SuperKEKB Overview Update

10th KEKB Accelerator Review Committee

22 February 2005

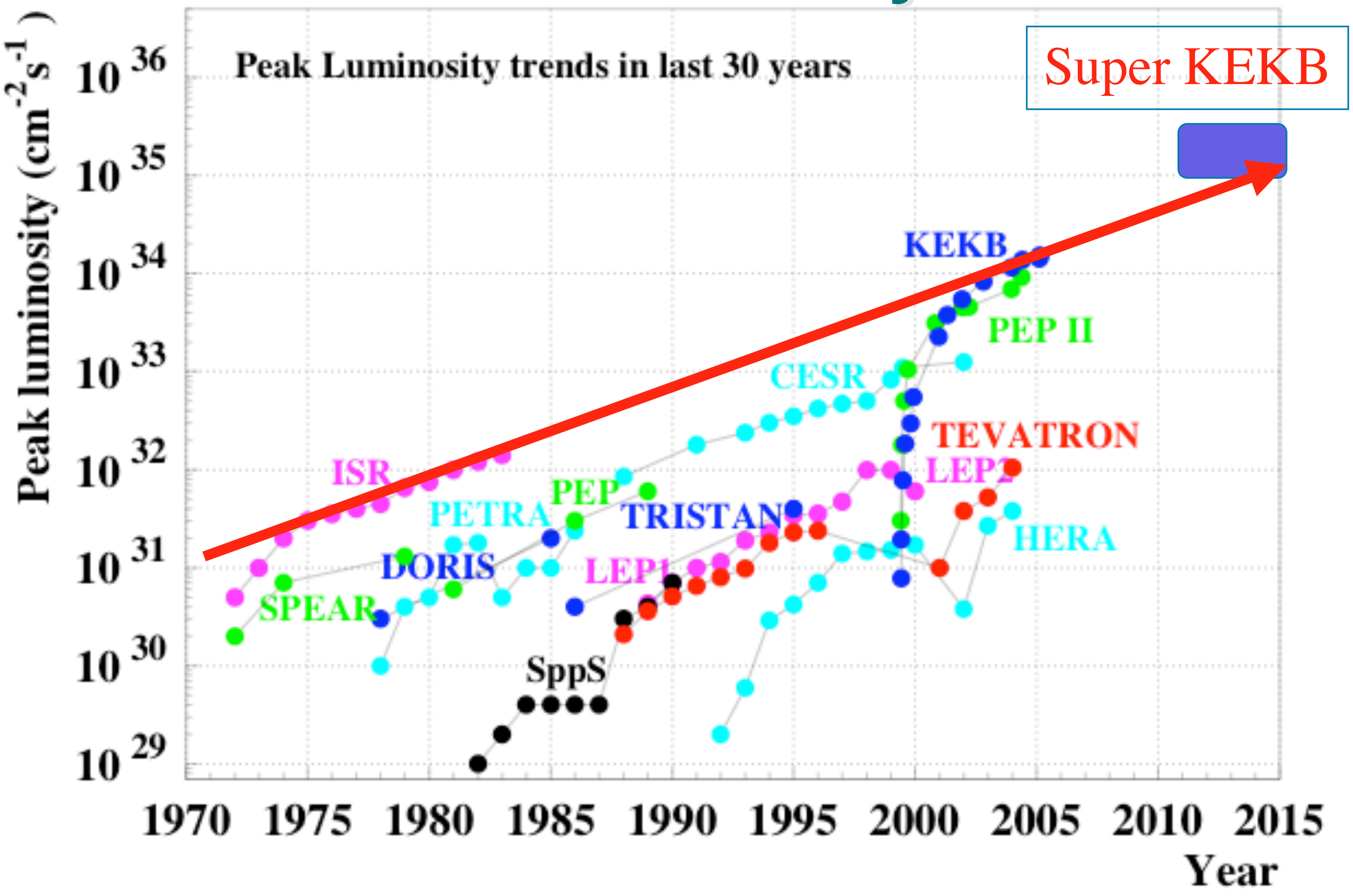
Toshihiro Mimashi, KEK

(Many of the slides are borrowed from M.Masuzawa)

Contents

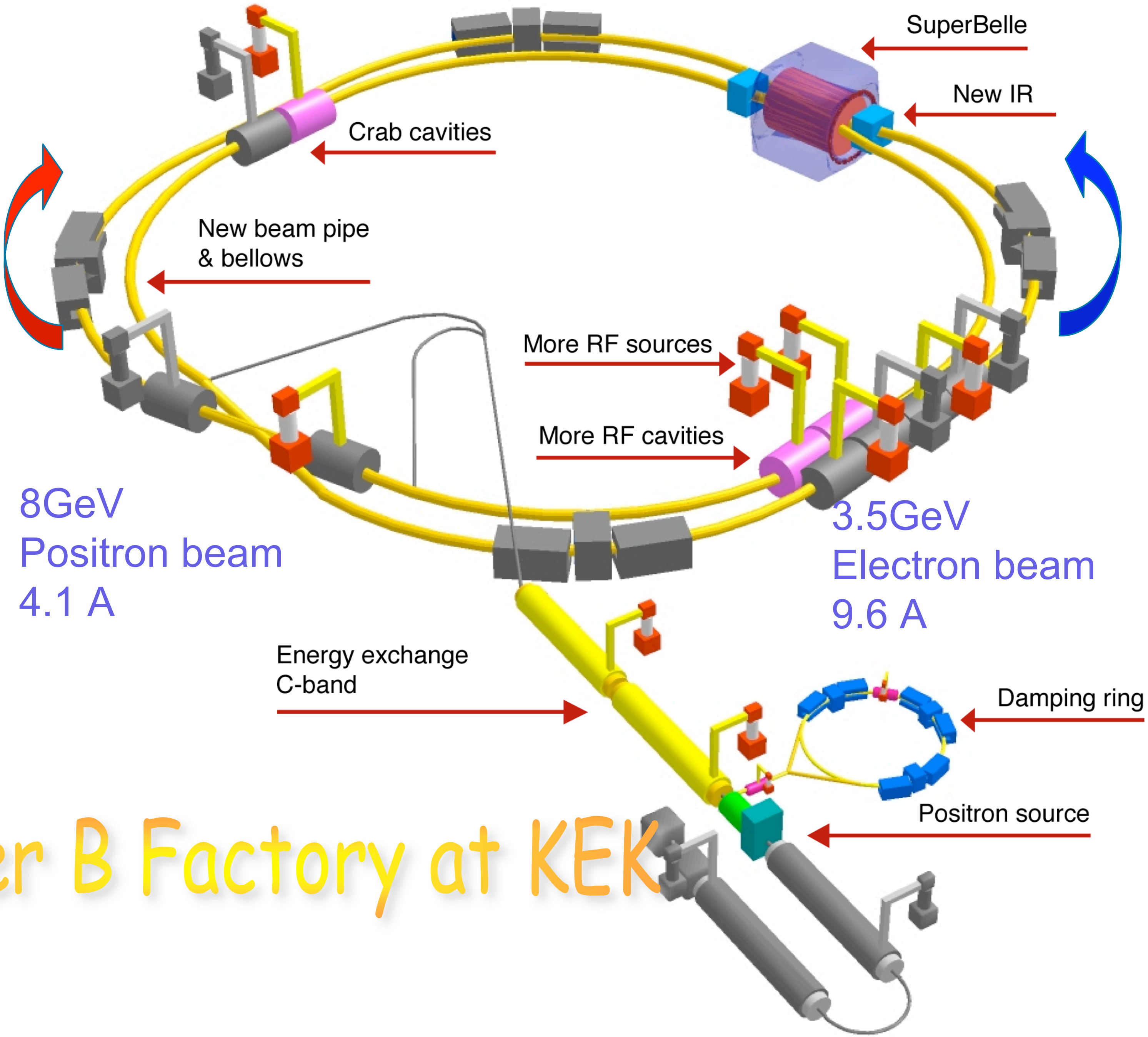
- Goal of SuperKEKB
- Strategy to reach the goal of SuperKEKB
- Overview of each components
  - What is the problem ? Where we stand.
- Summary

Peak Luminosity Goal

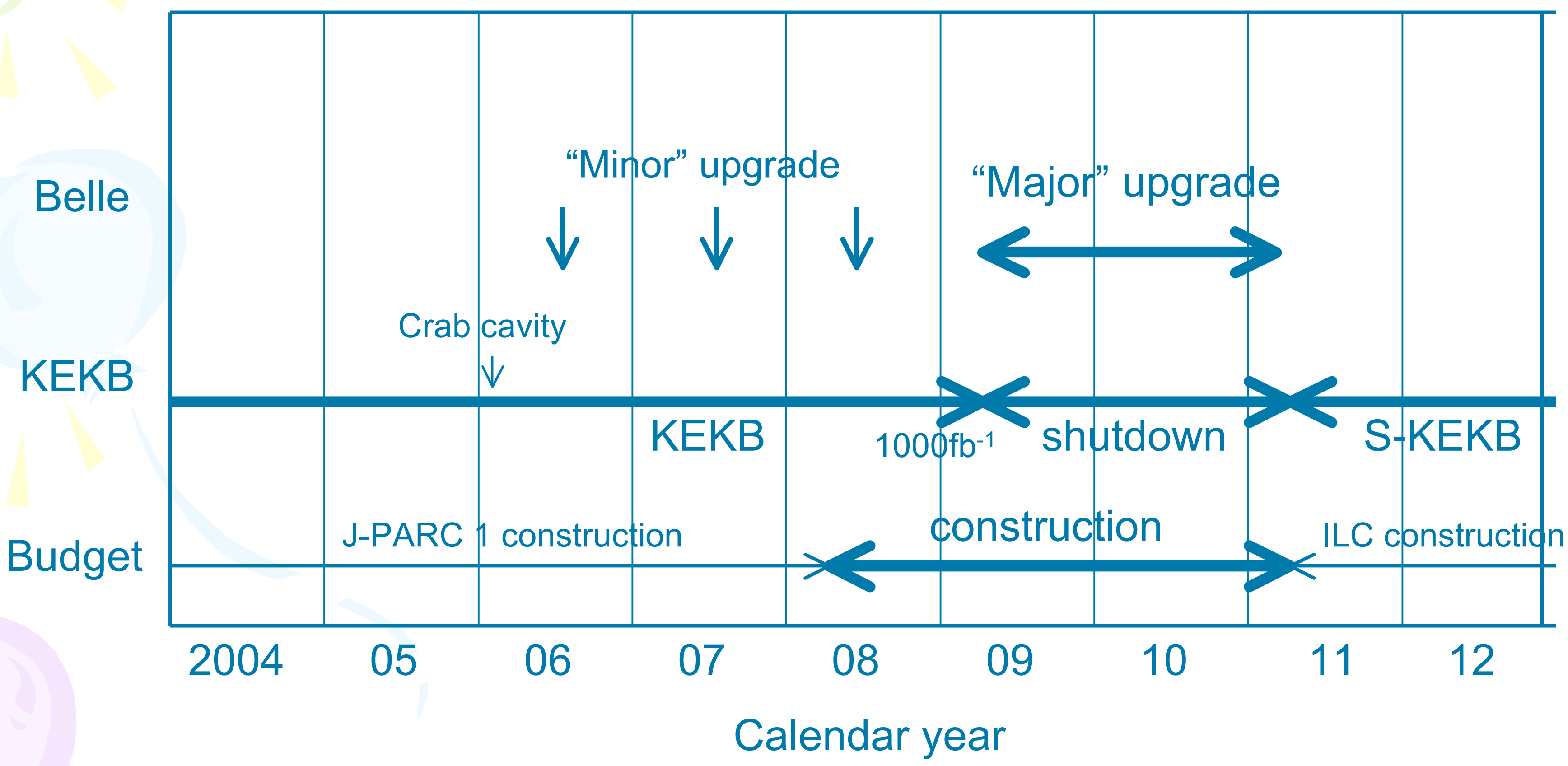


from Samo Stanic and modified by T.Mimashi

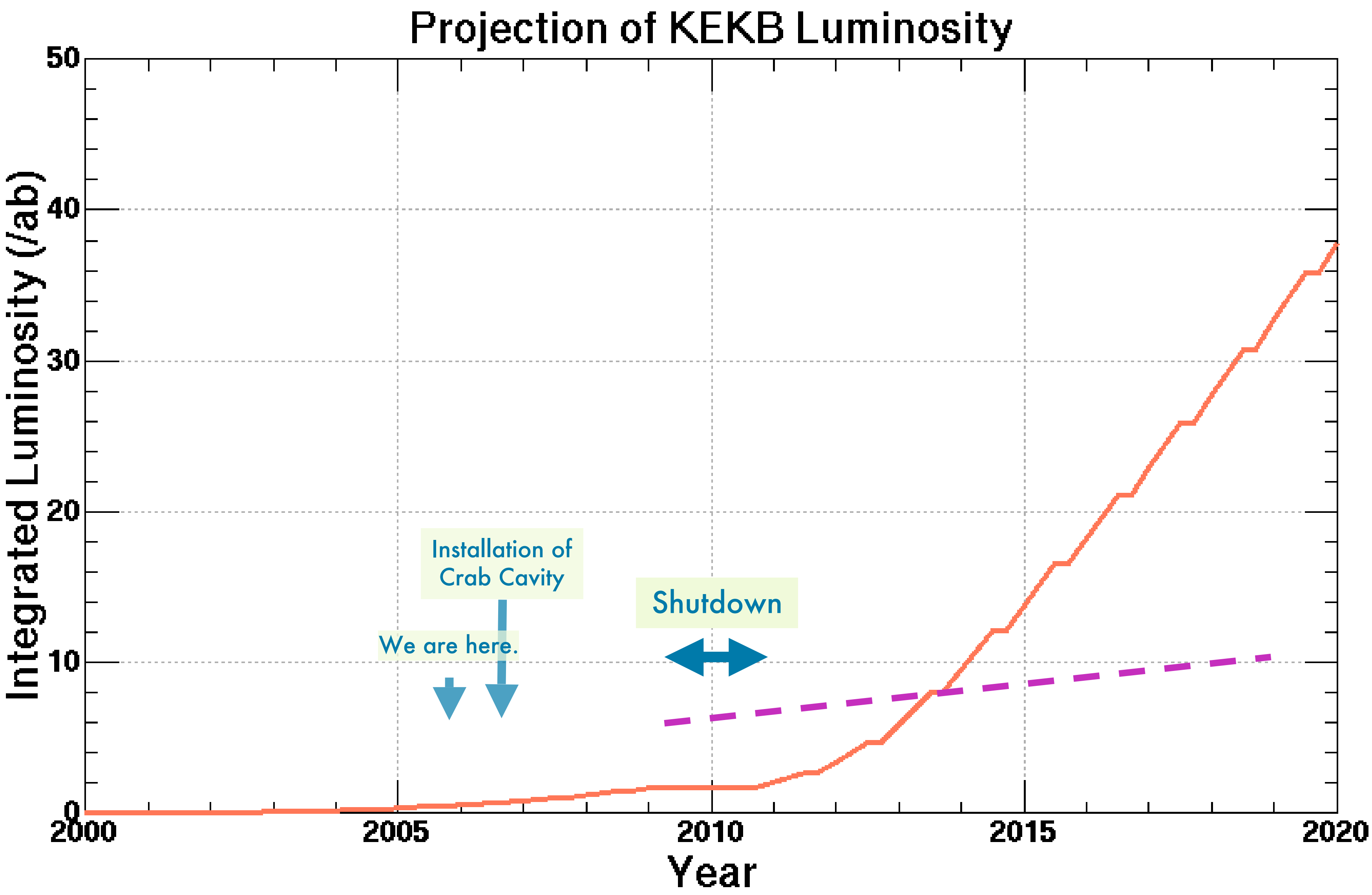
Super B Factory at KEK



Construction Scenario

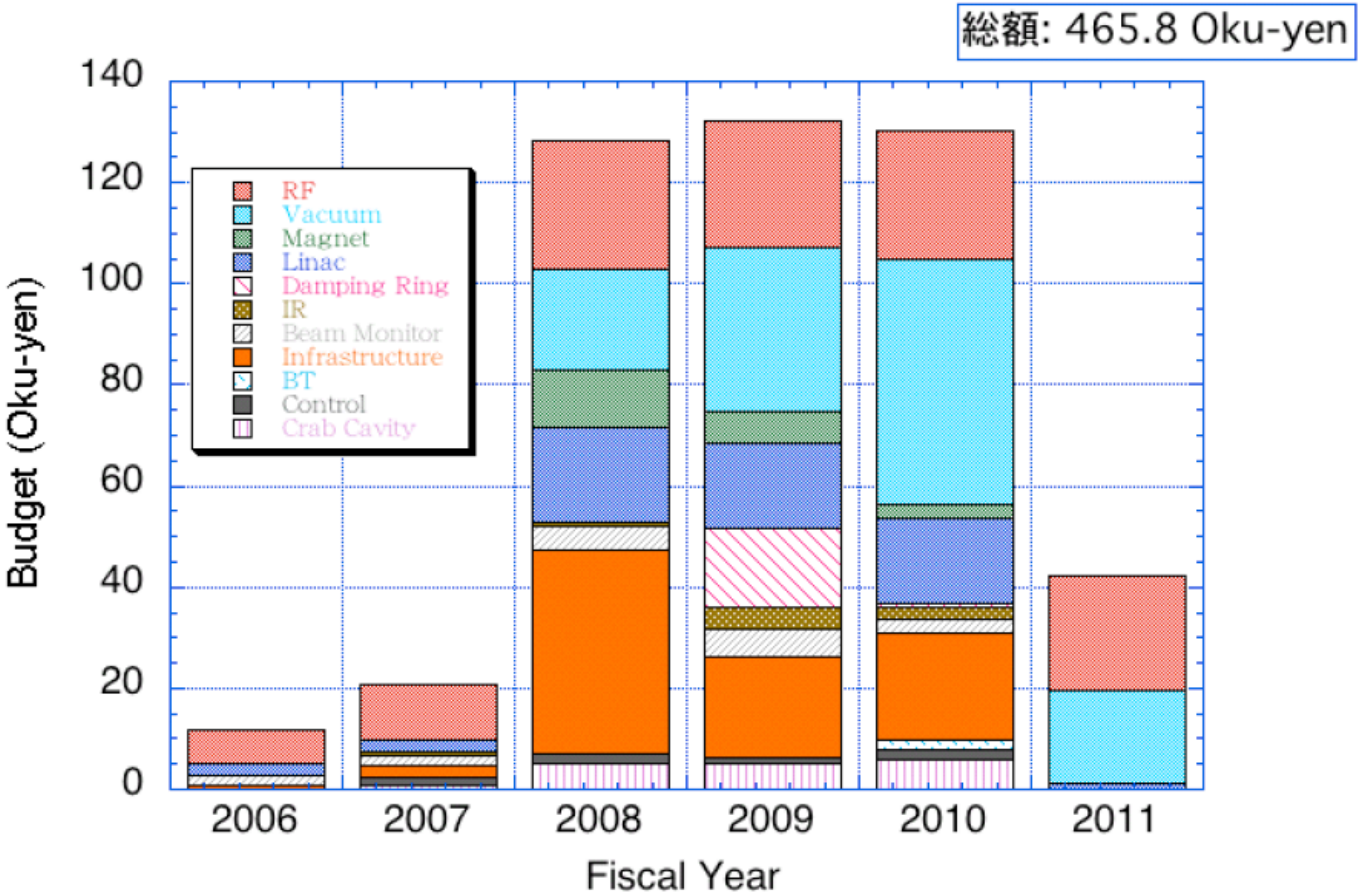


Most of the components (magnets, klystrons, etc) will be re-used.



Shutdown for 18-26 months in 2009-2010 for upgrade.
0.6 /ab/month in 2020.

SuperKEKB Budget profile



Strategy

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

Lorentz factor

Beam current

Beam-beam parameter

Classical electron radius

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

Vertical beta function@IP

Ratio of luminosity & tune shift reduction factors: 0.8 ~ 1 (short bunch)

Increase beam currents

- 1.6 A (LER) / 1.2 A (HER) → 9.6 A (LER) / 4.1 A (HER)

Smaller β_y^*

- 6 mm→3 mm

Increase ξ_y

- 0.05→0.14

For Peak Luminosity improvement

- Increase Beam current
  - Vacuum Upgrade (*Y.Suetsugu*)
  - ARES & SCC Upgrade *(T.Abe,T.Furuya)*
- Smaller β_y^*
  - Lattice *(Y.Ohnishi)*
  - QCS *(N. Ohuchi)*
  - IR design *(Y.Funakoshi,K.Kanazawa)*
- Increase ξ_y
  - Crab crossing increase Luminosity ?

For Integrated Luminosity improvement and others

- Injector Upgrade
  - Continuous injection @ 50Hz ?
    - Minimize Belle dead time caused by the injected beam (Dumping Ring)
      - 3.5msec dead time x 50Hz => 17.5% dead time
  - Charge exchange : 8Gev e+ beam *(T.Kamitani)*
  - Positron source *(T.Suwada)*
- Others

Issues

- Charge exchange ? (LER:e- and HER:e+)
- LER/HER Current ratio is 9.1/4.5 ?
- Can we fill 5000 buckets ?
  - Bunch-by-bunch Feedback System
  - Beam-Beam
    - Parasitic collision ? *(M.Tawada)*
  - Single Beam
    - Photoelectron (Ante-chamber+Energy switch +Low SEY surface chamber + Solenoid)

      (S.Katoh, Y.Suetsugu)
- Can we get enough budget ?

Summary

- SuperKEKB aims at a peak luminosity of $1\text{-}5\times10^{35}$ cm^{-2} s^{-1}, a new luminosity frontier for colliders.
- The basic design work has been finished and a Letter of Intent was published this year (Edited by J.W.Flanagan and Y.Ohnishi,KEK Report 2004-4 June 2004).
- More simulation and intensive hardware R&D work towards SuperKEKB are on-going.

Impedance and Collective Effects

(K.Shibata)

- Resistive Wall Instability
  - Growth rates (800-1000 s^{-1}) <damping rate of feedback system (5000 s^{-1}).
- Closed Orbit Instability due to long-range resistive wake (Danilov)
  - Thresholds (12.3/12.2 A for LER/HER) > design currents
- Electron Cloud Instability (Positron Ring)
  - With ante-chambers and positrons in the HER, simulations show that 60G solenoid field should clear the electrons.
  - Uncertainties:
    - Distribution on walls and amounts of electrons.
    - Behavior of electrons inside lattice magnets.
- Ion Instability (Electron Ring)
  - Currently suppressed by feedback.
  - With electrons in LER, simulated initial growth rate faster than feedback damping rate, leading to dipole oscillation with amplitude of order of vertical beam size $\rightarrow$possible loss of luminosity.
- Coherent Synchrotron Radiation *(T.Agoh)*

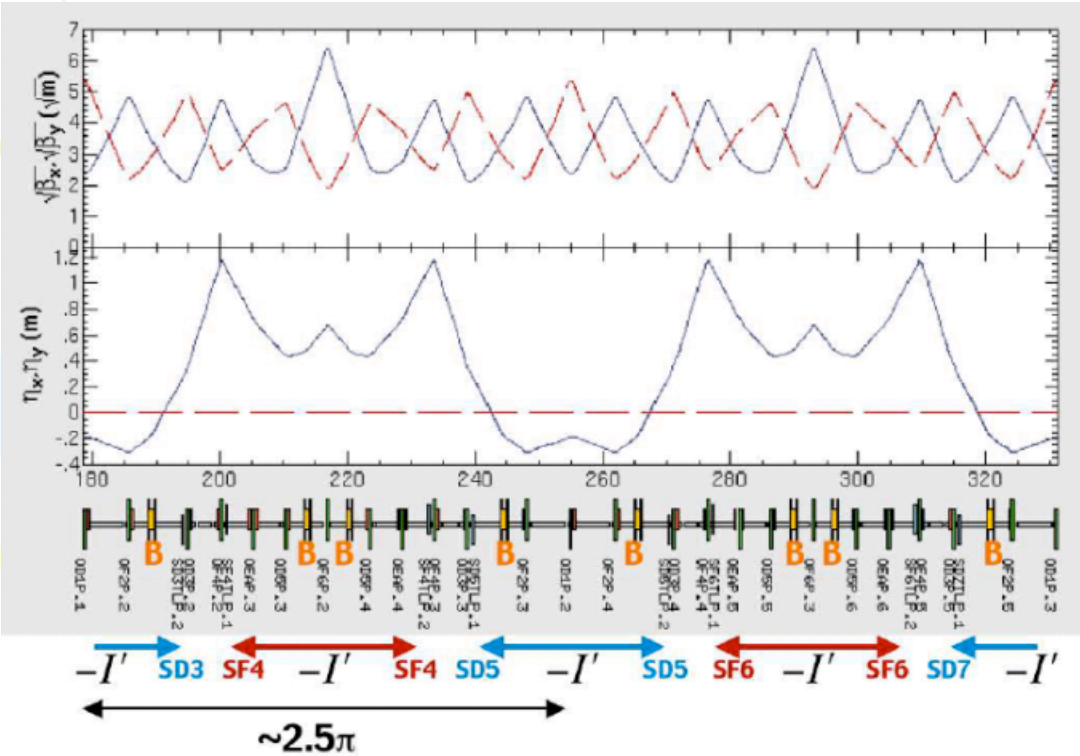
Lattice Design
Beam Optical Parameters

		LER	HER	Unit
Horizontal emittance	ε_x	24	24	nm
Beta function at IP	β_x / β_y	200/3	200/3	mm
Momentum compaction	α_p	2.7×10^{-4}	1.8×10^{-4}	
Momentum spread	σ_δ	7.2×10^{-4}	6.8×10^{-4}	
RF voltage	V_c	15	20	MV
Bunch length	σ_z	3	3	mm
Synchrotron tune	ν_s	0.031	0.019	

Lattice Parameters and Beam-Beam Effect *(from Ohnishi)*

		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	77	nm
Horizontal beta at IP	β_x*	20	4.5	cm
Vertical beta at IP	β_y*	3	2.3	mm
Horizontal beam size	σ_x*	69	59	μm
Vertical beam size	σ_y*	0.7	1.4	μm
Beam size ratio	$r = \sigma_y^*/\sigma_x^*$	1	2.4	%
Crossing angle	θ_x	0	0	mrad
Luminosity reduction	R_L	0.86	0.81	
ξ_x reduction	$R_{\xi x}$	0.99	0.97	
ξ_y reduction	$R_{\xi y}$	1.11	1.17	
Reduction ratio	$R_L/R_{\xi y}$	0.78	0.70	
Horizontal beam-beam (estimated with S-S simulation)	ξ_x	0.08	0.05	
Vertical beam-beam (estimated with S-S simulation)	ξ_y	0.14	0.12	
Luminosity	L	2.5 x 10^{35}	2.5 x 10^{35}	$cm^{-2}s^{-1}$

Lattice Design: the arc section



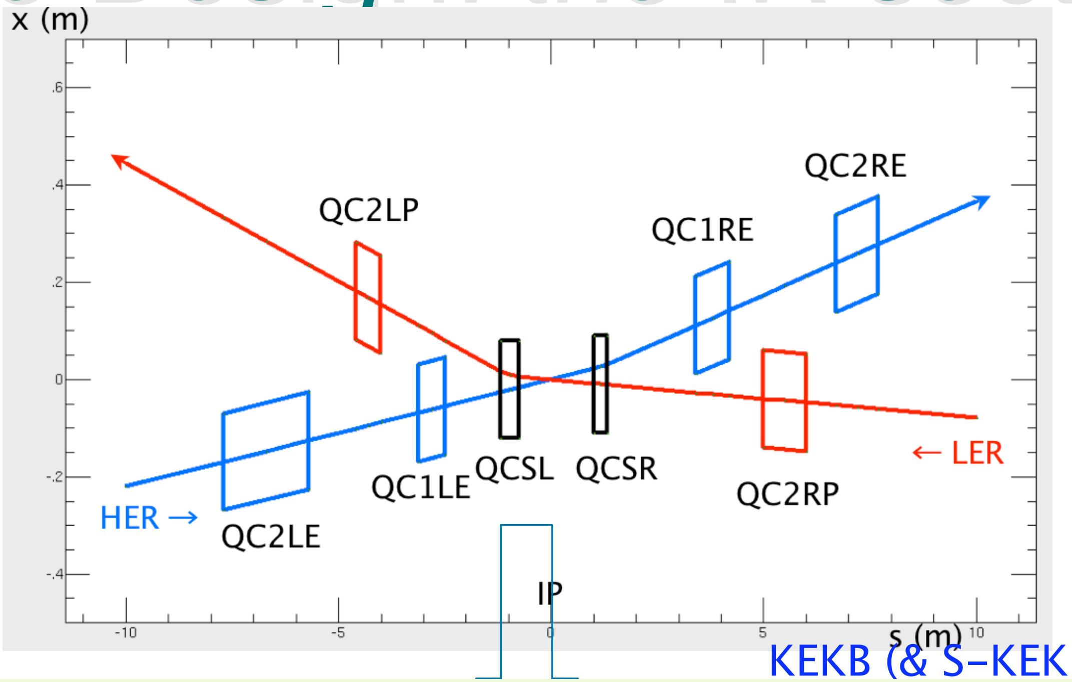
The beam-optical parameters can be adjusted to SuperKEKB <u>without</u> changing the lattice in the arc section.

KEKB lattice: 2.5π cell and non-interleaved chromaticity correction scheme.

→Wide tunability of horizontal emittance, momentum compaction factor.

→Principle nonlinearities in sextupole pairs cancelled out to give large dynamic aperture

Lattice Design: the IR section



KEKB (& S-KEKB HER)

Issues:
- QC1 normal or superconducting?
- Strong synchrotron light from QCS.
- Aperture

→need damping ring for positrons, at least.

Move final focus quadrupoles closer to IP for lower beta functions at IP.
QCS and solenoid compensation magnets overlap in SuperKEKB.
Rotate LER 8 mrad (total crossing angle of 30 mrad).

Vacuum parameters (SR related) for SuperKEKB

	LER	*HER*	*Unit*
Beam energy	*3.5*	*8.0*	*GeV*
Beam current	*9.4*	*4.1*	*A*
Bunch length	*3*	*3*	*mm*
# of bunches	*5018 (with 2% abort gap)*		
Bending radius	*16.31*	*104.46*	*m*
Bending angle	*56.1*		*mrad*
Half aperture	*112*		*mm*
Total SR power	*7.65 (without wiggler)*	*14.21*	*MW*
Max.line power density from SR	*27.8 (~2 times higher)*	*21.6 (~4 times higher)*	*kW/m*
Max.power density from SR	*38.7(almost same as KEKB, ante-chamber)*	*35.0 (2.4 times higher)*	*W/mm*^{2}
Critical SR energy	*5.84*	*10.88*	*keV*
Ave. photon density	1.21×10^{19}*(4 times higher)*	1.20×10^{19}*(4 times higher)*	*/m/s*
Ave. gas load	4.56×10^{-8}	4.54×10^{-8}	*Pa m*^{3}*/s/m*

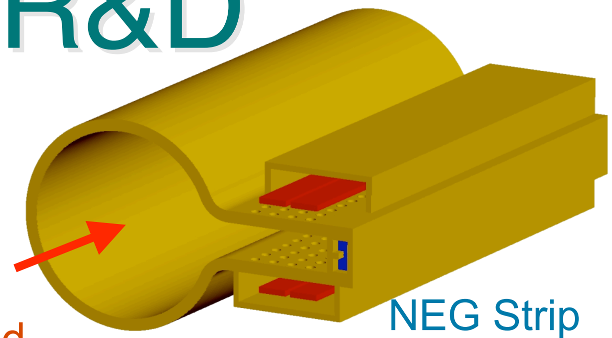
Vacuum parameters (HOM related)for SuperKEKB

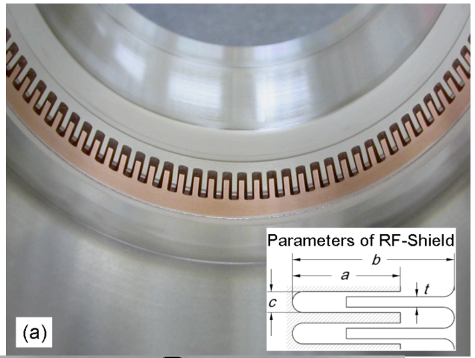
	Loss factor *k* *(V/C)*	Length or # of components	Total *k* *(V/C)*	HOM power(kW)
Resistive wall	4.1×10^{9}	*2200 m*	8.9×10^{12}	*1780*
Pumping holes	8.8×10^{5}	*2200 m*	1.9×10^{9}	*0.38*
Flanges	1×10^{8}	*800*	8×10^{10}	*16*
Bellows	4×10^{9}	*800*	3.2×10^{12}	*640*
Photon mask	1×10^{4}	*800*	8×10^{6}	*0.0016*
Gate Valve	3×10^{9}	*16*	4.8×10^{10}	*9.6*
Movable mask	1×10^{12}	*16*	1.6×10^{13}	*3200*
Taper	3×10^{9}	*72*	2.2×10^{11}	*44*

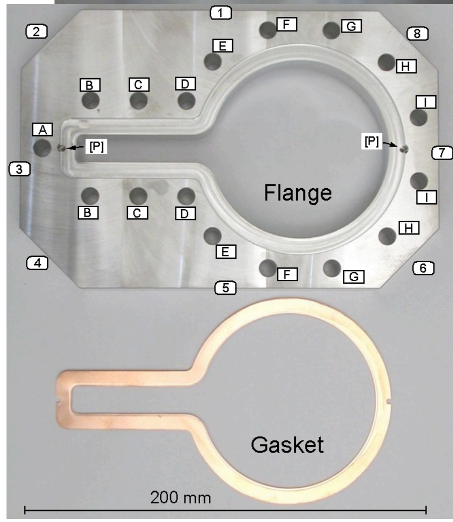
HOM dampers needed.

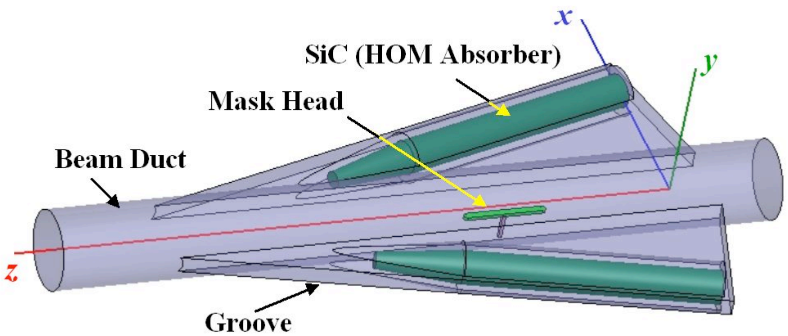
Vaccum components R&D

- Proposed basic designs for arc are:
  - Beam Duct:
    - Copper beam duct with an ante-chamber
    - Distributed pumping by NEG strips
    - Inner surface with low SEY [e+] or/and solenoid
  - Bellows and gate valves:
    - With comb-type RF shield
  - Connection flange:
    - MO-type flange or conventional
    - RF bridge + vacuum seal
  - Movable mask (collimator)
    - New design with low impedance









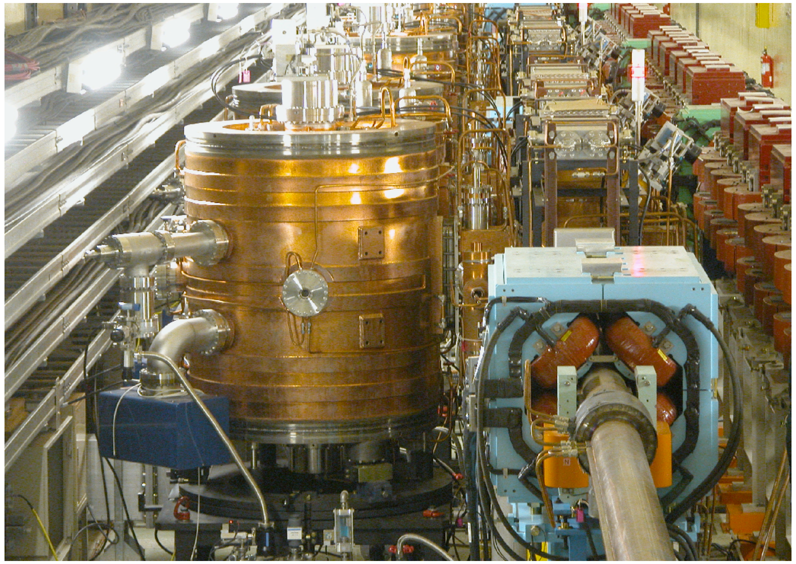
From Suetsugu

RF parameters for SuperKEKB

Parameters		LER	HER	Unit
Beam current	I_b	**9.4**	**4.1**	A
Energy loss/turn	U_0	1.2	3.5	MeV
Loss factor	k_{total}	40	50	V/pc
Bunch length	σ_z	3	3	mm
Radiation loss power	$P_{b,rad}$	11.3	14.3	MW
Parasitic loss power	$P_{b,para}$	7.1	1.7	MW
Total beam power	$P_{b,total}$	**18.4**	**16.0**	**MW**
Total RF voltage	$V_{c,\ total}$	14.0	23.0	MV
RF frequency	f_{RF}	508.887		MHz
Revolution frequency	f_{rev}	99.4		kHz
Type of cavities		ARES	ARES/SCC	
# of cavities		28	16/12	
Voltage/cavity	V_c	0.5	0.5/1.3	MV
Beam power/cavity	P_b	650	650/460	kW
Wall loss/cavity	P_c	233	150/-	kW
Detuning frequency	Δf_a	45	31/74	kHz
# of klystrons		28	16/12	
Klystron power	P_{kly}	930	850/480	kW
Total AC power		40	23/10	MW

- Required RF power provided to beam is four times as high as those of KEKB. But the required RF voltage is relatively low.
- Adopt the same RF frequency as KEKB and use the existing RF system as much as possible.

ARES Upgrade for Super-KEKB



- HER: 4.1 A (N_b = ~5000, σ_z = 3mm) by 16 ARESs + 12 SCCs
  - ARES cavities of the current version. (KEKB 12ARESs+8SCCs)
- LER: 9.4 A (N_b = ~5000, σ_z = 3mm) by 28 ARESs (KEKB 20 ARESs)
  - Remodel the A-cav part together with upgrading the HOM loads
  - The S-cav will be reused.
  - 8 or more sets of ARES cavities are needed to increase the beam current up to 9.4 A.
- Super KEKB one ARES/klystron configuration

  (KEKB: two ARES/one klystron)
  - The input power to each cavity will be nearly doubled.
  - The number of klystrons will be more than doubled.

From Kageyama

Remodeling ARES Cavity (A-cav Part)

Increase k_a (the coupling factor between A-cav and C-cav) by enlarging the coupling aperture between A-cav and C-cav

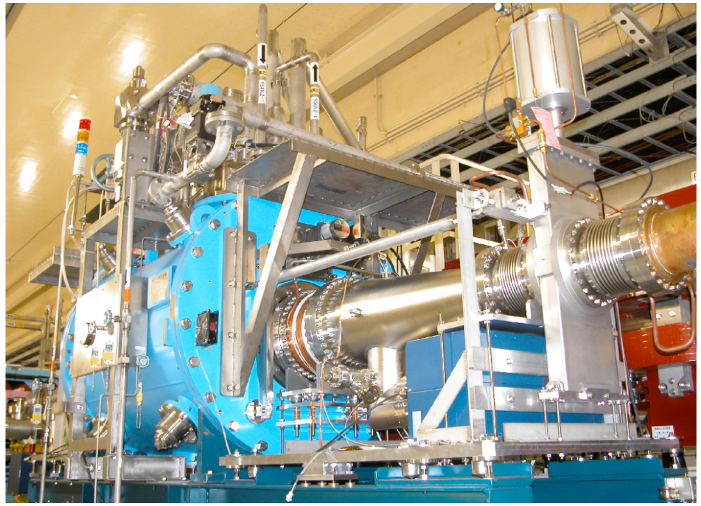
→ Increase the stored energy ratio: $\frac{U_s}{U_a} = \frac{k_a^2}{k_s^2}$

Upgrade HOM Waveguide Load

Upgrade GBP Load

KAGEYAMA, T.
HL6, KEK,
Nov. 16, 2004

Superconducting Cavity



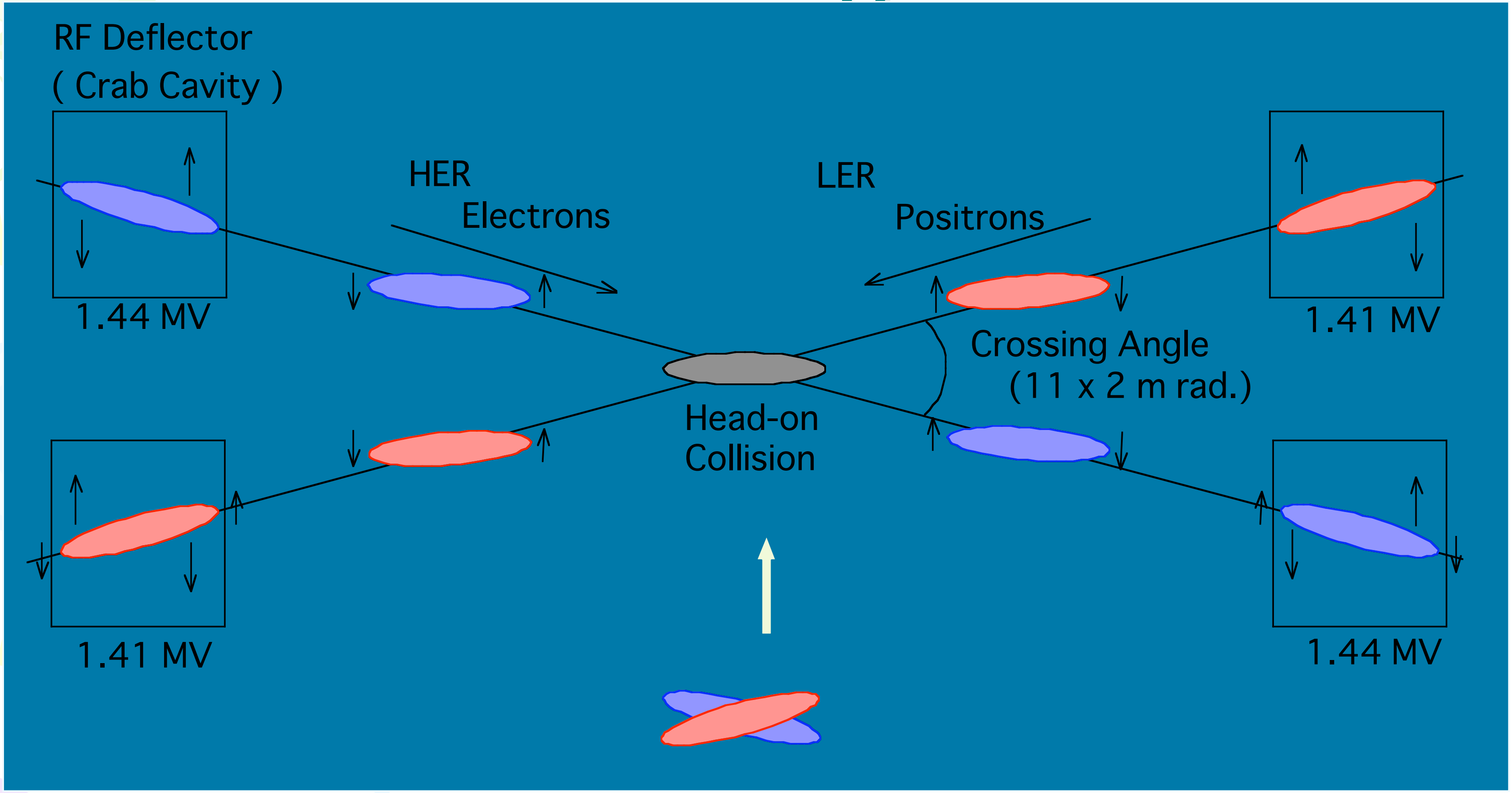
- Cavity Field 1.4-2.0MV OK
- Input Coupler 380kw → 460kW OK (test)
  - Coupler already tested more than 500kW(800kW in short time),beam test will be done.
- HOM Power 10 kW → 60kW to be solved
  - HOM damper is most important issue for Super-KEKB SCC. Max Power of 40kW have been tested in air condition. High power test under high vacuum will be done.
- Add 4 Cavities
- If possible 4mm bunch length is help full reducing HOM problems and saving cost.

From Mitsunobu

Coupled-Bunch Instabilities due to RF Cavities

Item	Freq. (MHz)	LER		HER		Cure
		# of cav.	Growth rate (ms)	# of cav.	Growth rate (ms)	
Longitudinal modes						
ARES-HOM	*1850*	*26*	*5*	*16*	*47*	Bunch by bunch FB
SCC-HOM	*1020*			*12*	*49*	No need
Crab-HOM at LFM	*655*	*2*	*41*	*2*	*214*	No need
ARES 0/p modes	*504*	*28*	*4*	*16*	*29*	Bunch by bunch FB
Fundamental -1 mode	*508.79*	*28*	*1.6*	*16+12*	*1*	FB in RF control system
Fundamental -2 mode	*508.69*	*28*	*20*	*16+12*	*21*	FB in RF control system
Transverse modes						
ARES-HOM	*633*	*28*	*4*	*16*	*33*	Bunch by bunch FB
SCC-HOM	*688/705*			*12*	*12*	Bunch by bunch FB
Crab-HOM	*773*	*2*	*4*	*2*	*12*	Bunch by bunch FB

Crab crossing scheme



Palmer for LC (1988)
Oide and Yokoya for storage rings :Phys,Rev.A40,315(1989)

Recent simulations by Ohmi showed significant increase of luminosity with crab crossing. It effectively creates a head-on collision.

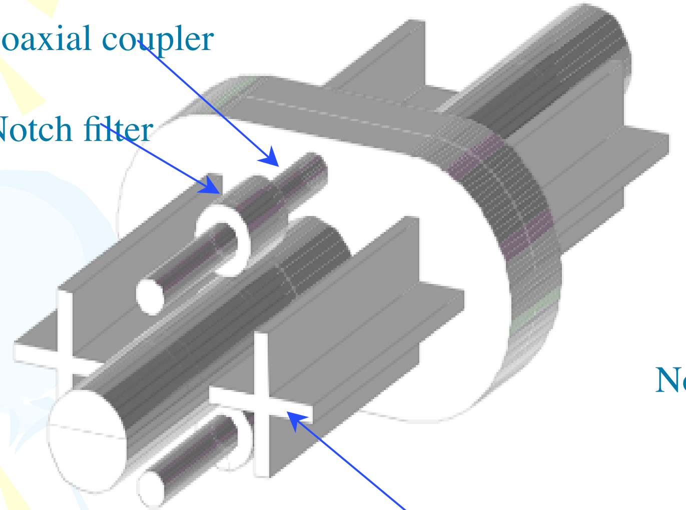
Crab crossing in KEKB and Super-KEKB

	KEKB		*Super-KEKB*	
Ring	LER	HER	LER	HER
Beam energy (GeV)	3.5	8.0	3.5	8.0
Beam current (A)	2.6	1.1	9.4	4.1
Bunch length (mm)	7	7	3	3
RF frequency (MHz)	508.887		508.887	
Crossing angle (mrad)	±11		±15	
βx* (m)	0.6	0.6	0.2	0.2
βx, crab (m)	40	200	100～200	300～400
Required kick (MV)	1.47	1.51	1.10 ～ 0.78	1.45 ～ 1.26
Restore kick?	No (single kick)		Yes (both sides of IP)	

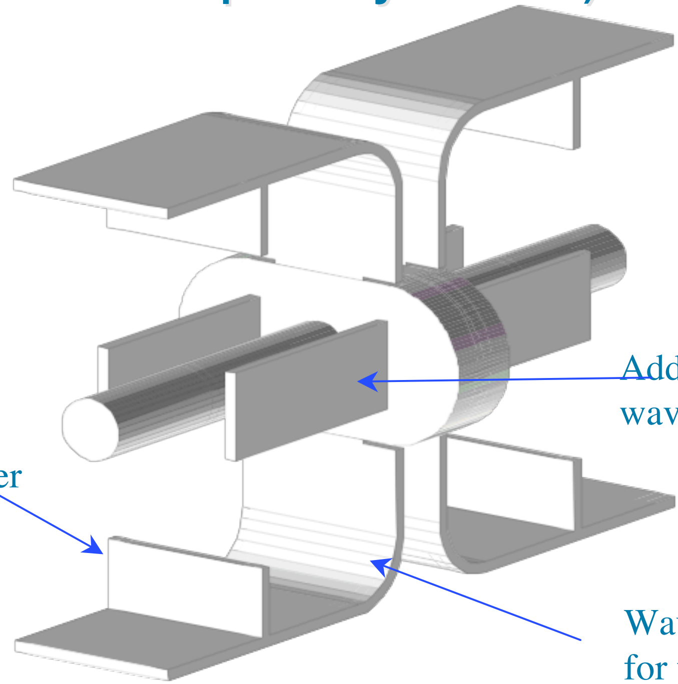
Crab cavity in Super-KEKB

- Possible problems for 10A with σ_z=3mm
  - Large HOM power (300kW) to dampers.
  - Growth rate can be higher than the radiation damping rate.
- Improvements needed → New design
  - Reduce the loss factor for σ_z= 3mm.
  - Much heavier damping of parasitic modes.

Two different types based on different methods to damp the accelerating mode (Lower Frequency Mode).



(1) Coaxial couplers Type



(2) Waveguide damper Type

From Akai

Other Components

- **Beam Position Monitors**
  - Use same front-end electronics
  - New button electrodes

12 mm →6 mm diameter

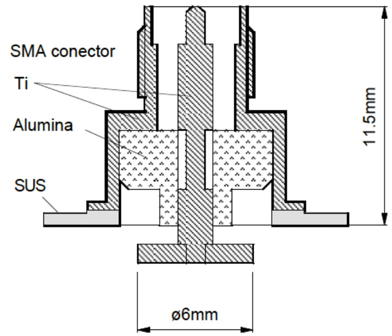


Figure 10.1: Feedthrough of the button electrode with a special SMA connector for KEKB.

-> Signal power matches dynamic range of existing front-end electronics.

- **Main Ring Magnets**
  - Outside of the IR, will largely reuse present KEKB magnets & power supplies.

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/p mode instability →Target damping time 1ms
  - -Use DAϕNE-type (low-Q cavity) kicker.

- New general-purpose feedback signal processor under development at/with SLAC will be used.

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

-Extensive beam diagnostics.

Linac Upgrade Requirements

		KEKB		SuperKEKB
(1) Beam Energy	(e^-)	8.0 GeV	----->	3.5 GeV
	(e^+)	3.5 GeV	----->	8.0 GeV !
(2) Beam Intensity	(e^-)	1.0 nC x 1 bunches	----->	2.5nC x 2 bunches !
	(e^+)	0.6nC x 2 bunches	----->	1.2nC x 2 bunches !

-> with 7-10 Tesla flux concentrator in e+ capture section

(3) Smaller e^+ emittance to fit for IR & C-band module apertures

-> e^+ damping ring

(4) Faster e^+/e^- mode-switching for Continuous e^+/e^- Injection

-> separated e^+/e^- beam lines

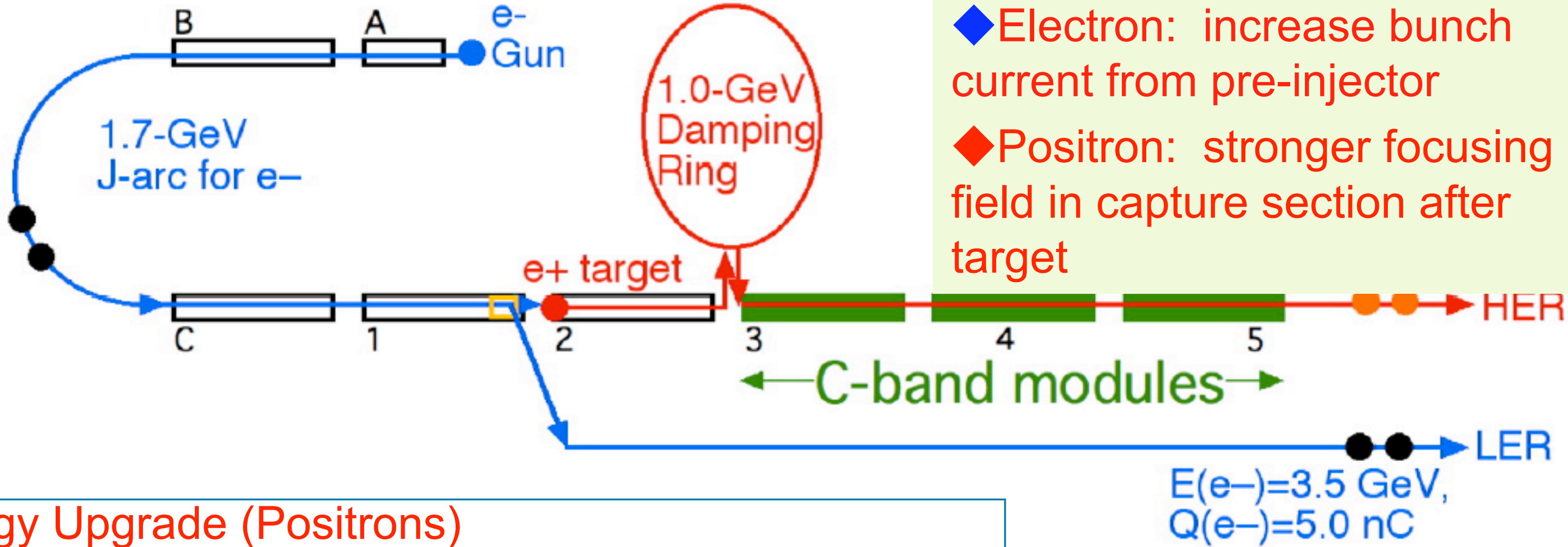
-> non-destructive beam monitoring

From Michizono

Linac Upgrade

Intensity Upgrades

- ◆Electron: increase bunch current from pre-injector
- ◆Positron: stronger focusing field in capture section after target



Energy Upgrade (Positrons)

KEKB:21 MV/m (S-band) x 231 m = 4.8Gev max

⇩

e+ energy is boosted by C-band accelerator modules

SuperKEKB:
21 MV/m (S-band) x 46 m
+ 42 MV/m (C-band) x 185 m=8GeV

The kicker magnet will be installed before positron target for quick switching between beams (50 Hz).

Damping Ring

Positron emittance needs to be damped, to pass reduced aperture of C-Band section and to meet IR dynamic aperture restrictions.(e+ Injection)

		Unit
Energy	1.0	GeV
Number of bunch trains	2	
Number of bunches/train	2	
Bunch spacing	98	ns
Bunch charge	2.56	nC
Repetition frequency	50	Hz
Circumference	131.3	m
Energy loss per turn	73	keV
Horizontal damping time	11.95	ms
Injected-beam emittance	1.23	μm
Equilibrium emittance	12.2	nm
Emittance at extraction	13.7	nm
Energy spread of injected beam	4.06×10^{-3}	
Bunch length of injected beam	6.05	mm
Energy spread	5.29×10^{-4}	
Bunch length	5.03	mm
Bend-angle ratio of reverse-bend	0.35	
Phase advance/cell	1.932	rad
Momentum compaction factor	0.0019	
Number of normal-cells	40	

Electron DR may be considered later to reduce injection backgrounds in physics detector.

Summary

- SuperKEKB aims at a peak luminosity of $1\text{-}5\times10^{35}$ cm^{-2} s^{-1}, a new luminosity frontier for colliders.
- The basic design work has been finished and a Letter of Intent was published this year (Edited by J.W.Flanagan and Y.Ohnishi,KEK Report 2004-4 June 2004).
- More simulation and intensive hardware R&D work towards SuperKEKB are on-going.