Plan of SuperKEKB

Y. Funakoshi
KEK

Introduction

Why do we propose SuperKEKB?

- Physics Motivations
  - Next milestone of KEKB/Belle: 1 ab^{-1} (Now: 0.49 ab^{-1})
  - Search for New Physics: 10~50 ab^{-1}
    - New source of CP violation
    - New source of flavor mixing
    - Lepton favor violation of τ−lepton

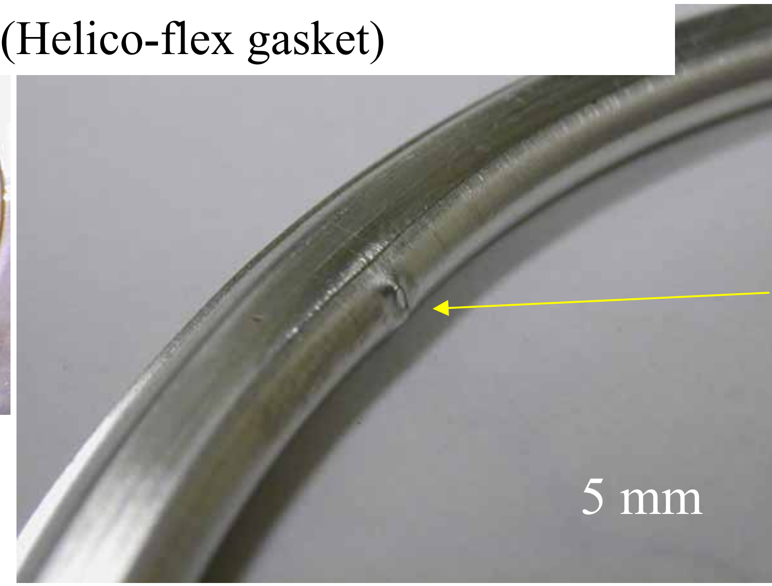
Why do we propose SuperKEKB? [cont'd]

- Machine Motivations
  - We have a lots of properties to be useful for a super B factory.
  - We have accumulated technologies and techniques for high Luminosity.
    - High beam current accumulation
    - High beam-beam parameters
    - Cures of harmful effects (e- could, ion…)
  - Use of legacy of KEKB
    - 3-km tunnel
    - RF sources and cavities
    - Magnets
    - Etc.

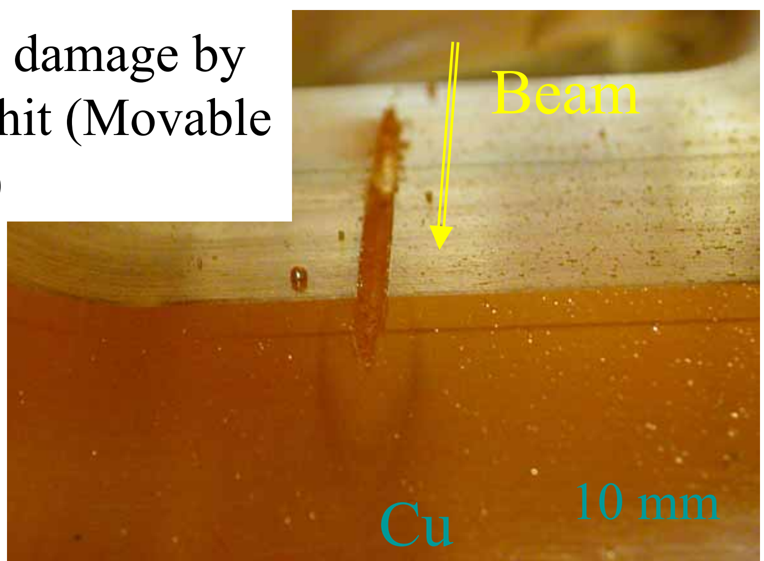
Vacuum troubles due to high beam current
(some examples from KEKB experiences)

Damaged RF-shield fingers of bellows due to HOM

Vacuum leak due to SR irradiation (Helico-flex gasket)



Direct damage by beam hit (Movable Mask)



We had to overcome a number of vacuum troubles for attaining high beam currents.

Boundary conditions and constraints

- Other projects
  - J-PARC
    - Construction of J-PARC will be finished at the beginning of 2008.
  - ILC (my personal view)
    - Construction will start in 2010? (-> maybe delayed)
    - Physic experiments will start 2015? (-> maybe delayed)
    - Super B factory will naturally fit into the time table of developments of HEP.
- Strategy of SuperKEKB
  - The plan should be realistic.
    - Construction will start in 2008.
      - Avoid adoptions of new devices which required long-term R&D's such as an RF system with a new frequency.

Three factors to determine luminosity:

Stored current:

1.34 / 1.8 A (KEKB)

→ 4.1 / 9.4 A (SuperKEKB)

Beam-beam parameter:

0.057 (KEKB)

→ 0.19 (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 reduction factors due to crossing angle and hour-glass effect

Luminosity:

0.15×10^{35} $cm^{-2}s^{-1}$ (KEKB)

4×10^{35} $cm^{-2}s^{-1}$ (SuperKEKB)

Vertical β at the IP:

5.2/6.5 mm (KEKB)

→ 3.0/3.0 mm (SuperKEKB)

Bunch length (σ_s)

7 ~ 9 mm -> 3 mm

Key points of upgrade for SuperKEKB

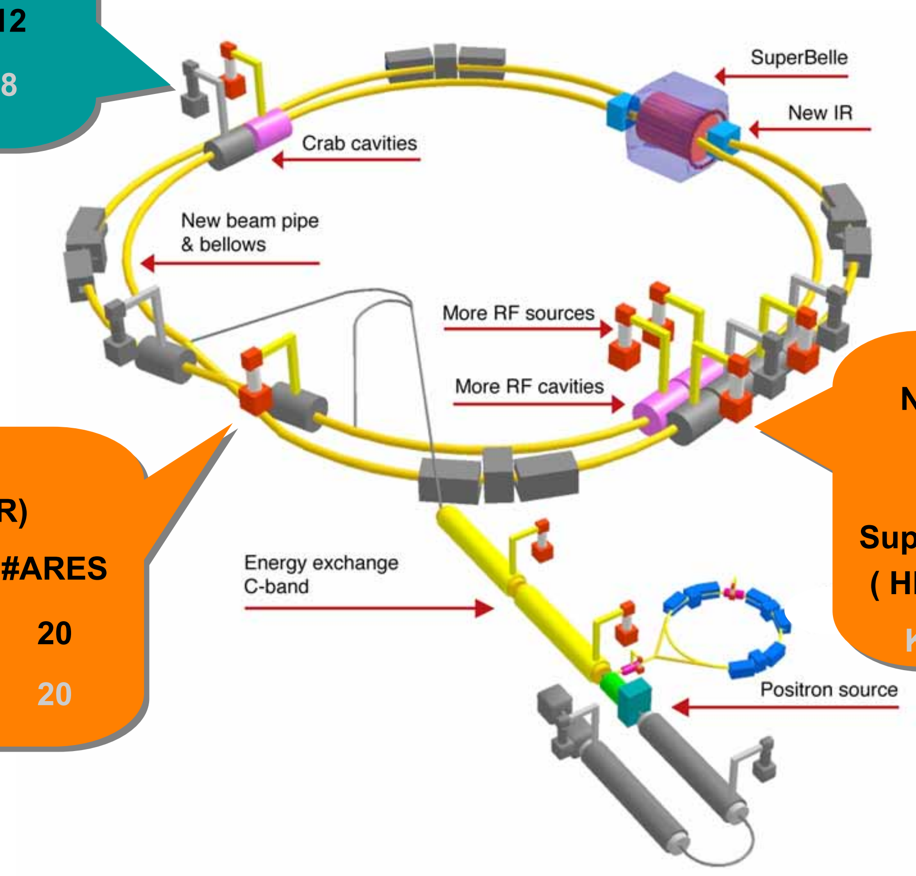
Key points of upgrade[1]

- High Beam Currents
  - RF system
    - RF power
    - Frequency detuning due to beam loading
    - Handling of high HOM power
  - Vacuum System
    - Handling of high SR power
    - Tolerance against high HOM power
    - Electron cloud instability
  - Linac upgrade
    - Energy switch between e- and e+
  - Bunch-by-bunch feedback
    - Faster damping (transverse)
    - Longitudinal feedback (no need at the present KEKB)

SuperKEKB Requires More RF Sources and More RF Cavities

Nikko
SC RF section (HER)

	#Kly.*	#SCC
SuperKEKB	12	12
KEKB	8	8



Fuji
NC RF section (LER)

	#Kly.	#ARES
SuperKEKB	20	20
KEKB	10	20

Oho
NC RF section (HER&LER)

	#Kly.	#ARES
SuperKEKB (HER/LER	24 8 / 16	24 8 / 16)
KEKB	6	12

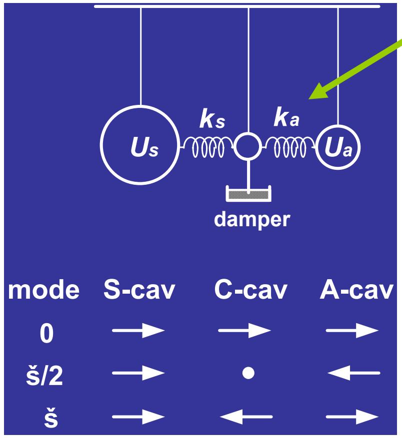
* 1MW CW Klystron (509 MHz)

1klystron:2 NC cavity -> 1klystron:1 NC cavity
KEKB -> SuperKEKB

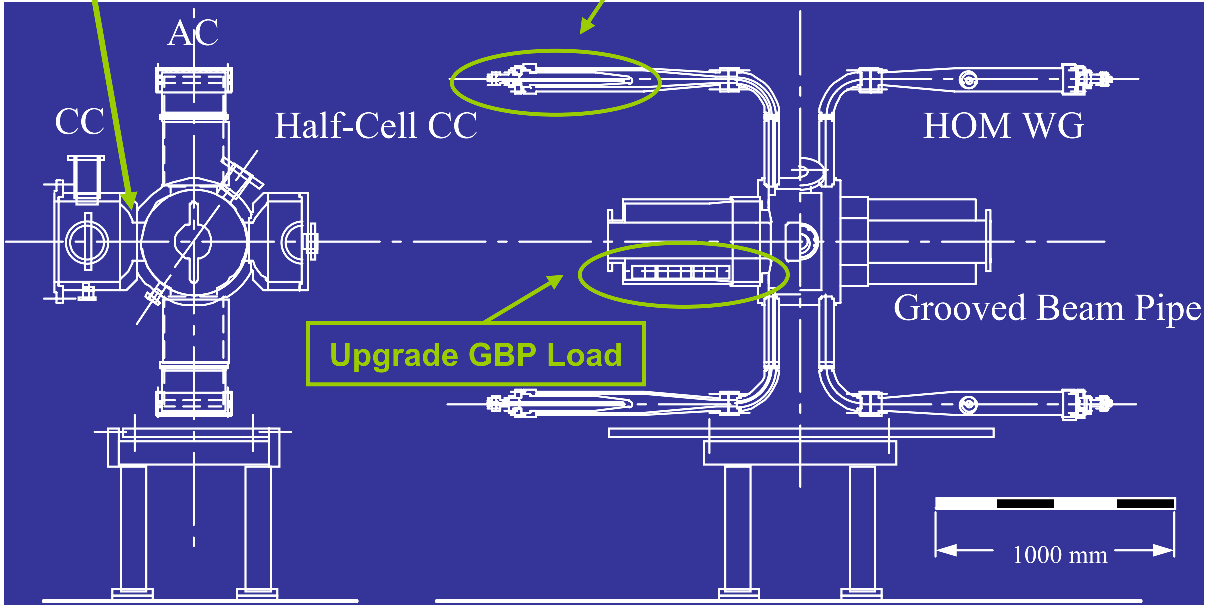
Upgrading ARES Cavity

Increase k_a by enlarging the coupling aperture between A-cav and C-cav.

Upgrade HOM WG Load



$$\frac{U_s}{U_a} = \frac{k_a^2}{k_s^2}$$ ***for π/2 mode***

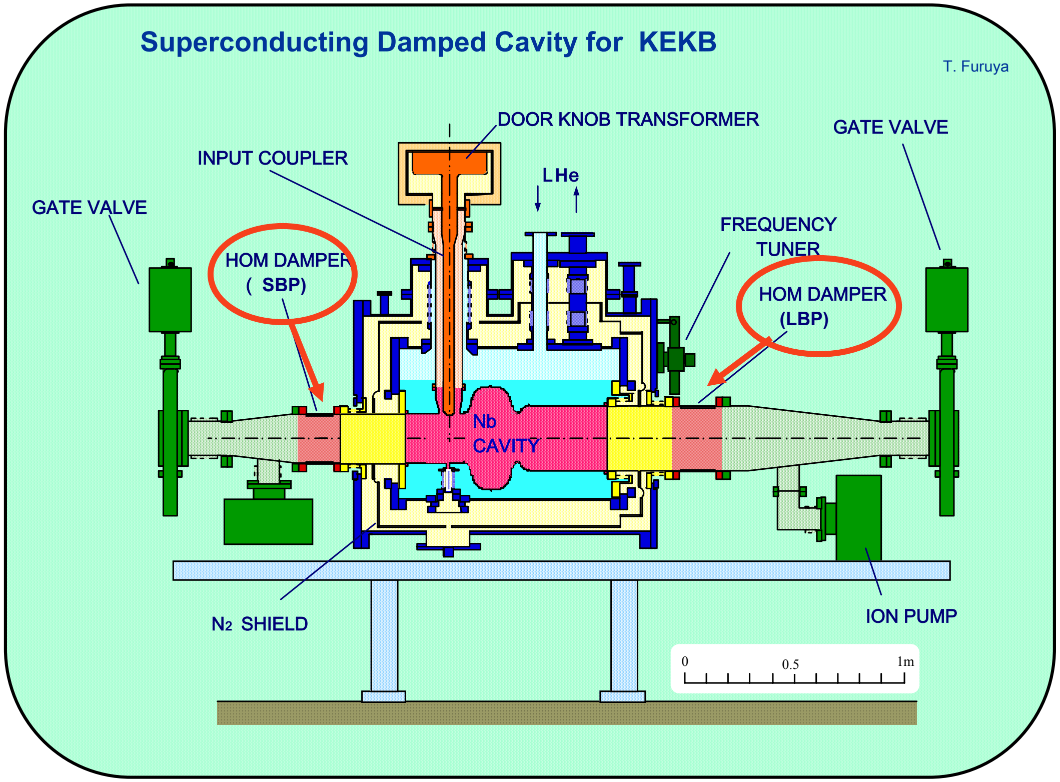


Upgrade GBP Load

• **Fortunately, ARES scheme is flexible to upgrade: By increasing U_s/U_a from 9 to 15, the severest beam instability can be eased by one order of magnitude and manageable with an RF feedback system.**

• **The HOM absorbers (SiC) need to be upgraded: The HOM power per cavity is estimated about 90 kW for the design beam current 9.4 A for LER.**

Upgrading Superconducting Cavity

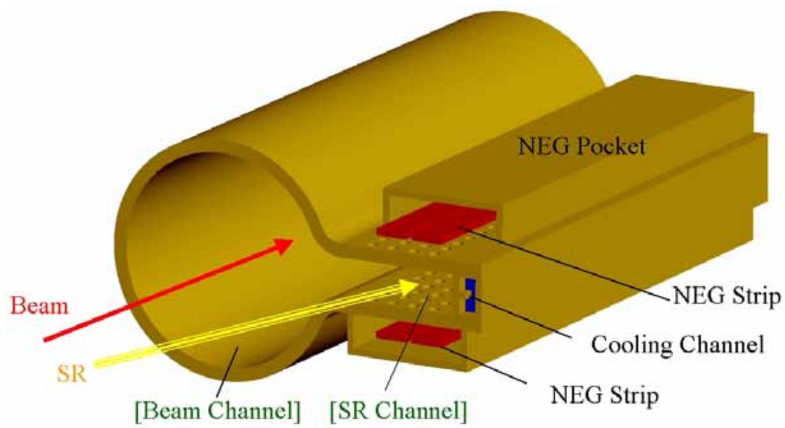


- **Cavity structure not changed.**

- **The HOM absorbers (ferrite) need to be upgraded: The HOM power per cavity is estimated about 50 kW for the design beam current 4.1 A for HER.**

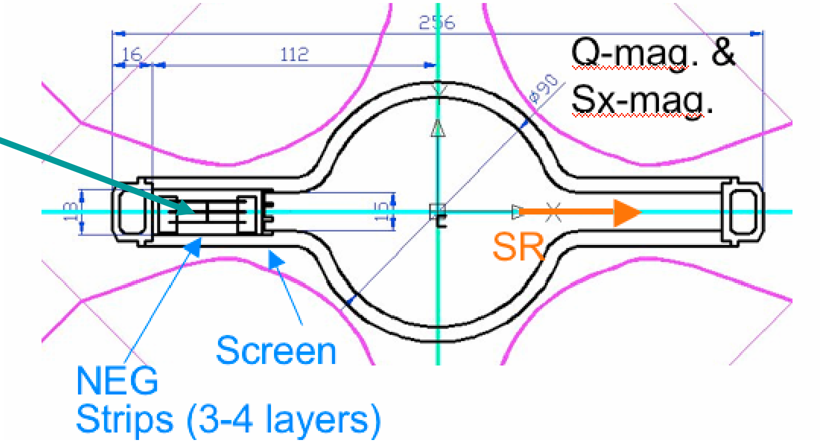
R&D of Vacuum Components for SuperKEKB

Beam duct with antechamber



- Smaller SR Power Density
- Lower Impedance
- Lower photoelectron production by TiN or NEG coating

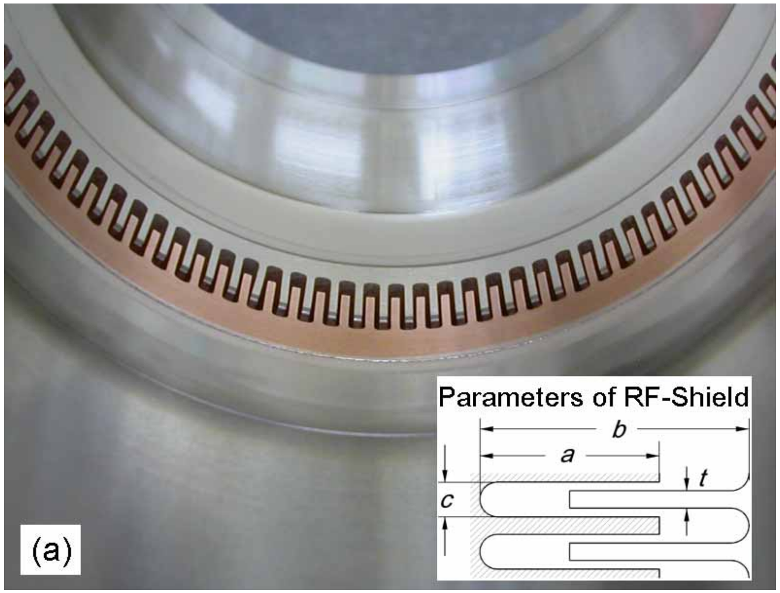
New design with pumps in Q and SX magnets → uniform pumping



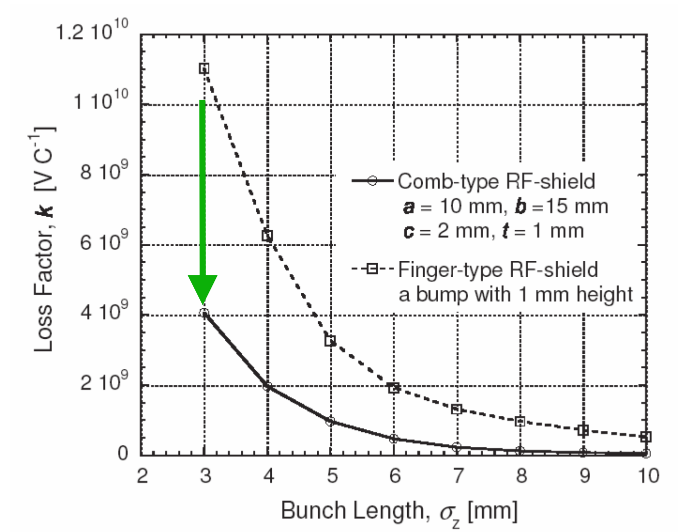
Y. Suetsugu et al.

R&D of Vacuum Components for SuperKEKB

Bellows chamber with comb type RF-shield:
Some prototypes have been tested in KEKB and showing good performance.



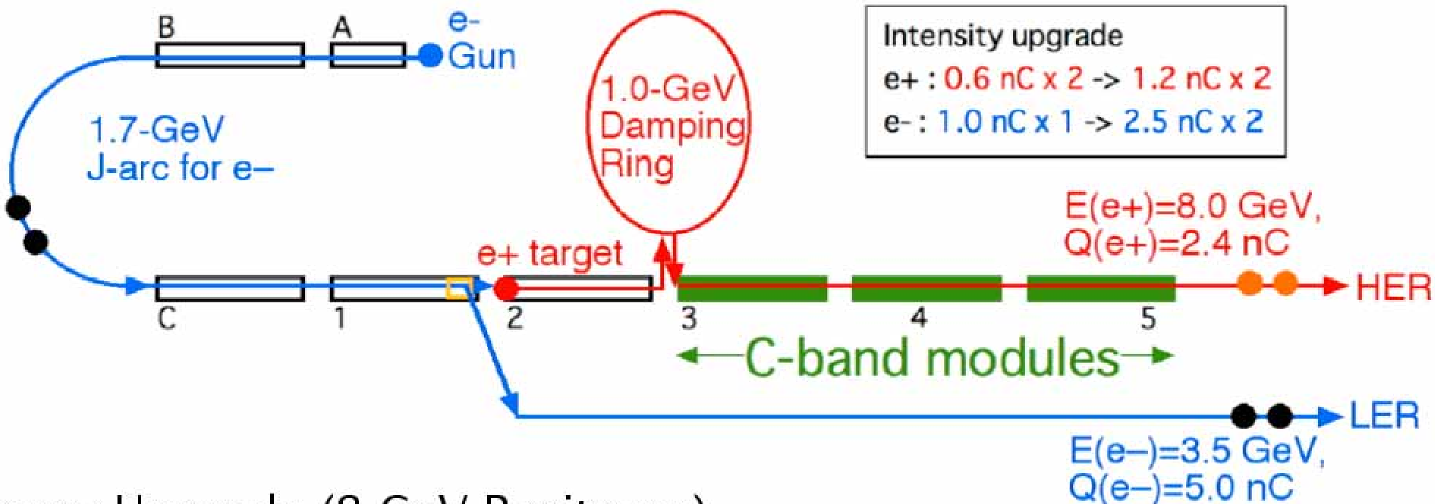
Y. Suetsugu



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

A bellows chamber damaged by the high-current beam.

Injector Linac Upgrade for SuperKEKB



Energy Upgrade (8 GeV Positrons)
Replace S–band (2856 MHz) RF system with C–band (5712 MHz) system to double field gradient in downstream section of linac.
(The present max. energy gain is 4.8 GeV)

T. Kamitani et al.

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 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.

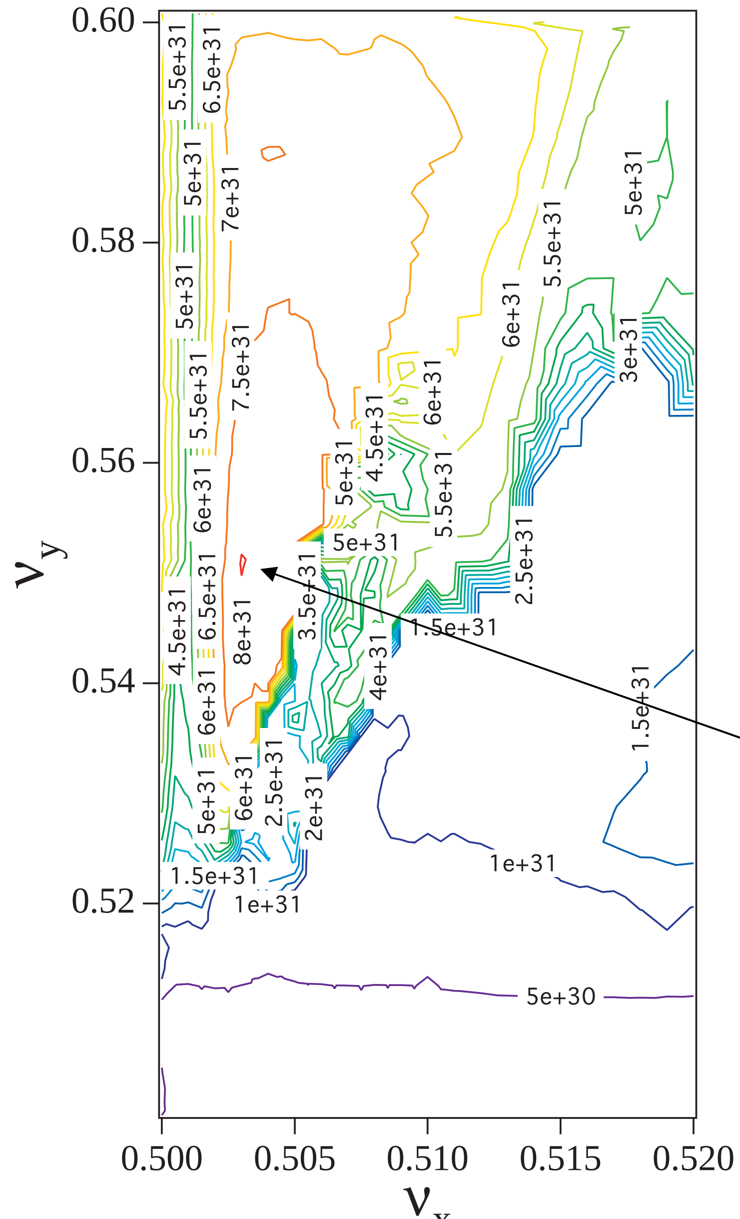
- Digital FIR and memory board to be replaced by new GBoard under development at/with SLAC
  - Low noise, high speed (1.5 GHz), with custom filtering functions.
  - Extensive beam diagnostics.

M. Tobiyama

Key points of upgrade[2]

- High beam-beam parameters
  - Combination of choice of betatron tunes and head-on collision
    - ν_x very close to half integer
    - Crab crossing

Beam-beam simulation



Tune Survey in SuperKEKB without parasitic collision effect.

L_{peak}=4.0x10^{35}cm^{-2}s^{-1}
(L/bunch=8.0X10^{31}, Nb=5000)

Head-on

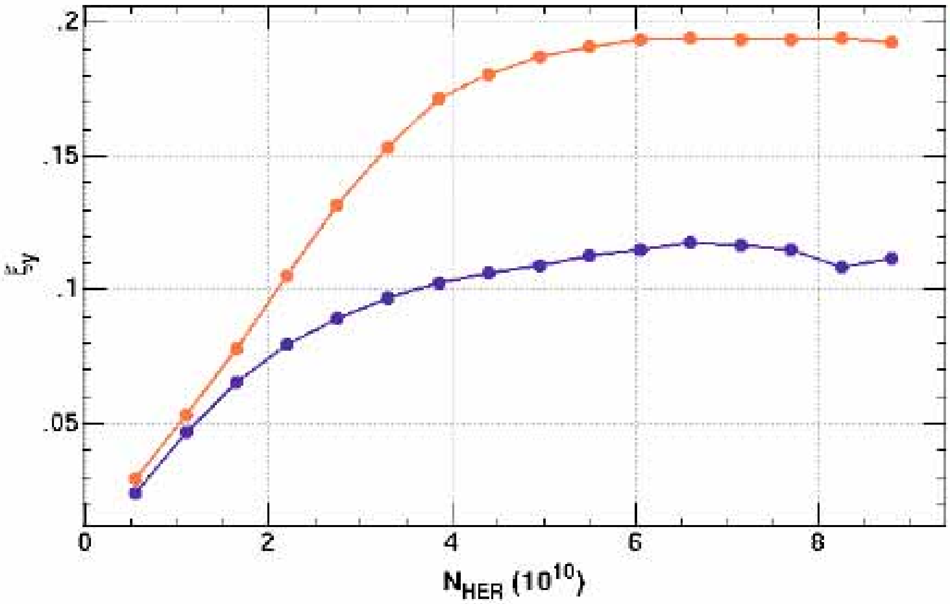
(.503, .550)

ξ_y ~0.19

Simulation by K. Ohmi

Crab crossing is coming soon!

- Crab crossing will boost the beam-beam parameter up to 0.19! K. Ohmi



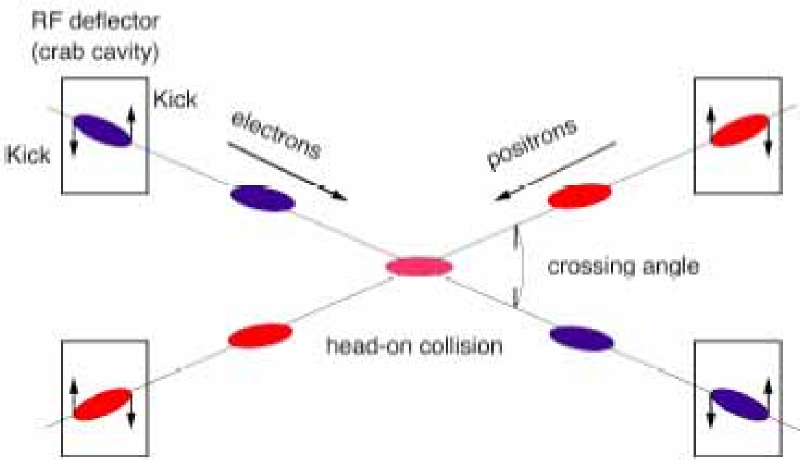
Head-on(crab)

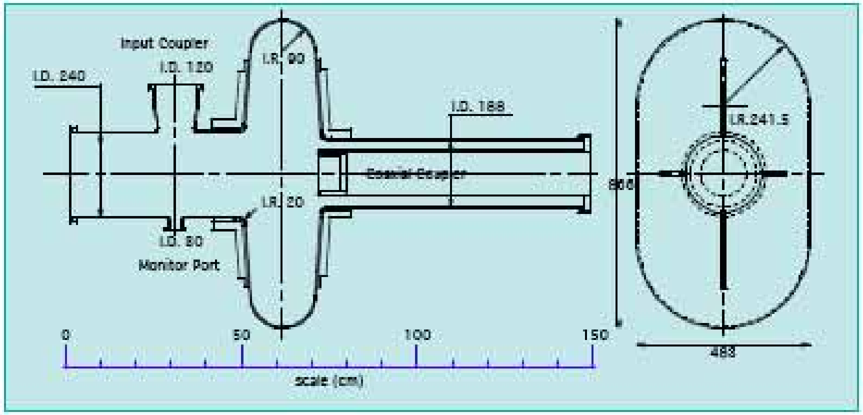
(Strong-strong simulation)

crossing angle 30 mrad

(at the optimum tune)

- Superconducting crab cavities are under development, will be installed in KEKB in early 2006.





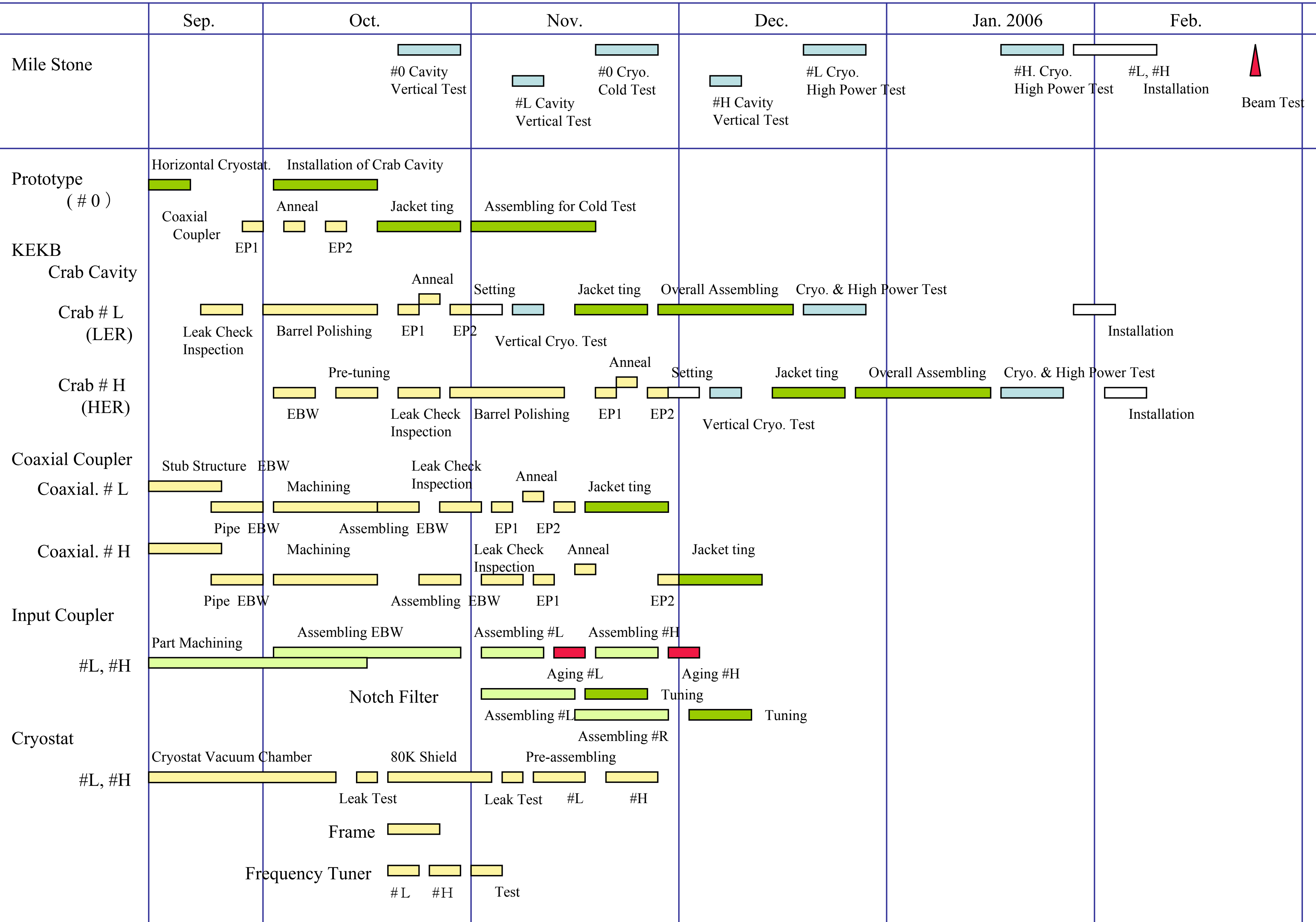
K. Hosoyama, et al

Crab Cavity Cell under Surface Treatment by High-Pressure Water Rinse

K. Hosoyama et al.

KEKB Superconducting Crab Cavity Construction Schedule

Sept. 30, 2005
K.Hosoyama



Key points of upgrade[3]

- Smaller β_y^*
  - IR design
    - Physical aperture
      - Damping Ring for e+
    - Dynamic aperture
    - Handling of SR from QCS'
    - Handling HOM power around IP
  - Short bunch length
    - CSR

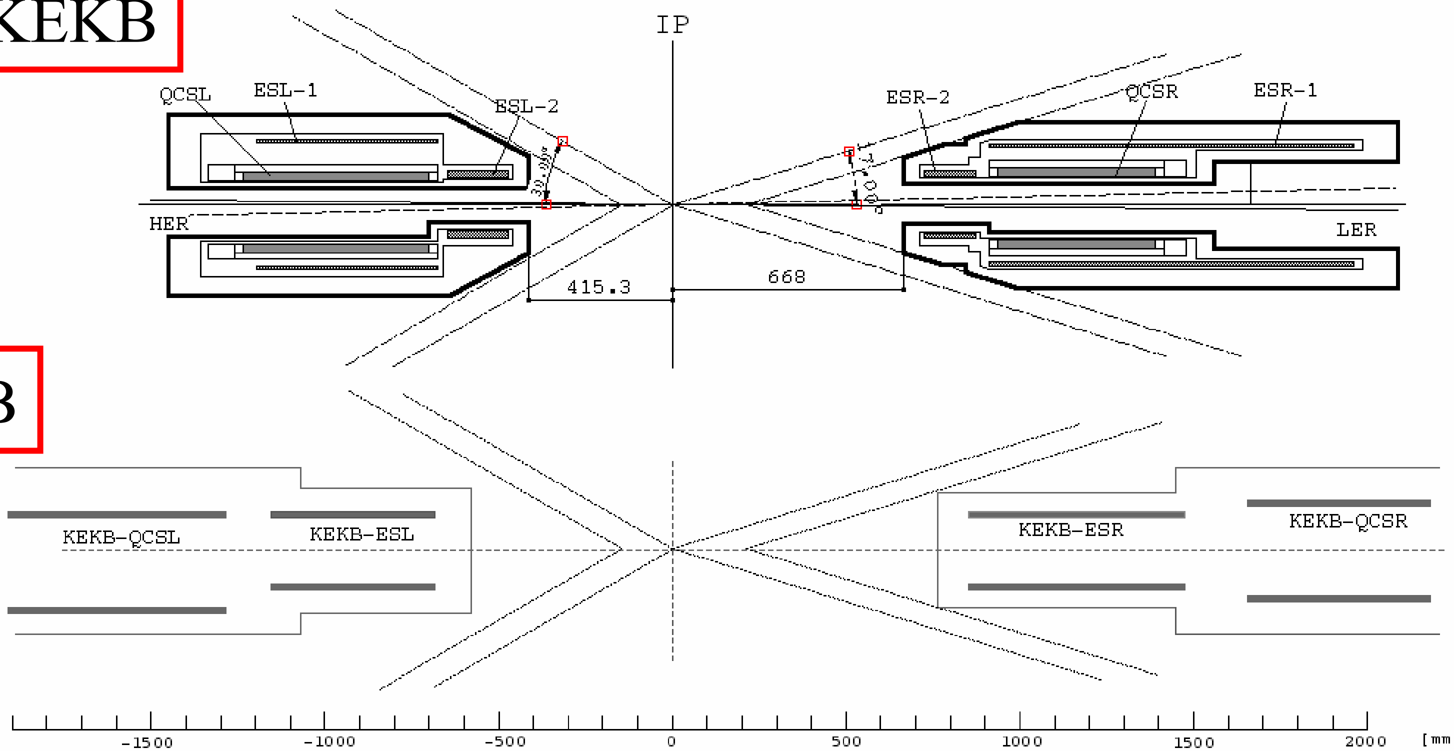
Issues of IR Design

Issues	Causes	Measures
Dynamic aperture	Lower beta’s at IP.	Place QCS magnets. closer to IP. Damping ring.
Physical aperture	Lower beta’s at IP.	Damping ring. Larger crossing angle. (22mrad -> 30mrad)
Heating of IR components	Higher beam currents. Higher power of SR from QCS magnets. Shorter bunch length.	Under study.
Detector beam background	Higher power and critical energy of SR from QCS magnets. Higher beam currents. QCS closer to the IP. Higher Luminosity.	Under study by Belle Group.

Place QCS magnets closer to IP

SuperKEKB

KEKB

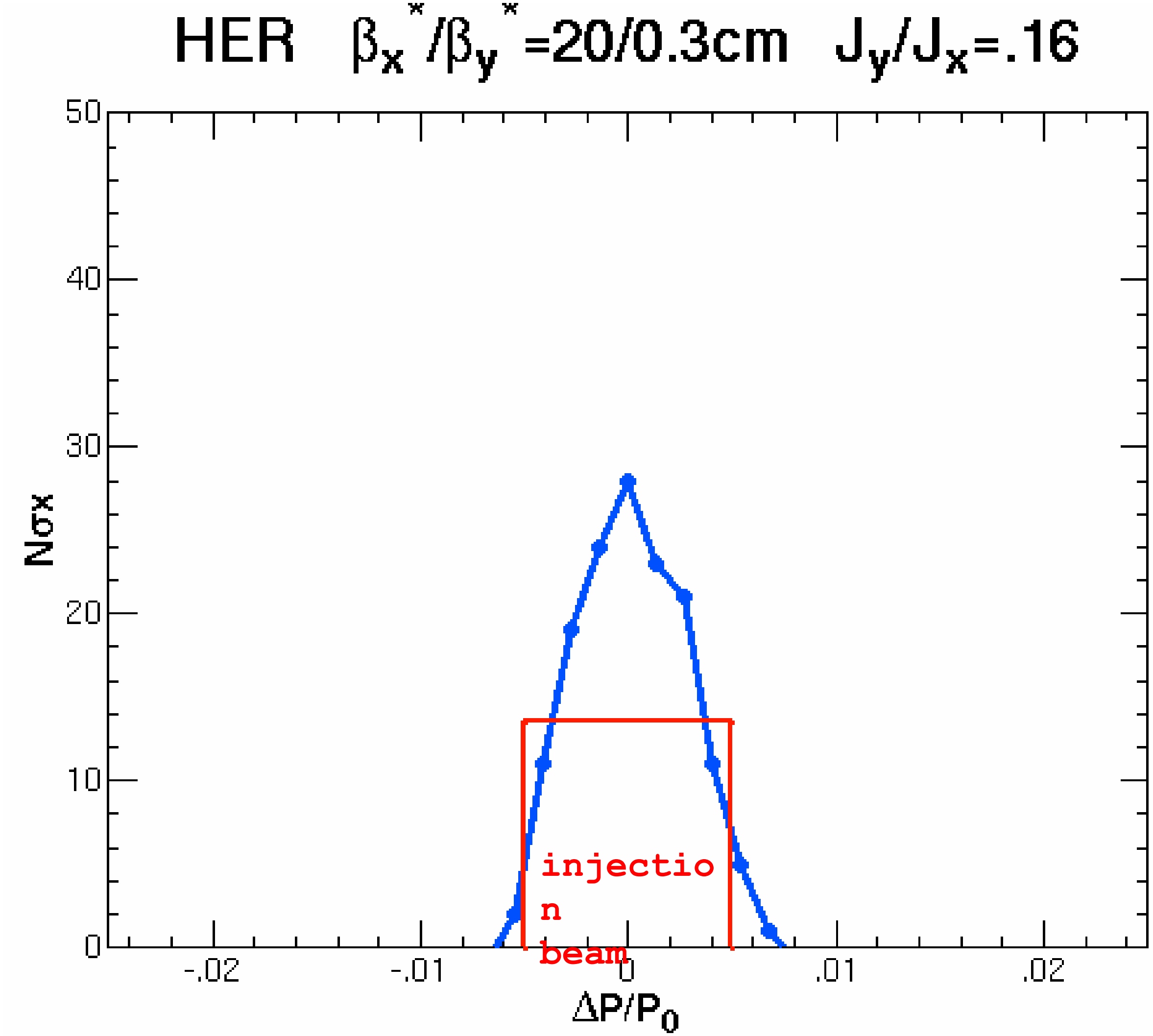


The boundary between KEKB and Belle is the same.
ESL and ESR will be divided into two parts (to reduce E.M. force).
QCSL (QCSR) will be overlaid with (the one part of) ESL(ESR).

H. Koiso

HER dynamic aperture

bare lattice BXBY=20/.3 cm (4cm-thick slices)



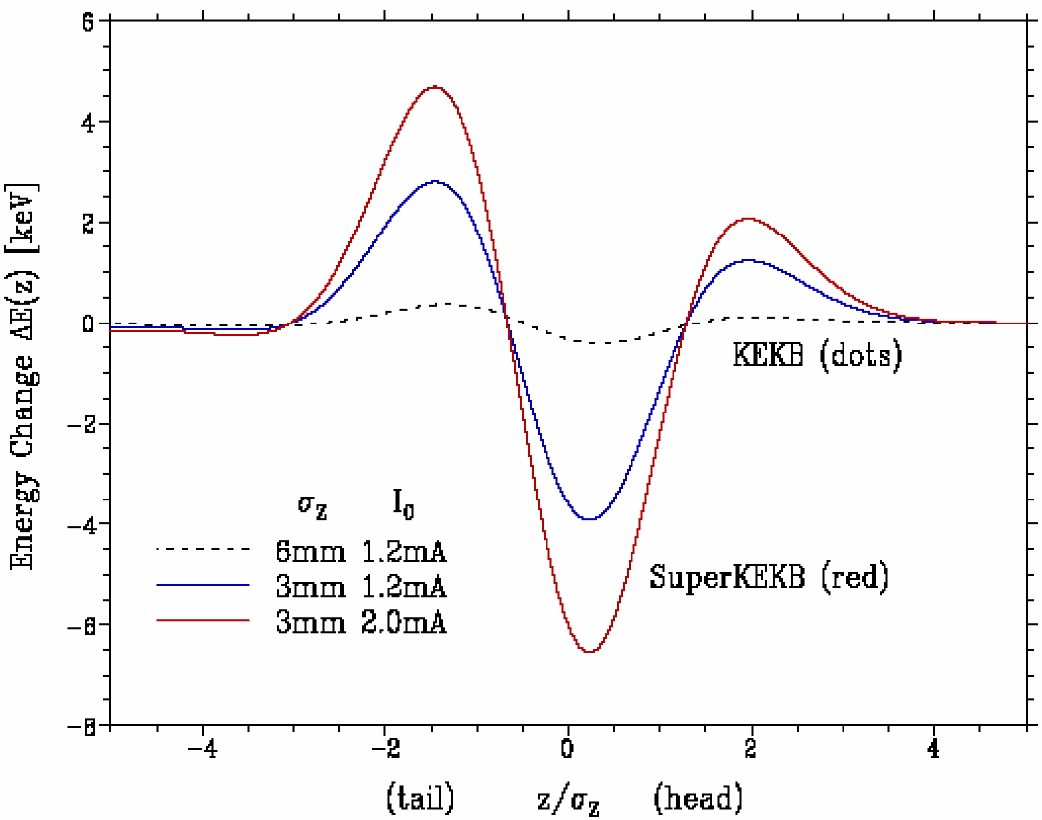
Required: H/V 4.5/0.52 $\times 10^{-6}$m

CSR at SuperKEKB

- Machine parameters
  - Bunch current: ~2mA <-> 1.2mA (KEKB)
  - Bunch length: 3mm <-> ~8mm (KEKB)
  - Vacuum chamber radius: 47mm(SuperKEKB original design) <-> 47mm(KEKB)
- CSR simulation (T. Agoh)
  - Serious effect of CSR was found with the original design in LER.
  - Possibility of smaller chamber radius (~30mm) is now under study.

Energy Change of Particles in KEKB and SuperKEKB

- Energy Change by CSR for one particle for one bend.

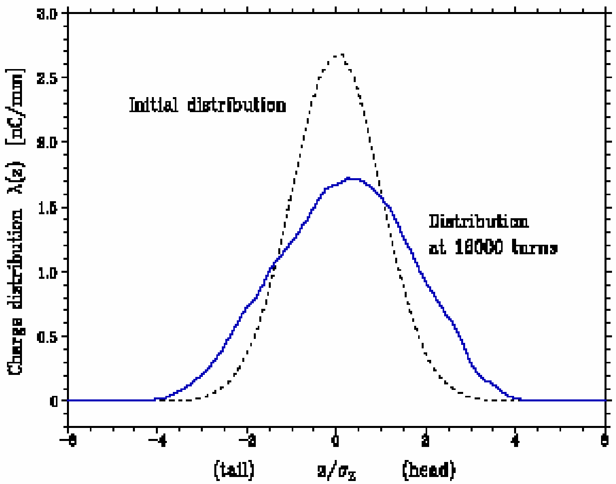


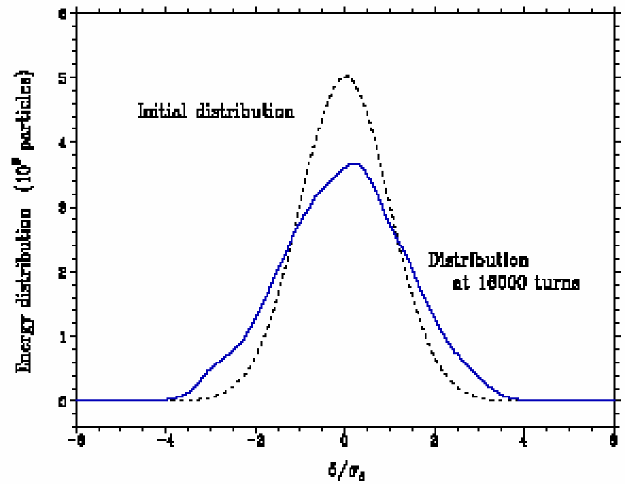
SuperKEKB (red line)
14 times larger ΔE
than KEKB (dotted line)

Chamber size
(half height)
$r = 47$mm
square cross section

T. Agoh

- Charge distribution
- Energy spread (r=47mm)





Initial

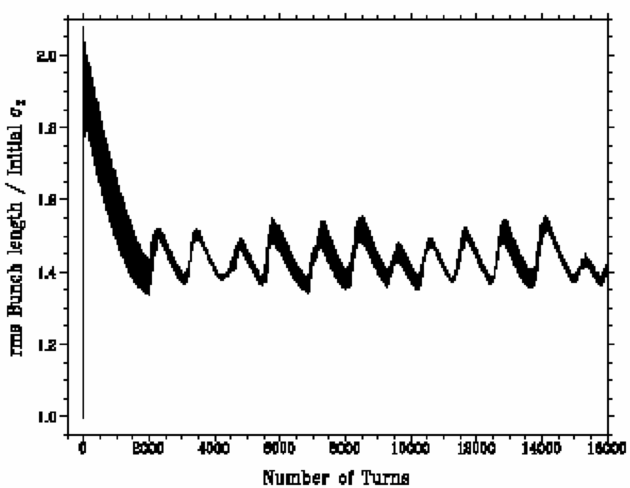
Bunch length

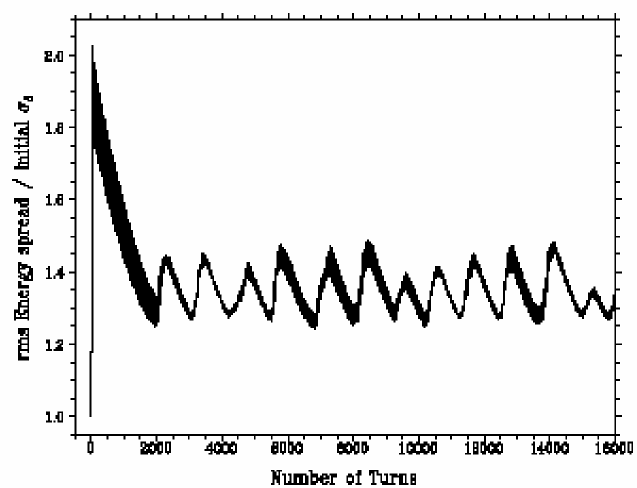
$\sigma_z = 3.0\text{mm}$

Initial

Energy spread

$\sigma_\delta = 7.1\times10^{-4}$





Equilibrium

Bunch length

$\sigma_z \sim 4.3\text{mm}$

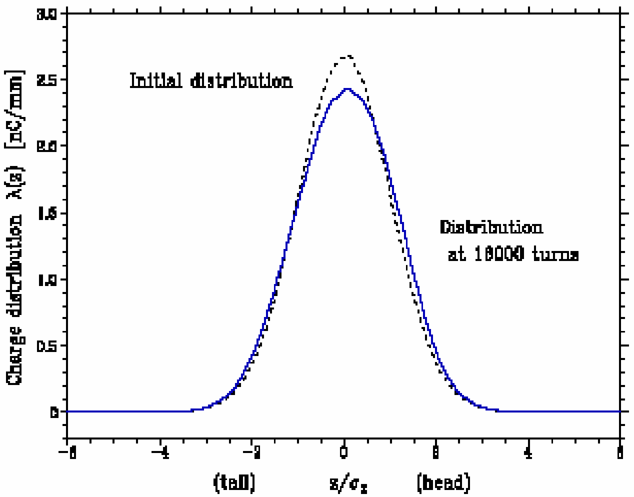
Equilibrium

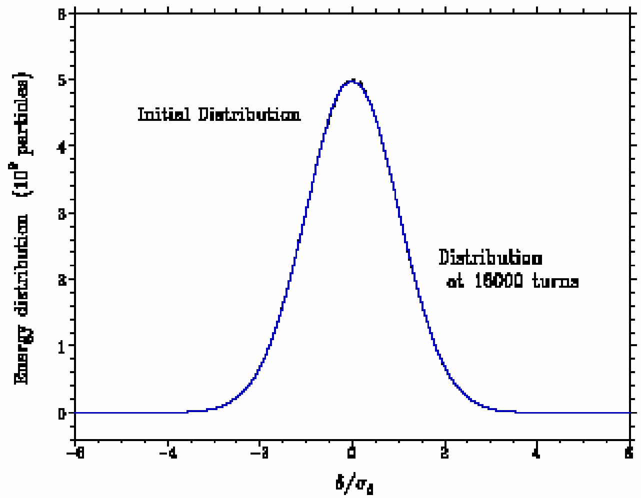
Energy spread

$\sigma_\delta \sim 9.0\times10^{-4}$

T. Agoh

- Charge distribution
- Energy spread (r=25mm)





Initial

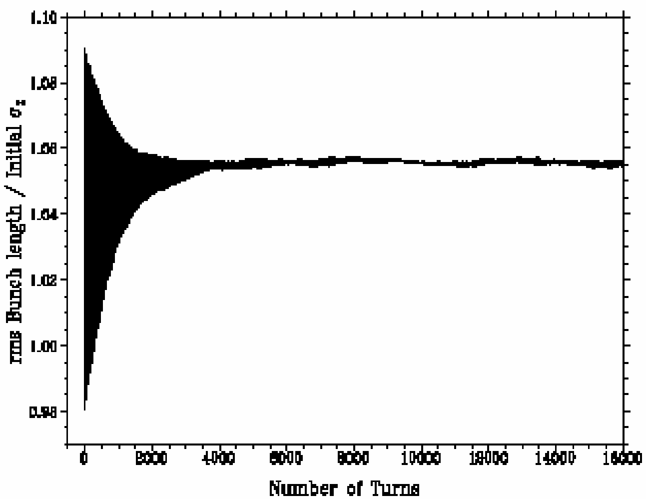
Bunch length

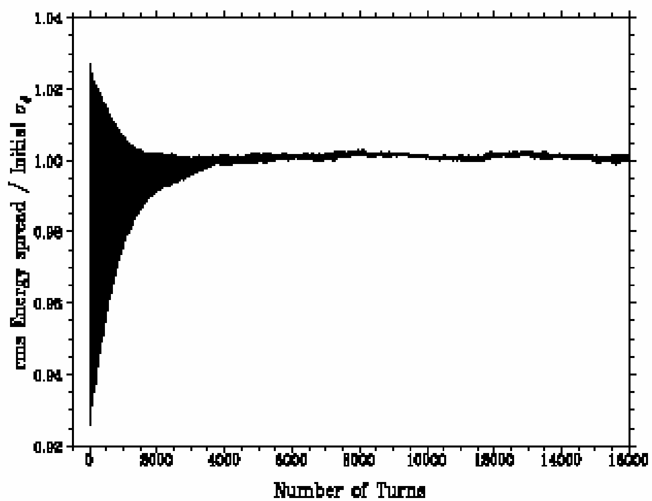
$\sigma_z = 3.0\text{mm}$

Initial

Energy spread

$\sigma_\delta = 7.1\times10^{-4}$





Equilibrium

Bunch length

$\sigma_z = 3.17\text{mm}$

Equilibrium

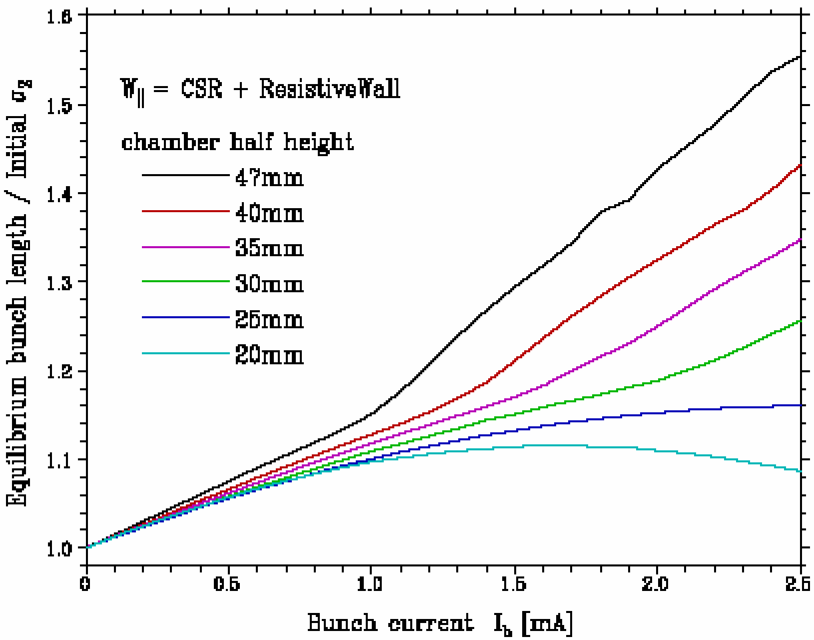
Energy spread

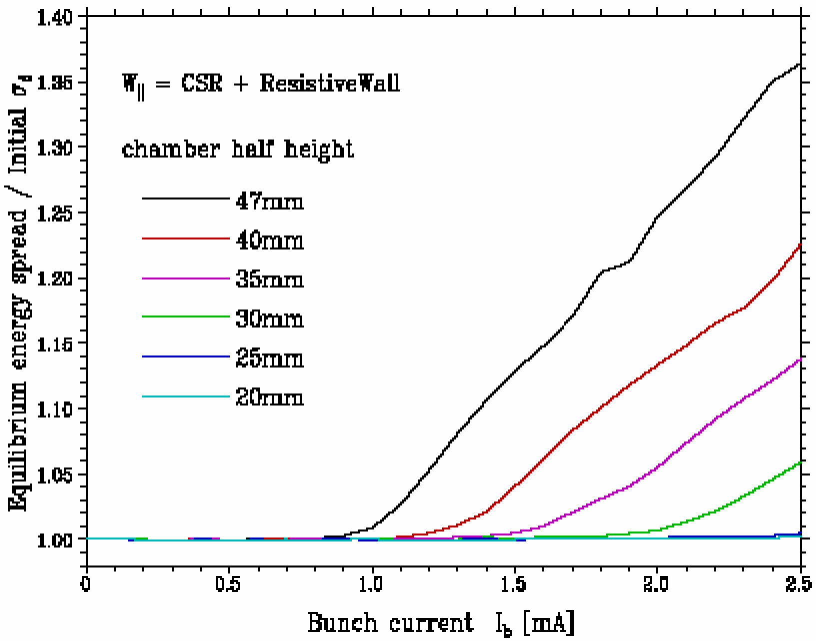
$\sigma_\delta = 7.1\times10^{-4}$

T. Agoh

CSR + Resistive Wall

Initial Bunch length: $\sigma_z = 3\text{mm}$ Energy spread $\sigma_\delta = 7.1 \times 10^{-4}$





- Threshold for I_b: similar to the case of only CSR
- Bunch shape: distorted due to ResistiveWall wakefield

T. Agoh

Performance Limitations

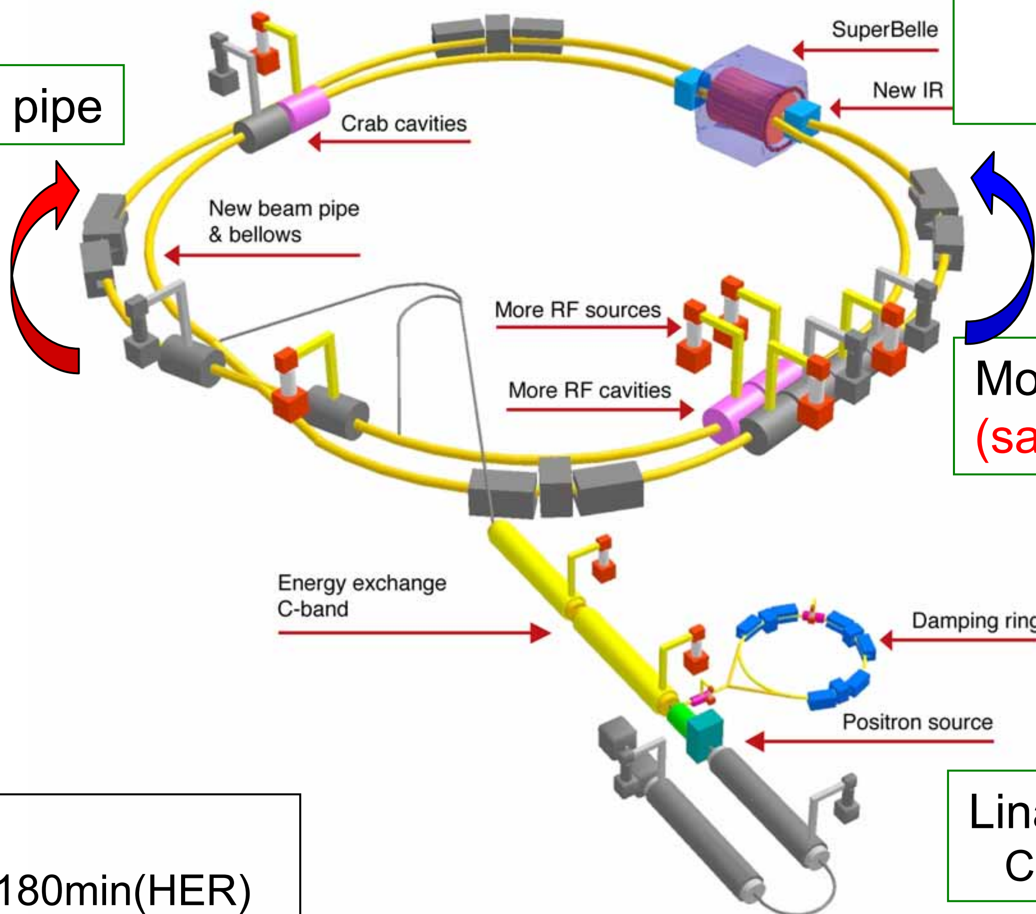
- Beam currents (with the same RF frequency)
  - RF power (space for RF cavities)
  - CSR
  - Fast ion instability (under study)
- Beam-Beam parameters
  - 0.019 already seems challenging.
- β_y^*
  - Bunch length (CSR)
  - Dynamic aperture is marginal.

Components to be upgraded

Electric power consumption (KEKB rings)
35MW (KEKB design) -> 83 MW

Interaction Region
Crab crossing
θ=30mrad.
β_y*=3mm
New QCS

New Beam pipe



More RF power
(same RF frequency)

Damping ring

Beam Lifetime
~140min(LER) / ~180min(HER)
-> ~40min(LER) / ~50min(HER)

Linac upgrade
Charge switch

Machine Parameters

		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	ε_x	24	128	nm
Horizontal beta at IP	β_x*	20	2.3	cm
Vertical beta at IP	β_y*	3	2.4	mm
Horizontal beam size	σ_x*	69	54	μm
Vertical beam size	σ_y*	0.73	1.23	μm
Beam size ratio	$r = \sigma_y^*/\sigma_x^*$	1.1	2.3	%
Crossing angle (30 mrad crab crossing)	θ_x	0	0	mrad
Luminosity reduction	R_L	0.86	0.82	
ξ_x reduction	$R_{\xi x}$	0.99	0.97	
ξ_y reduction	$R_{\xi y}$	1.11	1.16	
Reduction ratio	$R_L/R_{\xi y}$	0.78	0.72	
Horizontal beam-beam (estimated with S-S simulation)	ξ_x	0.152	0.041	
Vertical beam-beam (estimated with S-S simulation)	ξ_y	0.215	0.187	
Luminosity	L	4.0×10^{35}		$cm^{-2}s^{-1}$

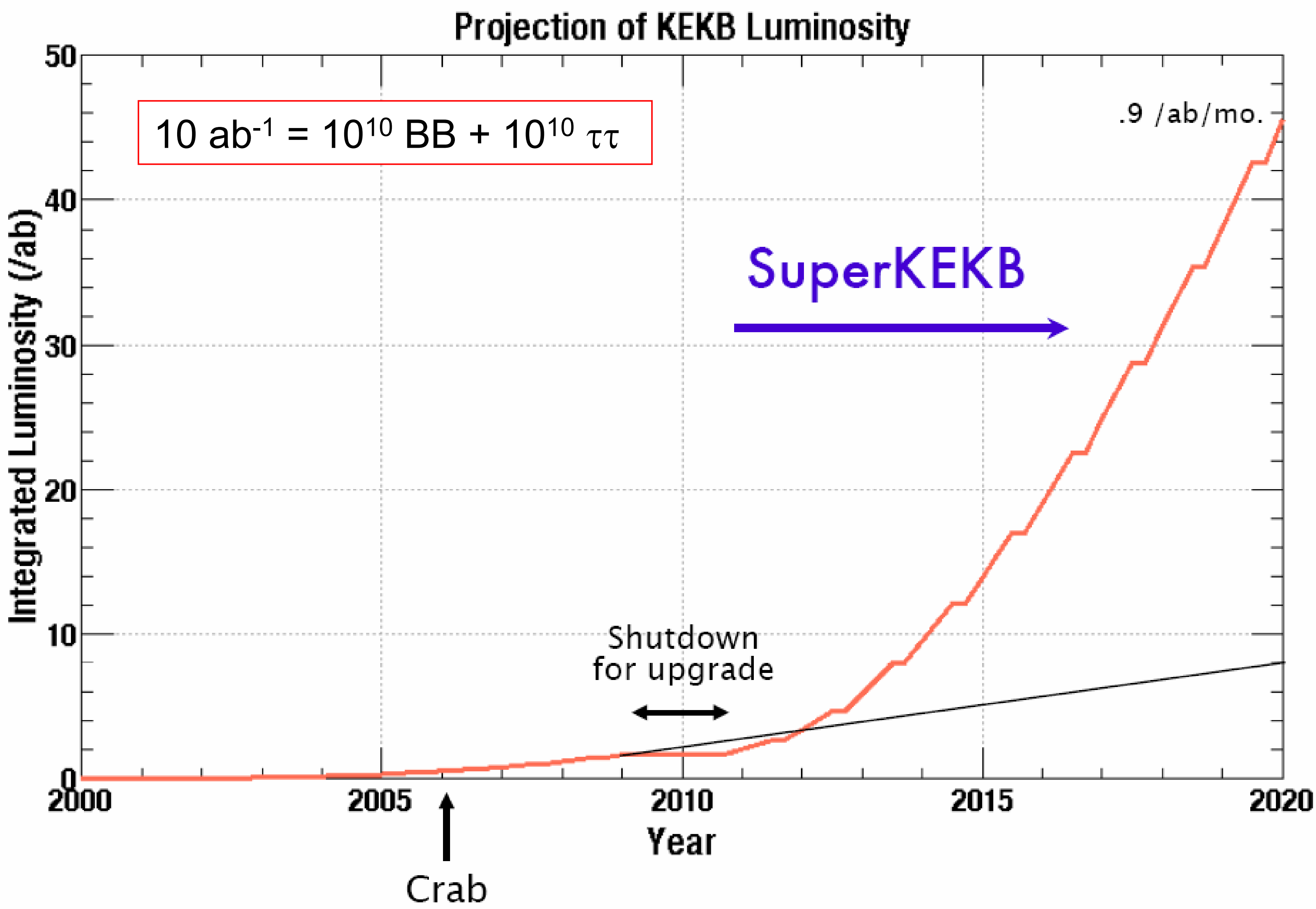
Machine Parameters [2]

	KEKB (design)		SuperKEKB	
	LER	HER	LER	HER
Energy [GeV]	3.5	8.0	3.5	8.0
U_0 (MeV)	1.5	3.5	1.23	3.5
Longi. Damping Time [turns/msec]	2300/23	2300/23	2850/28.5	2300/23
Current [A]	2.6	1.1	9.4	4.1
Radiation Loss [MW]	3.9	3.9	12	14
Bunch Length [mm]	5	5	3	3
Energy Spread	$7x10^{-4}$	$7x10^{-4}$	$7x10^{-4}$	$7x10^{-4}$
Momentum Comparction	$(1\sim2)x10^{-4}$	$(1\sim2)x10^{-4}$	$2.7x10^{-4}$	$1.8x10^{-4}$

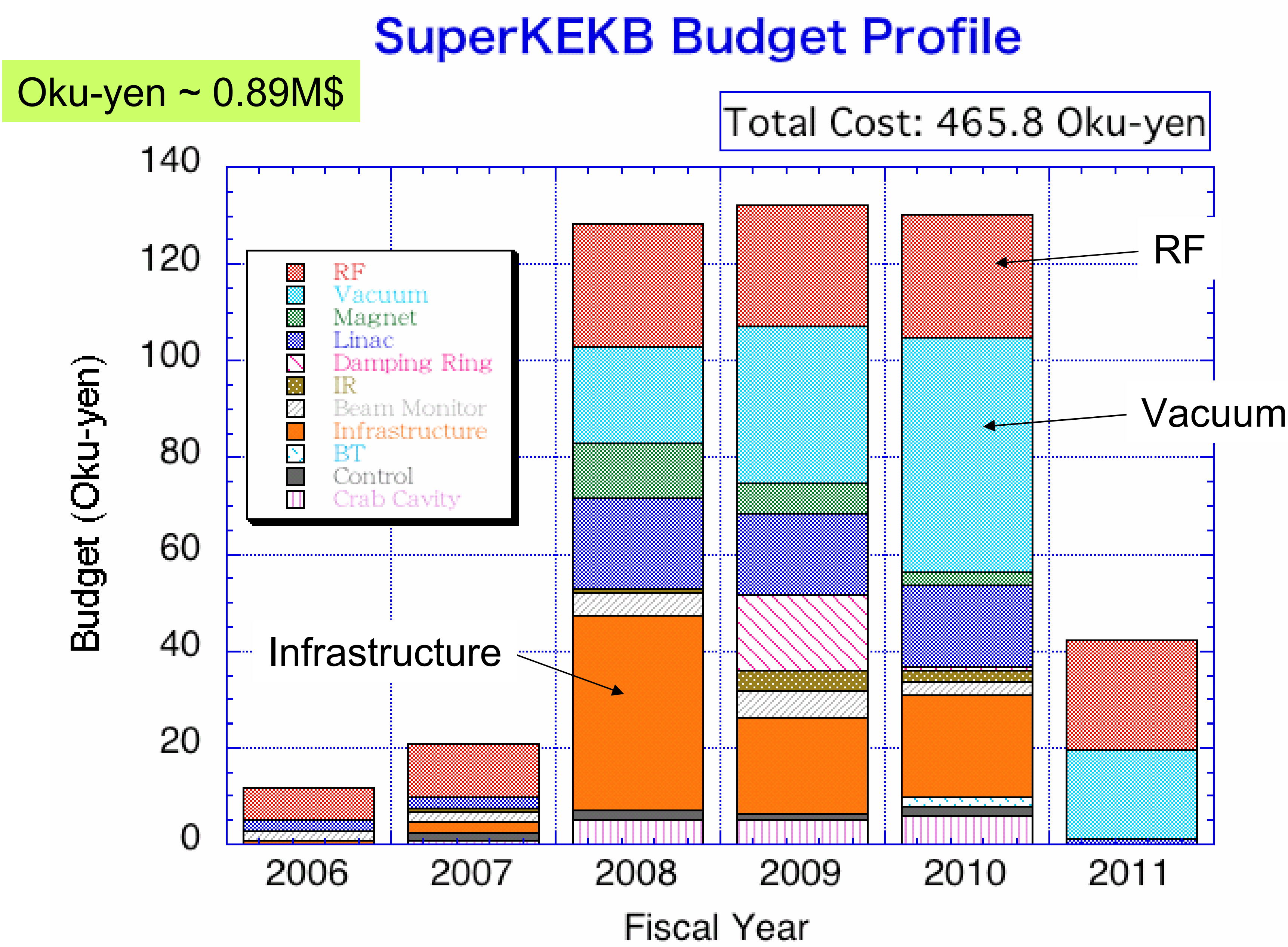
Status and future prospects of SuperKEKB

Status and Prospects of SuperKEKB

- R&D Status
  - Present KEKB offers great occasions of R&Ds for SuperKEK.
    - Crab cavity scheme (beginning of 2006) <- largest uncertainty
    - Vacuum chamber (ante-chamber) (ongoing)
    - Vacuum components (bellows, gate valve) (ongoing)
    - Upgrade of bunch-by-bunch Feedback system (ongoing)
    - Upgrade of ARES cavity (ongoing)
    - C-band acceleration units (Linac upgrade) (ongoing)
    - Accelerator physics study on CSR (ongoing)
    - Others
  - SuperKEKB machine R&D is already in the engineering phase rather than the conceptual design phase.
- Cost estimation
  - ~ 415 M$ in total (not included detector upgrade)
- Time Table for SuperKEKB
  - 2004 April: Letter of Intent for KEK Super B Factory
  - By the end of 2006: Decision making by KEK administration
  - 21 months shutdown for upgrade works (FY 2009-2010)
  - Early in 2011: First beams of SuperKEKB



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



SuperKEKB Budget Profile
Oku-yen ~ 0.89M$
Total Cost: 465.8 Oku-yen
Budget (Oku-yen)
140
120
100
80
60
40
20
0
RF
Vacuum
Magnet
Linac
Damping Ring
IR
Beam Monitor
Infrastructure
BT
Control
Crab Cavity
RF
Vacuum
Infrastructure
2006
2007
2008
2009
2010
2011
Fiscal Year

Backup slides

Luminosity Formula

Lorentz factor

Beam current

Beam-Beam parameter

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

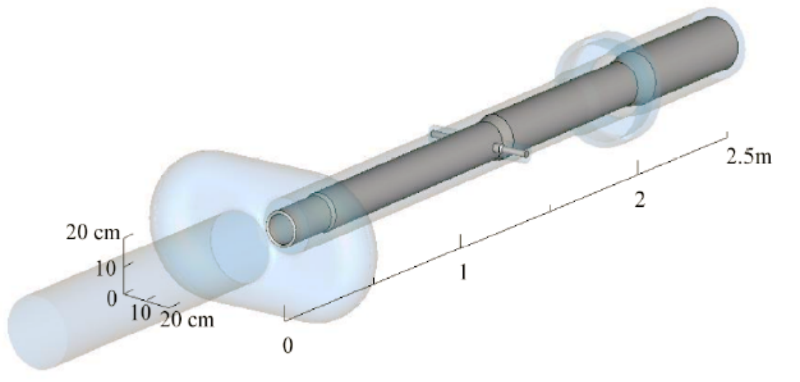
Geometrical reduction factors (crossing angle, hourglass effect)

Beam aspect ratio at IP

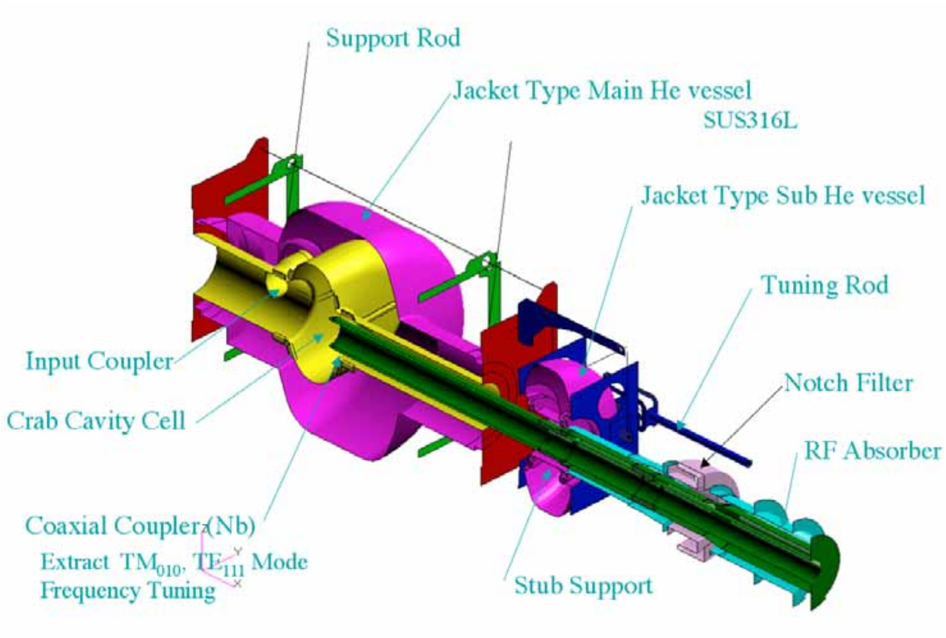
Vertical beta function at IP

$$\sigma_s \leq \beta_y^*$$

Superconducting Crab Cavity for KEKB



Crab cavity loaded with coaxial coupler for damping HOMs & LOMs other than the deflecting dipole mode.



Crab cavity in He vessel

K. Hosoyama et al.

<table>
<tr><th></th><th>KEKB (design)</th><th>SuperKEKB</th><th>Unit</th></tr>
<tr><td>Magnet p.s.</td><td colspan="2">3.84</td><td>MW</td></tr>
<tr><td>Magnet</td><td colspan="2">6.35</td><td>MW</td></tr>
<tr><td>SR</td><td>8</td><td>26</td><td>MW</td></tr>
<tr><td>HOM</td><td>0.43</td><td>9</td><td>MW</td></tr>
<tr><td>RF system</td><td>16</td><td>38</td><td>MW</td></tr>
<tr><td>Total</td><td>34.6</td><td>83.2</td><td>MW</td></tr>
</table>

Table 12.1: Power losses for KEKB and SuperKEKB.

今後の方針

(1)リングのインピーダンスソースの洗い出し、Wake再計算

	κ[*1] (V/C)	Number of items	Total κ (V/C)	HOM power[*2] (kW)
Resistive wall[*3]	4.1×10^9	2200 m	8.9×10^{12}	1780
Pumping holes	8.8×10^5	2200 m	1.9×10^9	0.38
Flange	1×10^8	800	8×10^{10}	16
Bellows	4×10^9	800	3.2×10^{12}	640
Photon mask	1×10^4	800	8×10^6	0.0016
Gate valve	3×10^9	16	4.8×10^{10}	9.6
Movable mask[*4]	1×10^{12}	16	1.6×10^{13}	3200
Taper	3×10^9	72	2.2×10^{11}	44
BPM	N/A	400	N/A	N/A
IR chamber	N/A	1	N/A	N/A
Total			$30\sim40\times10^{12}$	6~8 MW

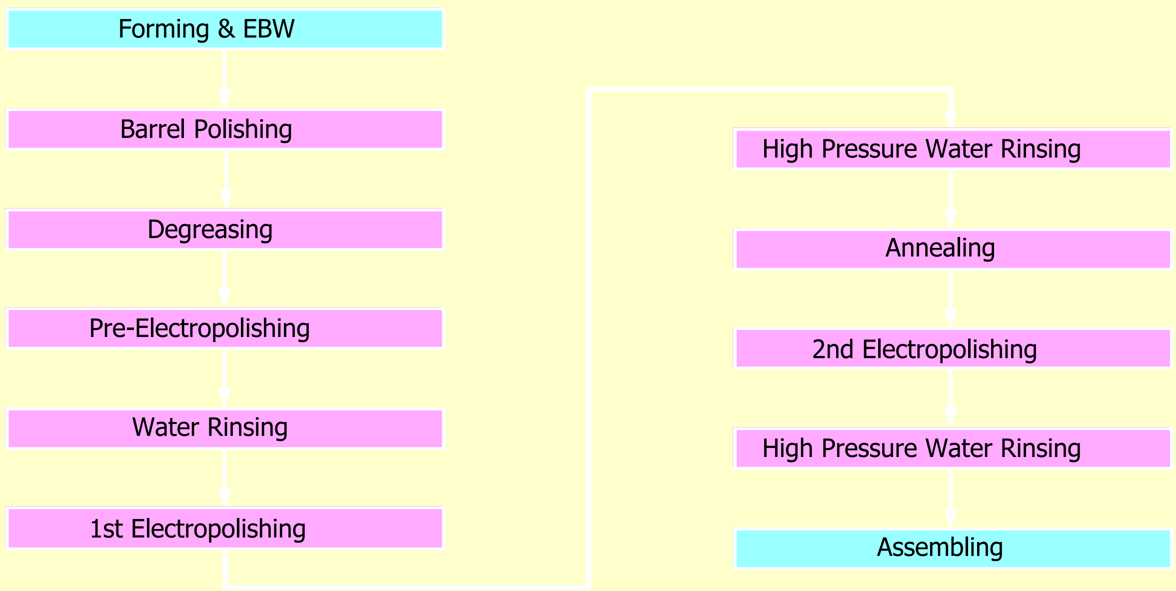
*1 $\sigma_z = 3$ mm
*2 n_b=5000, f_0=1×10^5 Hz, I_b=10 A
*3 Copper chamber with a radius of 25 mm
*4 8 horizontal and 8 vertical masks

r = 90 mm

(2)他コンポーネントのWakeを考慮した再検討？

クラブ空洞の表面処理方法

Crab Cavity



SuperKEKB 建設スケジュール （2005.1.18）

Fiscal Year		2006	2007	2008	2009	2010	2011		2012
Budget				SuperKEKB建設本予算					
KEKB Ring		KEKB運転			Shutdown			SuperKEKB運転	
Damping Ring				建設	設置	Commissiong		定常運転	
Linac Upgrade								e+ 8GeV	
	# of Units	2	2	2	14	14	14		
RF Upgrade									
	D1							2 (Crabs)	→
	D2							2 (Crabs)	→
	D4	3 (6A)	→	→	→	→	→	14(14AH)	→
	D5	3 (6A)	4 (6A)	→	→	→	→	10(2H+8L)	→
	D7	5 (10A)	→	→	→	→	→	10 (10AL)	→
	D8	5 (10A)	→	→	→	→	→	10 (10AL)	→
	D10	4 (4S)	→	→	→	→	→	6(6SH)	→
	D11	4 (4S)	→	→	→	→	→	6(6SH)	→
	DR					1(1A)	→		→
	Klystron fab.	5	6	7	7	6	5		0
施設									
	建屋	建屋建設							
	電気			建設					
	冷却水系			建設					
Vacuum Upgrade				建設、設置					