage ratio. (left)
- High power rf input couplers.
- SiC dummy load with higher power capability (right).

Y. Takeuchi, T. Kageyama, et al

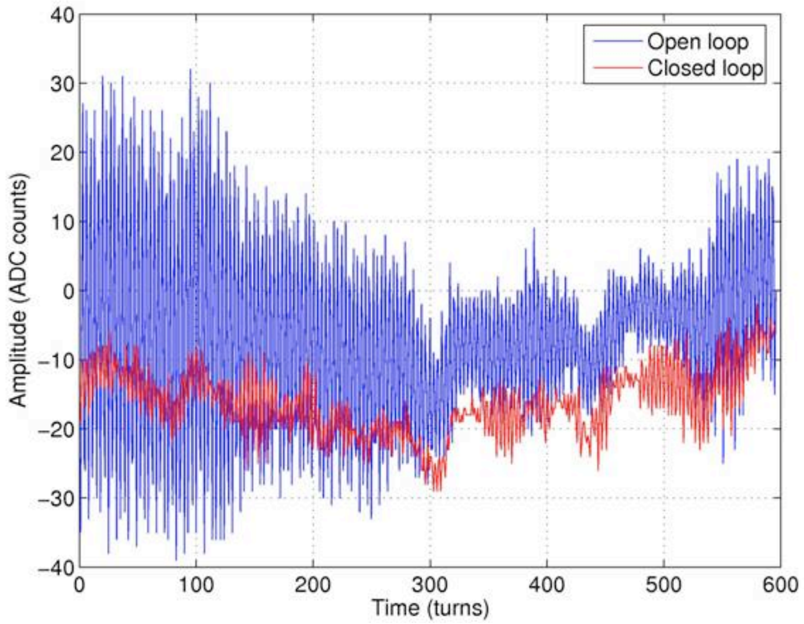
Superconpipeing Cavity

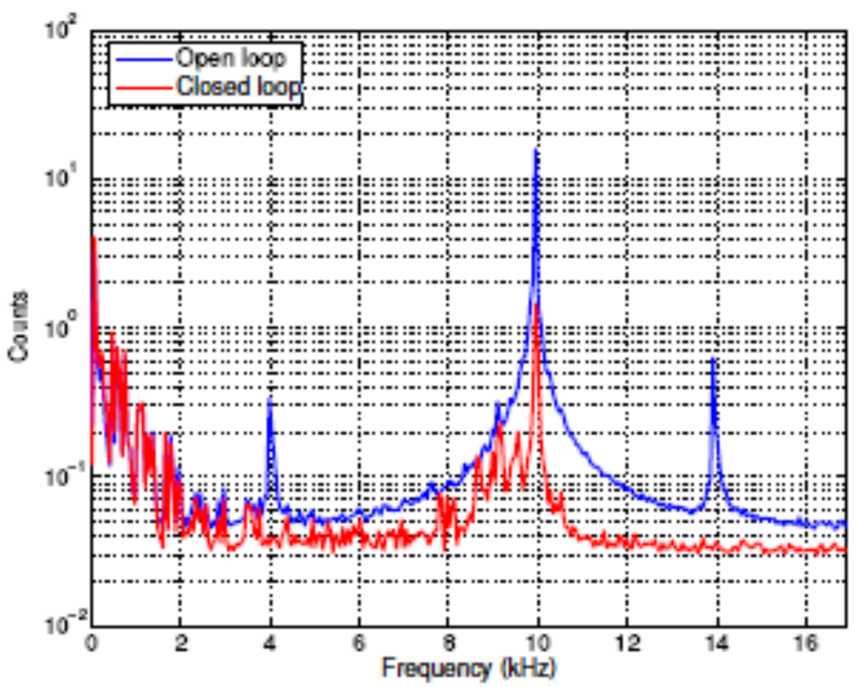
SuperKEKB challenges:
The expected power load to the HOM absorber is 50 kW/cavity at 4.1 A,
(even) with a larger beam pipe of 220 mmϕ.

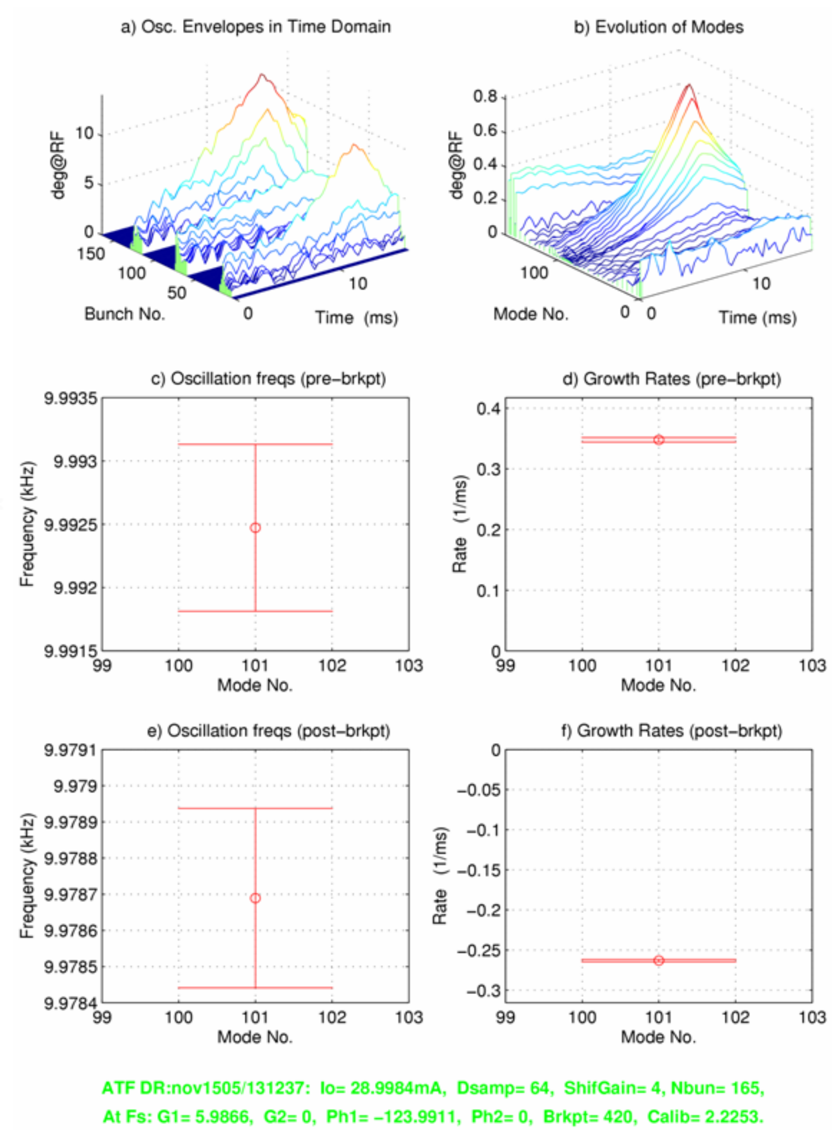
HOM damper upgrade may be needed.

S. Mitsunobu, et al

A prototype of the new bunch-by-bunch feedback system (G-board / Gproto) was tested at KEKB and ATF. The results were quite successful.





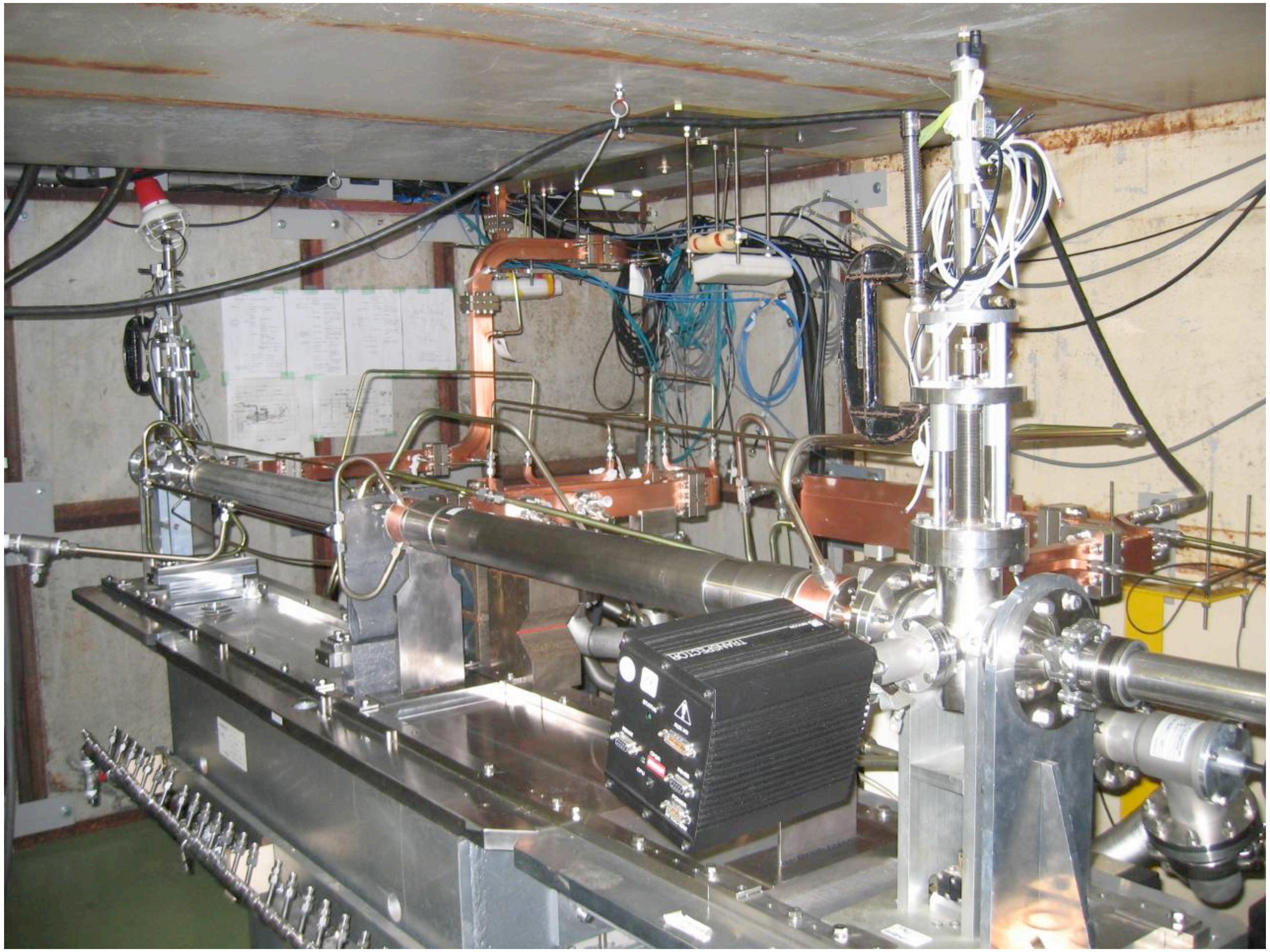


- Even in single-bunch mode, we observed a strong longitudinal instability at the ATF.
- In multi-bunch mode, we observed a strong CBI.
- Successfully damped the longitudinal CBI with the BxB feedback system using Gproto down to 1/10.
- Successfully analyzed strongest coupled-bunch mode. (218+n*357 MHz)
- For practical use, it will be necessary to build and install a good feedback kicker.

M. Tobiyama

- C-band linac: completed a single section in the linac with 4 structures.
- Performance was satisfactory with the beam.

T. Kamitani, et al



C-Band Klystrons

	S-band	C-band		
Parameters	KEKB	1-st prototype	2m-structure	Unit
total length	2.072	1.082	2.0	m
number of regular cells	54	54	108	
regular cell length (d)	35.0	17.5	17.5	mm
disk thickness (t)	5.0	2.5	2.5	mm
disk iris diameter (2a)	24.95 - 20.90	12.48 - 10.45	14.03 - 10.54	mm
cavity diameter (2b)	83.0 - 82.0	41.5 - 41.0	42.0 - 41.0	mm
group velocity (v_g/c)	1.4	1.9 - 1.0	2.8 - 1.0	%
shunt impedance	57	75 - 85	67 - 85	MΩ/m
Q factor	13700	9690	9700	
RF power in cells	30 - 15	34 - 15	59 - 15	
Field gradient	21	41.2 - 39.0	42.5 - 38.1	
Filling time	462	234	376	
Attenuation constant	0.302	0.434	0.696	

Table 11.3: Accelerating section characteristics

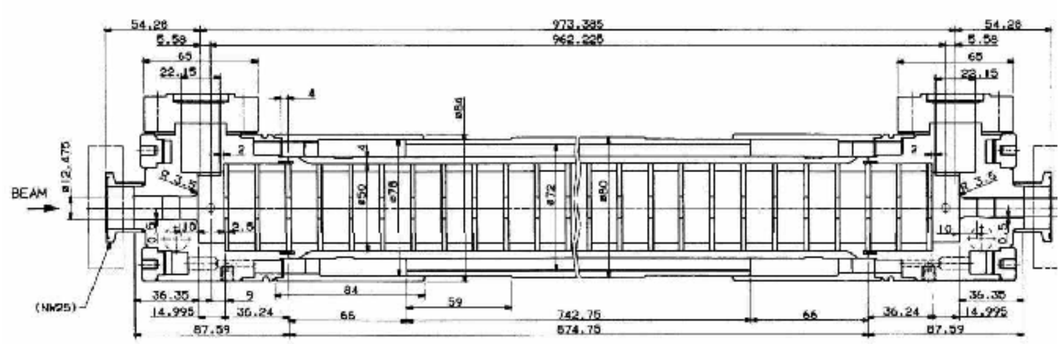
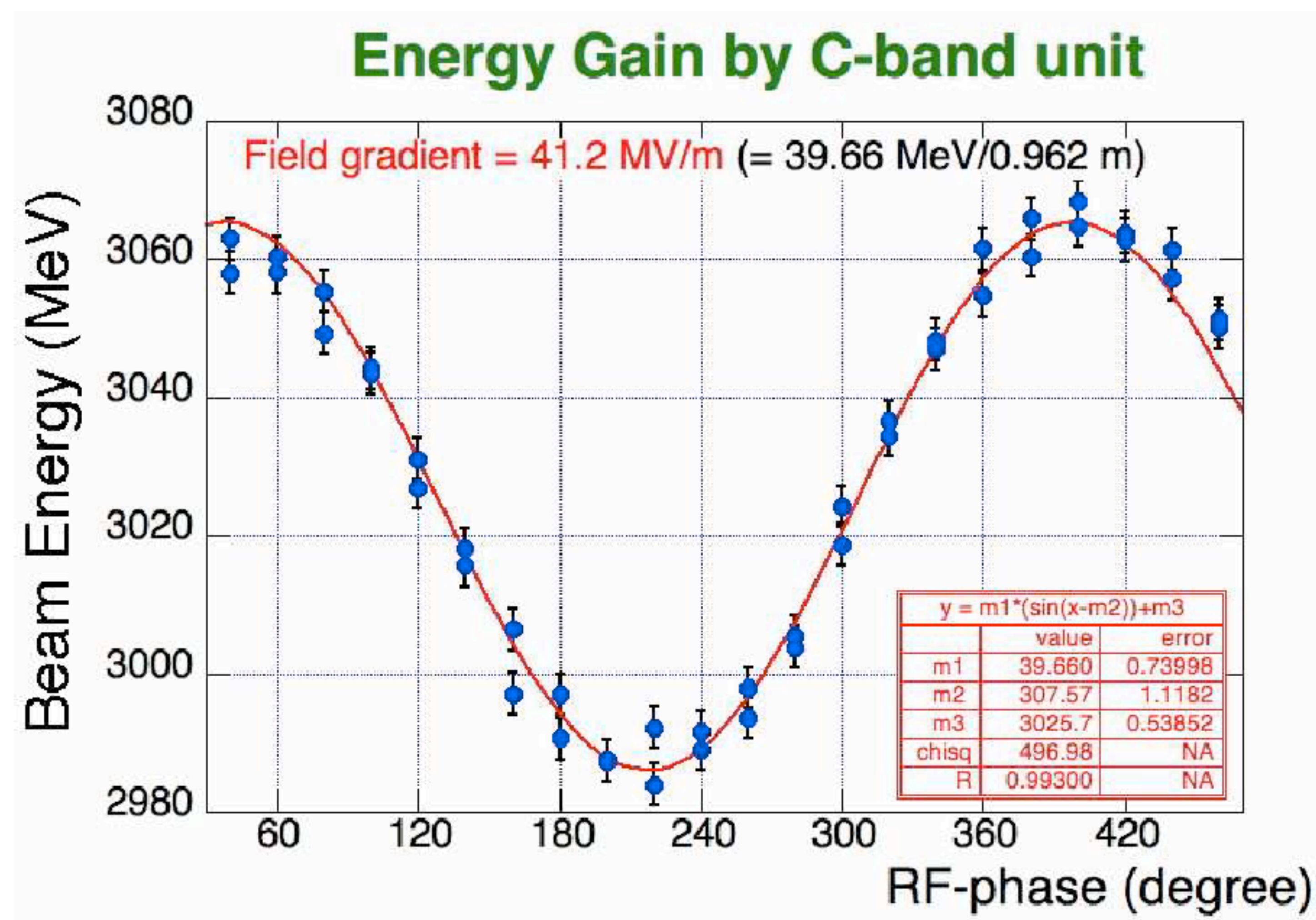


Figure 11.7: C-band 1m-long accelerating section (1-st prototy

Prototype C-band structure installed and tested at linac using actual beam (2003). Measured field gradient of 41 MV at 43 MW agrees with expectation.

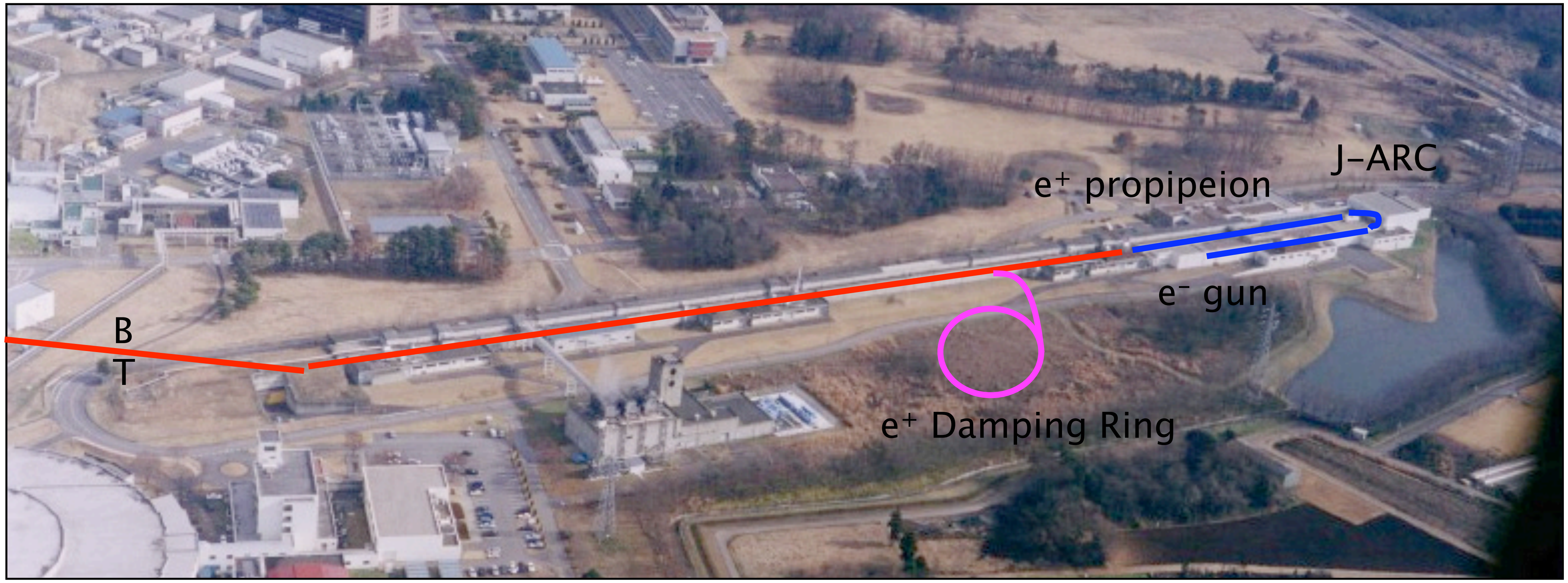


T. Kamitani, et al

Damping Ring

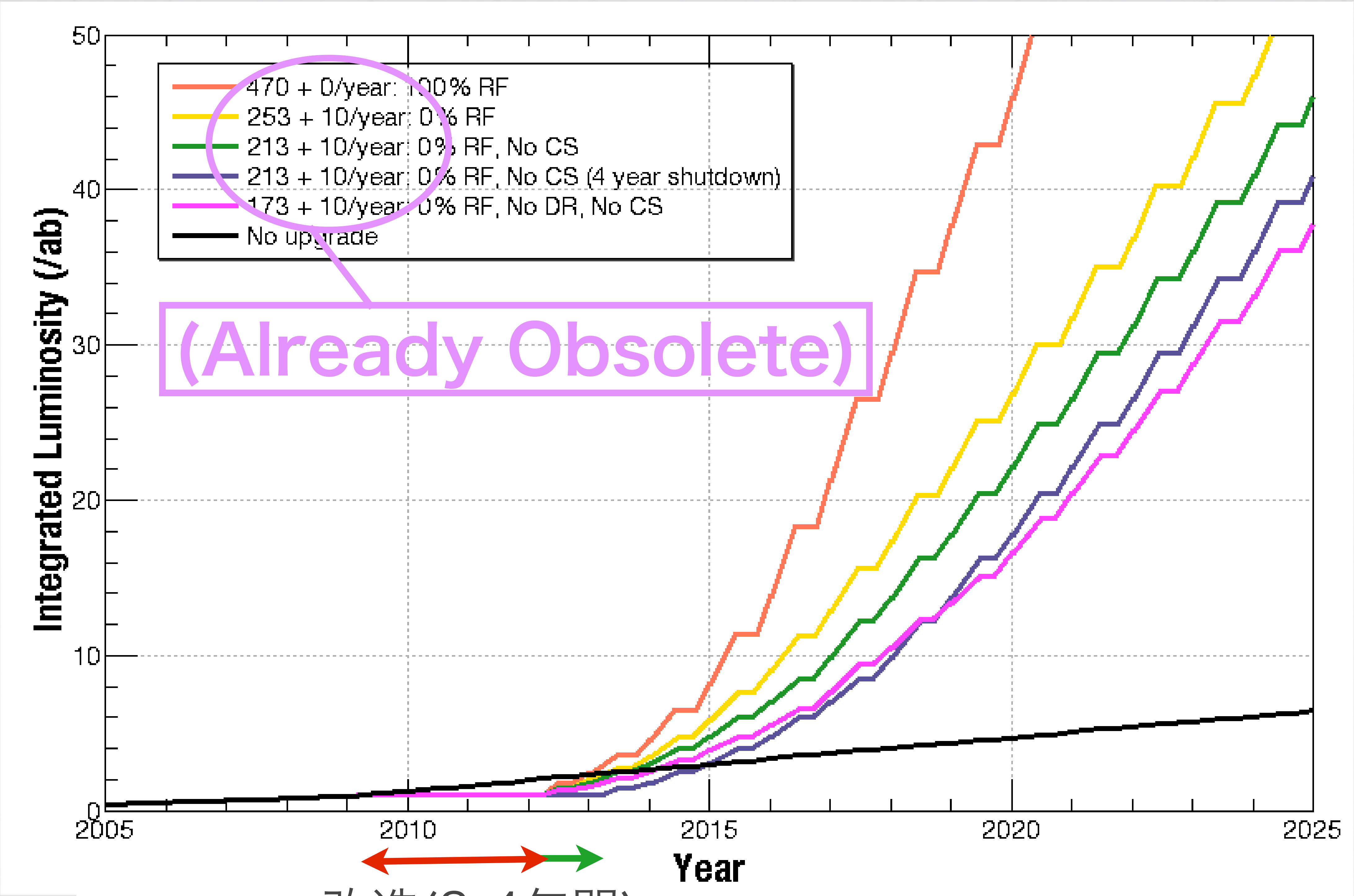
- Positron emittance needs to be damped, to pass reduced aperture of C-Band section and to meet IR dynamic aperture restrictions.
  - Electron DR may be considered later to reduce injection backgrounds in physics detector, but for now only positron DR considered.
- Damping ring located downstream of positron target, before C-Band accelerating section.

M. Kikuchi



Cost & Effect

Item	Object	Oku-yen = 0.6 M€	Luminosity
New beam pipes	Enable high current Reduce e-cloud	161 (incl. BPM, etc.)	x1.5
New IR	Small β^*	12	x2
e+ Damping Ring	Allow injection with small increase e+ capture	40 incl. linac upgrade	if not, x0.75
More RF and cooling systems	High current	200 (incl. facilities)	x3
Crab Cavities	Higher beam-beam param.	10	x2 - x4



470 + 0/year: 100% RF
253 + 10/year: 0% RF
213 + 10/year: 0% RF, No CS
213 + 10/year: 0% RF, No CS (4 year shutdown)
173 + 10/year: 0% RF, No DR, No CS
No upgrade
(Already Obsolete)
Integrated Luminosity (/ab)
Year
0
10
20
30
40
50
2005
2010
2015
2020
2025

改造(3-4年間)