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KEKB uest for CPV kekb.jp

WEXMA01

Status of KEKB and upgrade plan to SuperKEKB

Mitsuhiro Yoshida, Haruyo Koiso ,
on behalf of KEKB accelerator group.

KEK, Ibaraki, Japan

Asian Particle Accelerator Conference 2007
January 29- February 2, 2007, Indore, INDIA

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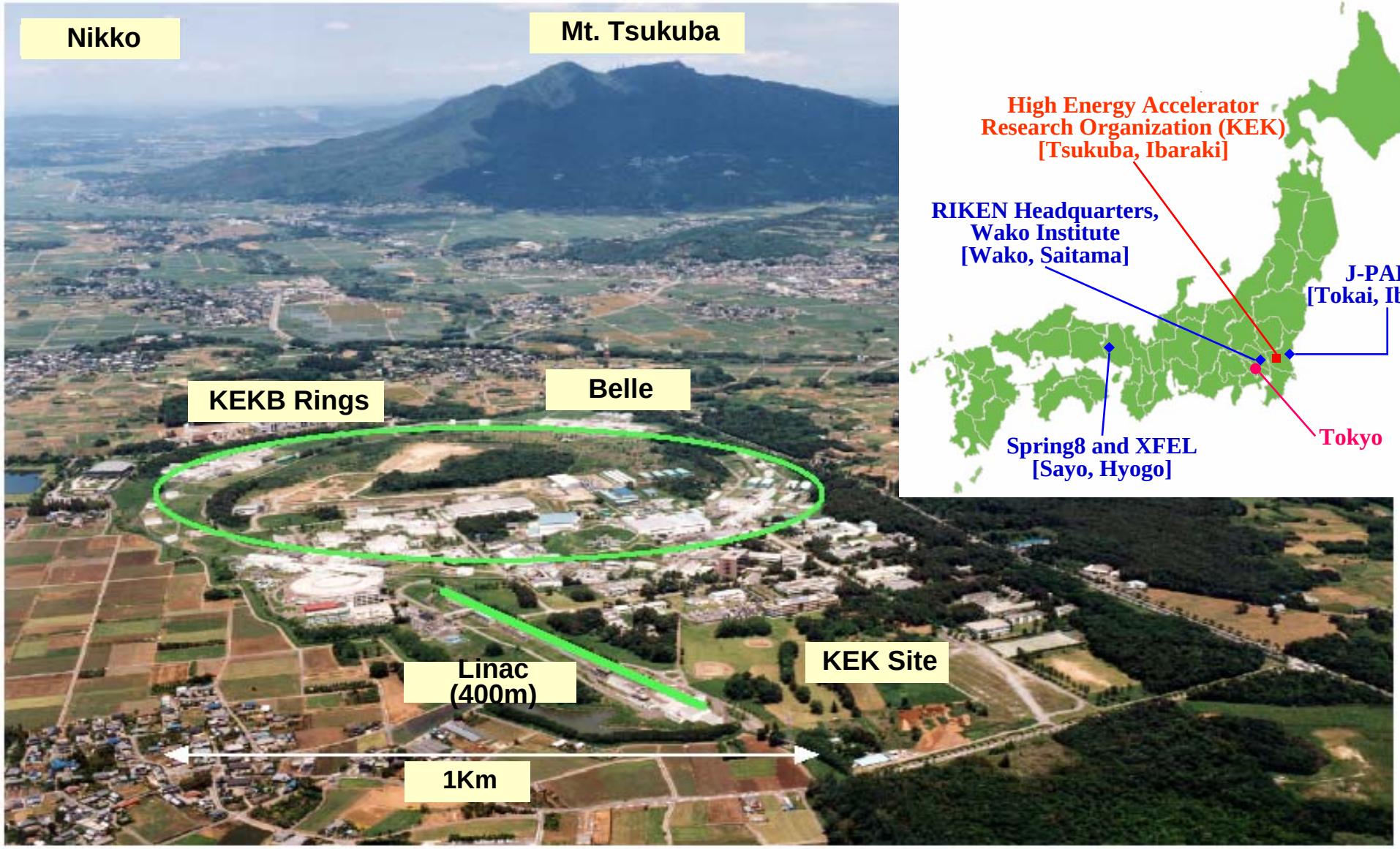
Place and Layout of KEKB



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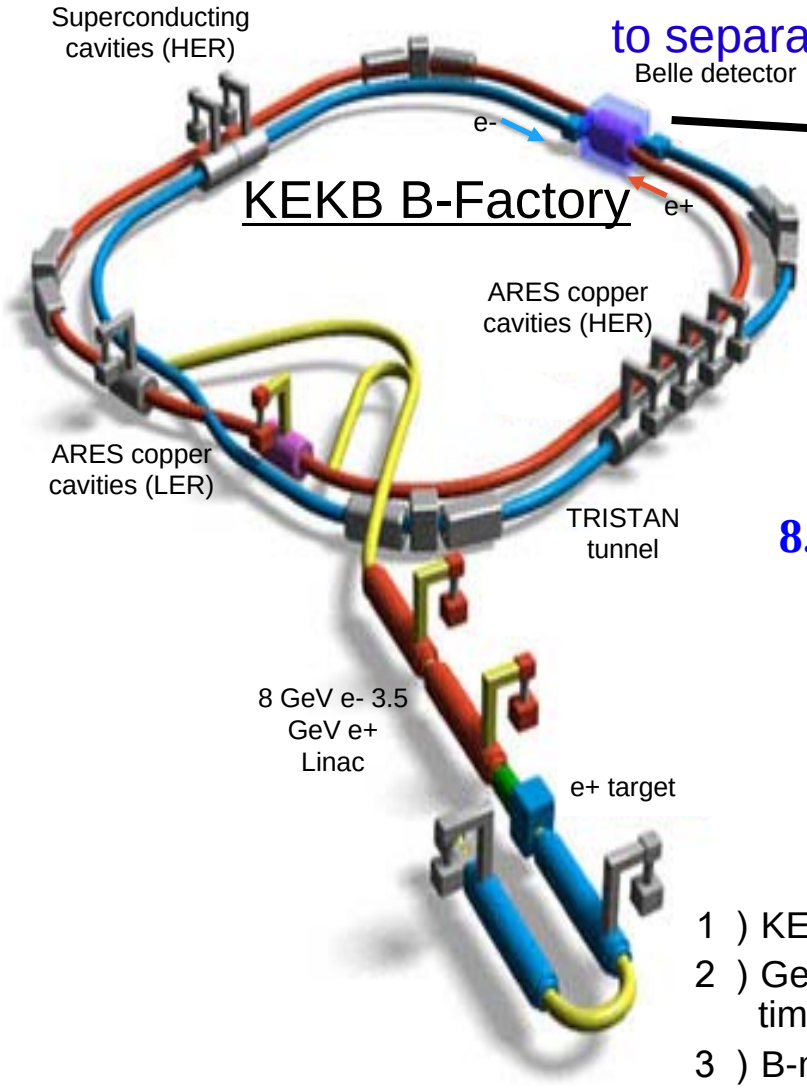
KEKB = Asymmetric Double-Ring Collider for B-Physics
8 GeV Electron + 3.5 GeV Positron

Crab cavity was installed.



Collision point has horizontal crossing angle of 22 mrad to separate 2 beams easily.

e+ 7.8×10^{10}/bunch

Hight= 2.1 μm

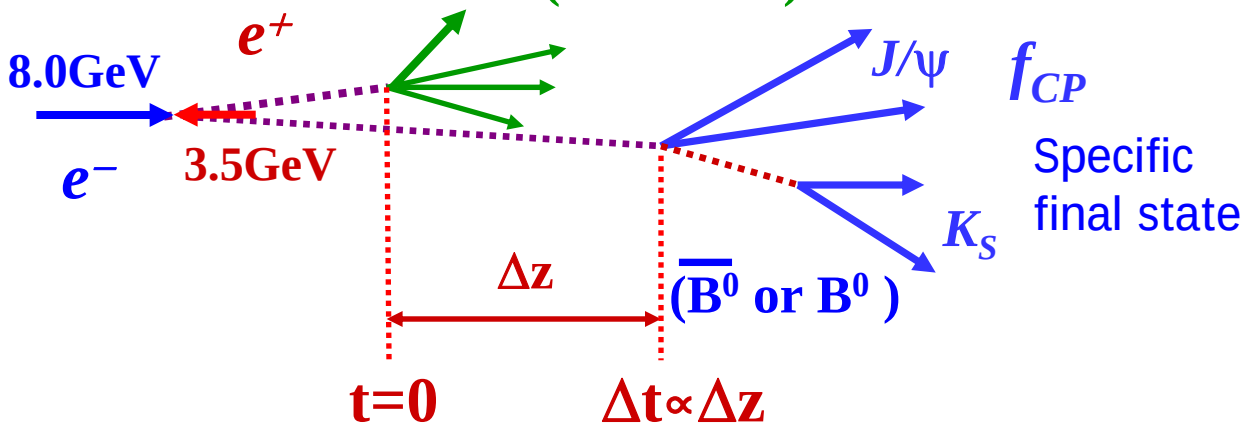
Width = 110 μm

7 mm

e- 5.8×10^{10}/bunch

100 kHz
1389 bunches

$(B^0$ or $\overline{B}^0$?)



1) KEKB is operating for asymmetric e^+ e^- collision at E_{cm}= 10.58 GeV (4s)

2) Generated B-meson pair have enough momentum to measure the decay time.

3) B-meson decay time is approximately 1 ps.

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Progress of KEKB for 7 years

KEKB
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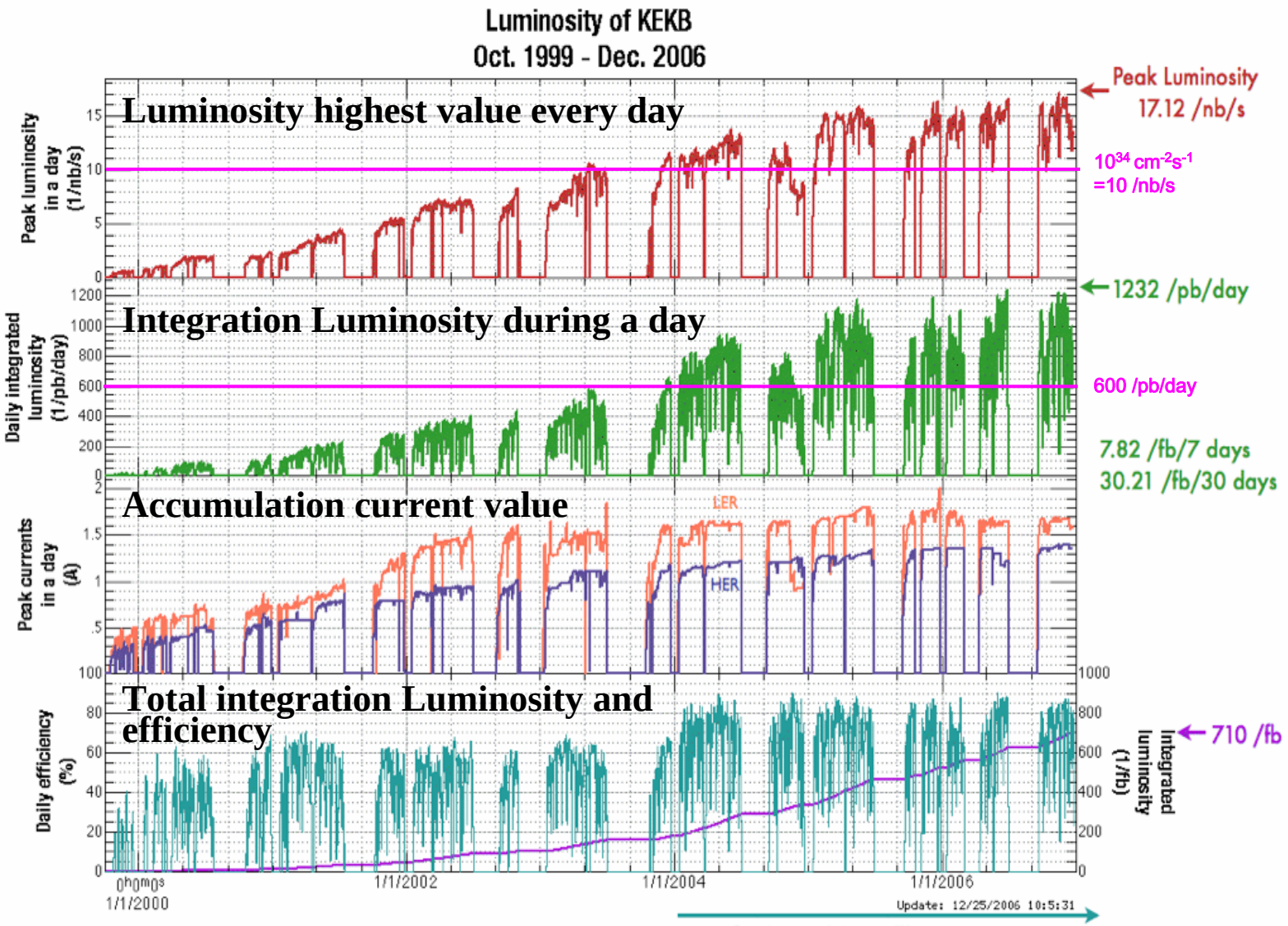
1989:	Design work started
1994:	Approval of the budget, construction started.
1995/6:	KEKB Design Report
1997/9:	Commissioning of the injector Linac started.
1998/12:	First beam at HER.
1999/1:	First beam at LER.
1999/5:	Belle roll-in.
1999/6:	First event at Belle.
2001/4:	World record of the luminosity, 3.4 /nb/s.
2002/10:	World record of the integrated luminosity, 100 /fb.
2003/05:	Exceeded the design luminosity, 10 /nb/s.

… continues rewriting own records …



Achieved >700 /fb in 7 years.

Continuous injection modes (CIM)

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Parameters to decide Luminosity

	Design		Dec. 2006	
	LER	HER	LER	HER
Circumference [m]	3016		3016	
RF Frequency [MHz]	508.88		508.88	
Emittance ε_x [nm]	18	18	18	24
Beam current [A]	2.6	1.1	1.662	1.340
Number of bunches	5000		1388	
Bunch current [mA]	0.52	0.22	1.200	0.965
Bunch spacing [m]	0.6		2.1	
beta's at IP β_x^* [cm]	33	33	59	56
beta's at IP β_y^* [cm]	1.0	1.0	0.65	0.59
Hor. Size@IP [μm]	77	77		
Ver. Size@IP [μm]	1.9	1.9	1.9	1.9
ξ_x	0.039	0.039	0.117	0.070
ξ_y	0.052	0.052	0.105	0.056
Beam lifetime [min.@mA]			110@1600	180@1340
Luminosity [/nb/s]	10		$17.12\times10^{33}/cm^2/s$	
$\int$ *Lum* /day [/fb]	~0.6		1.232	
$\int$ Lum/7 days [/fb]			7.809	
$\int$ Lum/30 days [/fb]			30.21	

Parameters to decide Luminosity

Stored current (HER/LER) :
1.1/2.6 A (Design)
→ 1.35/1.75 A (Achieved)

Beam-beam parameter:
0.052 (Design)
→ 0.056 (Achieved)

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:
1.0×10^{34} $cm^{-2}s^{-1}$ (Design)
1.712×10^{34} cm^2s (Achieved)

Vertical β at the IP:
10/10 mm (Design)
→ 5.9/6.5 mm (Achieved)

Vertical β at the IP is much less than the designed parameter, therefore we can obtain higher luminosity.

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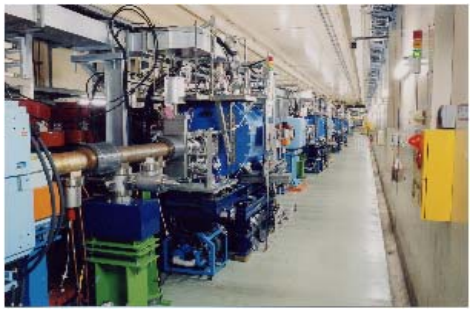
Features of KEKB

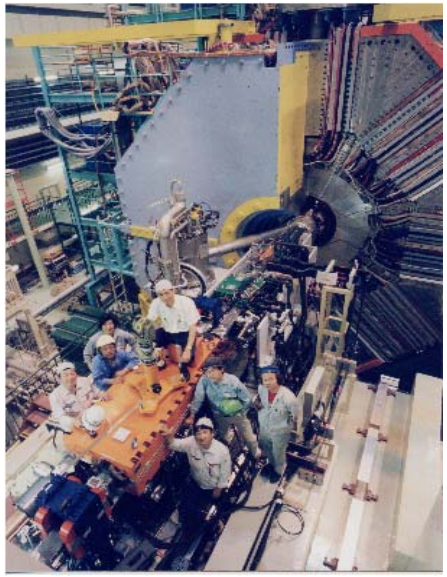
Superconducting cavity:

Accumulating beam
current of 1.35 A



2.5 π cell lattices:

- The minimum non-linearity and the maximum flexibility
- Close to half-integer resonance line.

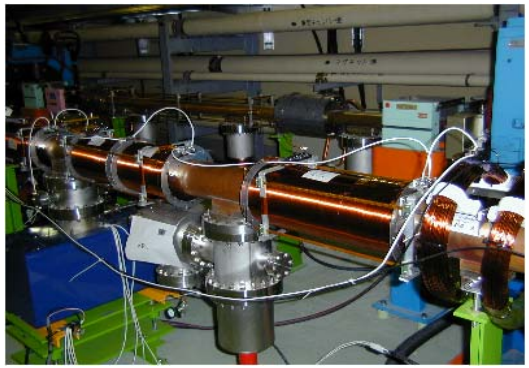


IP :

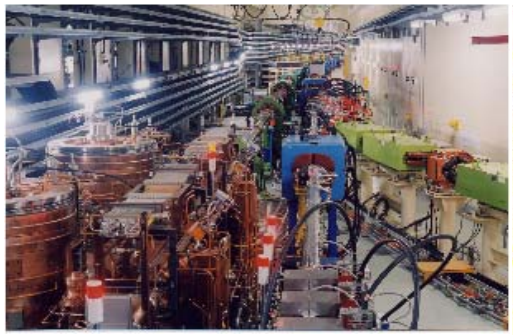
- Finite crossing angle.
- QCS
- Belle detector

Vacuum Components

- High current
- SR



Electron cloud is reduced by a solenoid magnetic field



Kicker/Separator and J-LINAC:

- It provides direct injection energy for continuous injection.

ARES cavity
(Normal conducting cavity with energy storage cavity):

- Stable acceleration of high current by huge accumulation energy.

Feedback system:

- contributes to the suppression of other instability by feedback of every bunch

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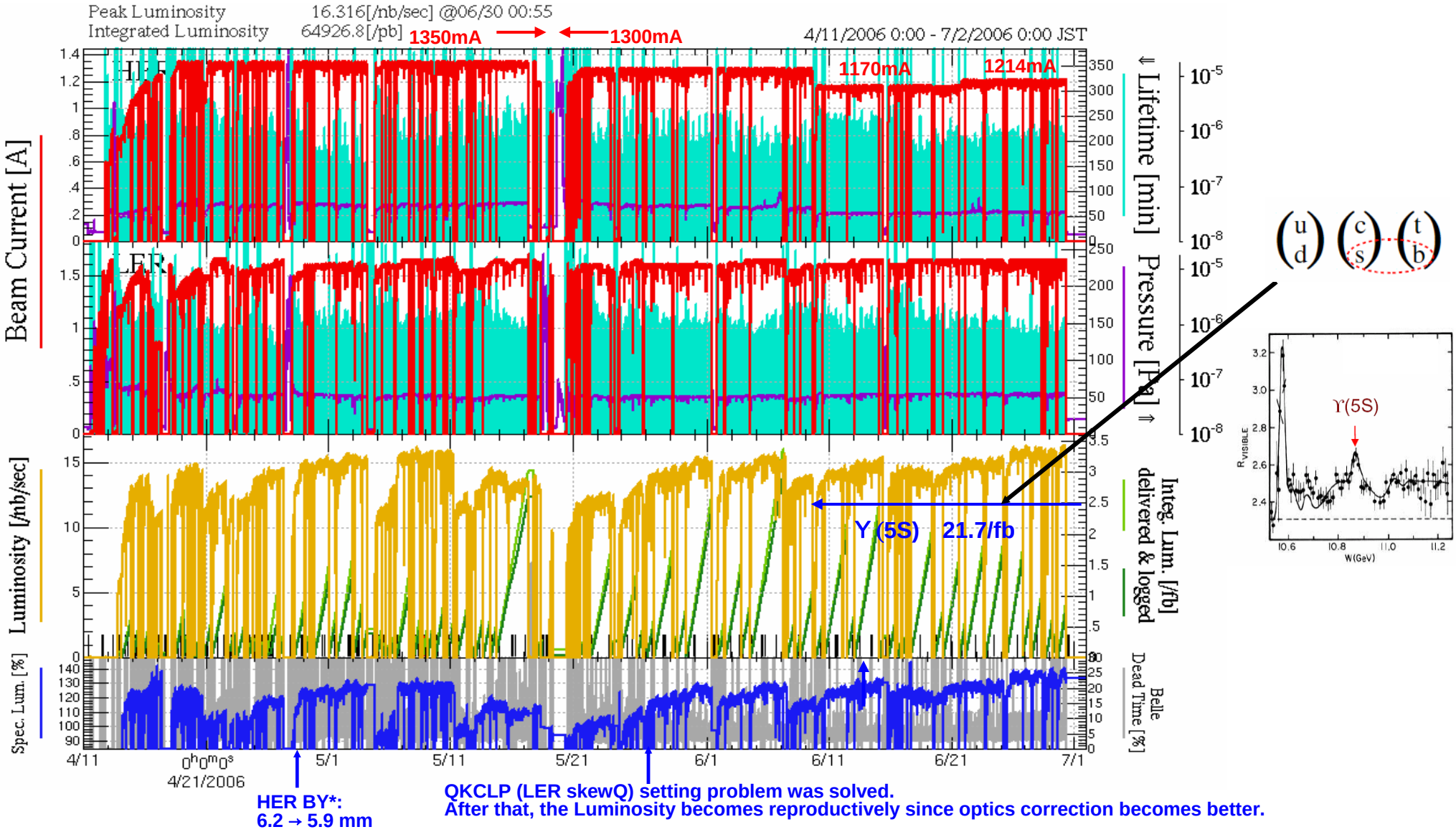
2006 April - July



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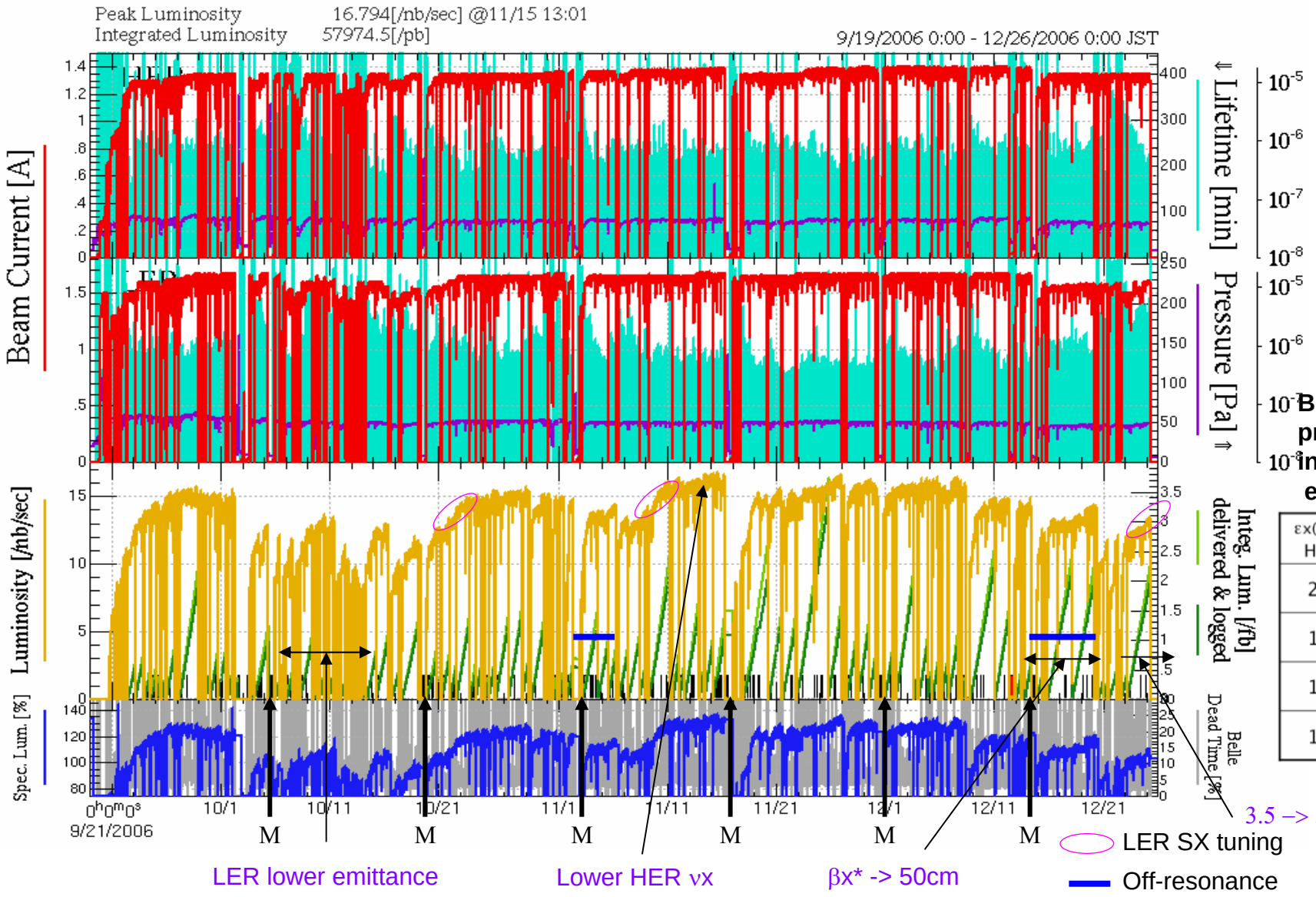
2006 September - December

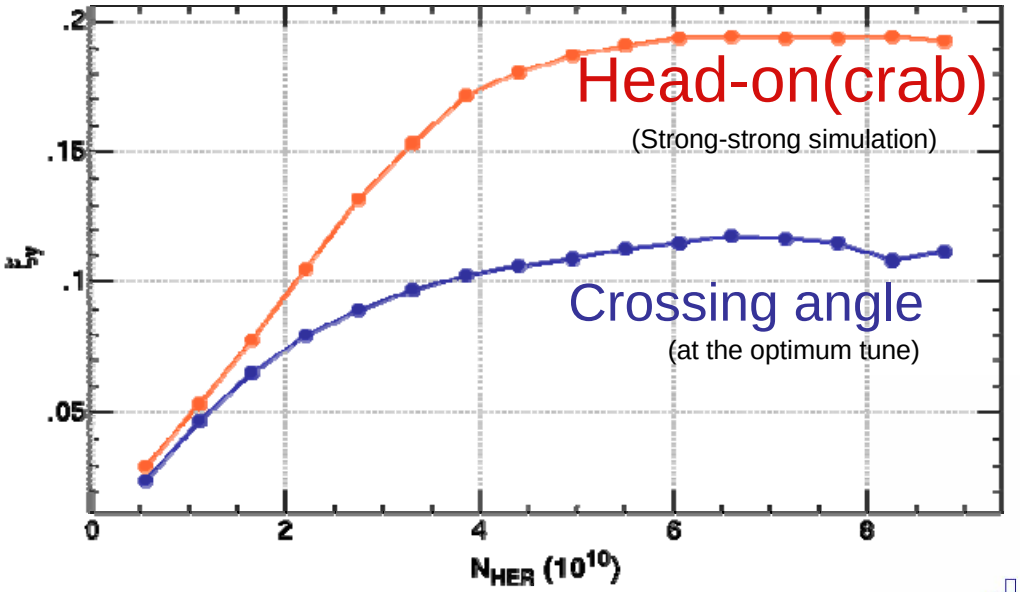


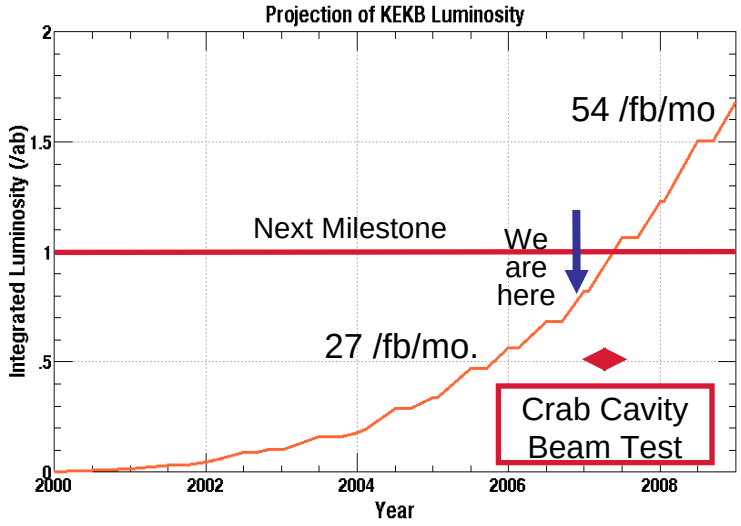
Beam-beam simulation predicts higher luminosity in the lower horizontal emittance.

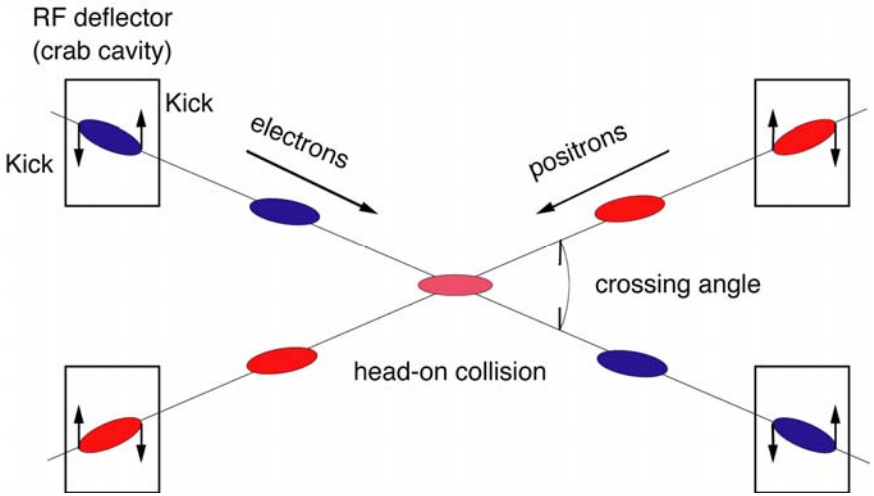
εx(nm) H\L	10	15	18
24	1.469 1.0770	1.414 1.0367	1.364 1
18	1.621 1.1884		1.420 1.0411
15	1.643 1.2045	1.505 1.1034	1.424 1.0440
10	1.595 1.1694	1.433 1.0506	1.249 0.9157

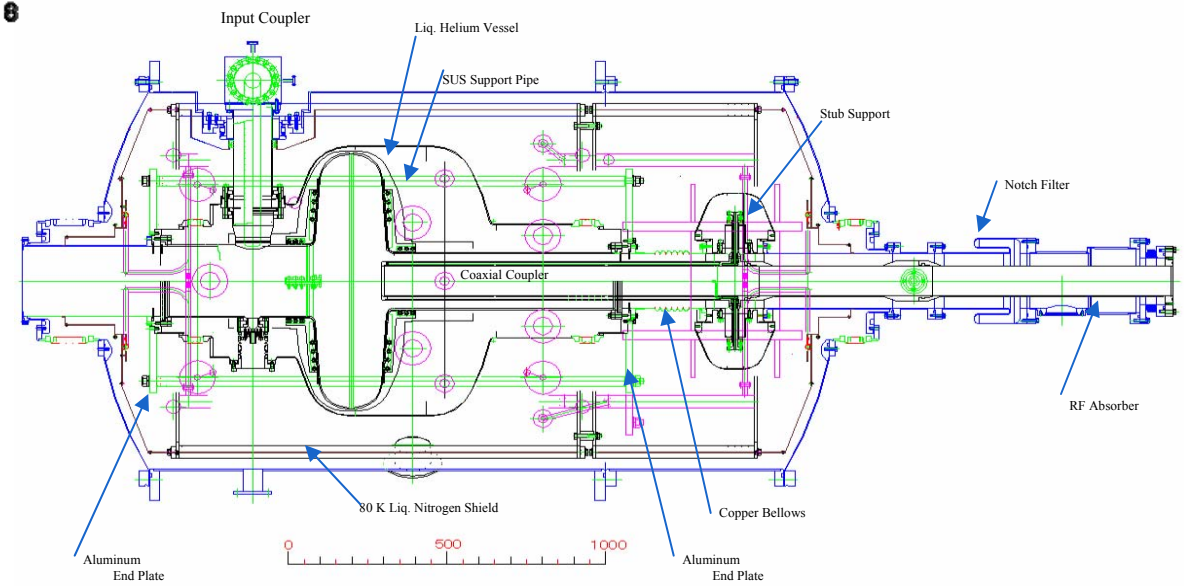
Crab Crossing is ready

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









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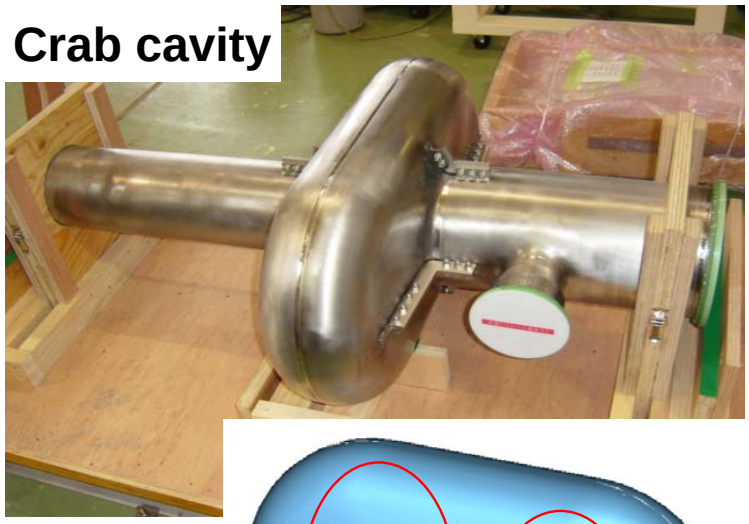
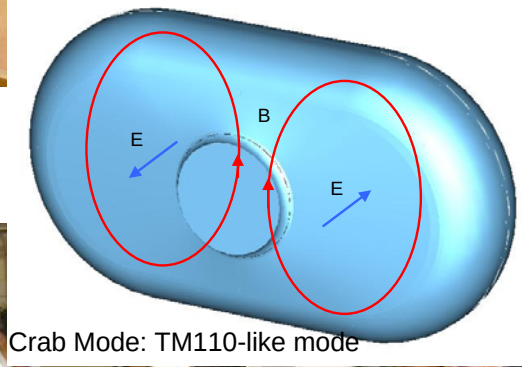
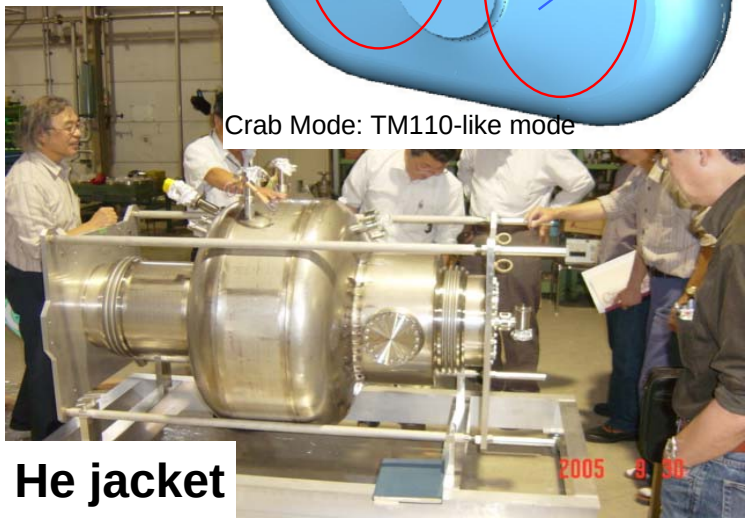
Crab Cavities were installed

Crab cavity

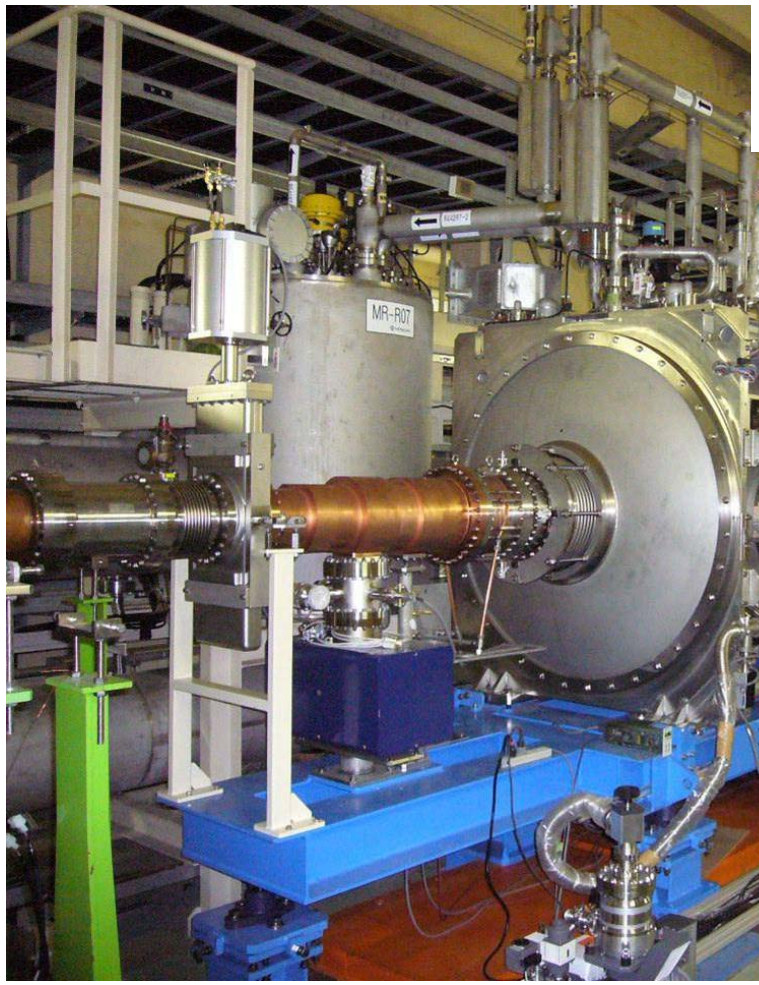




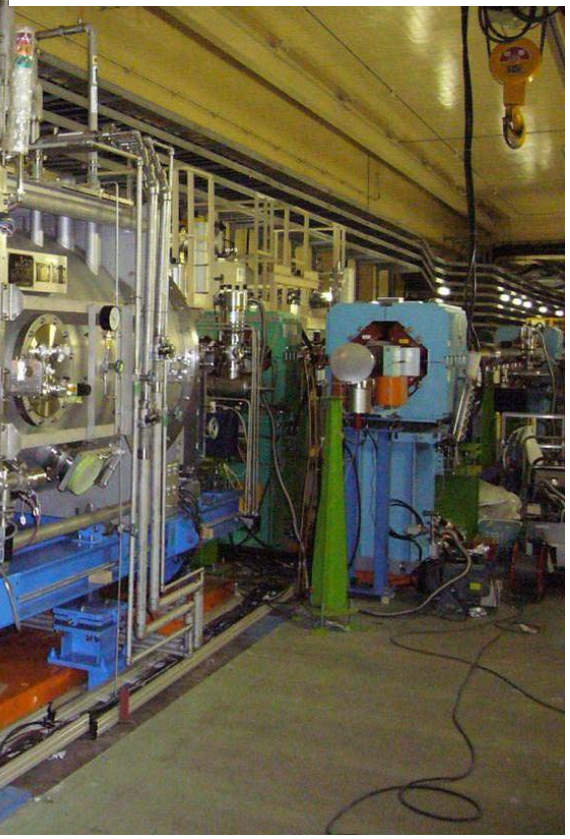
Crab Mode: TM110-like mode



He jacket



Presented by Morita (MOOPMA04)



Crab cavities were already installed.

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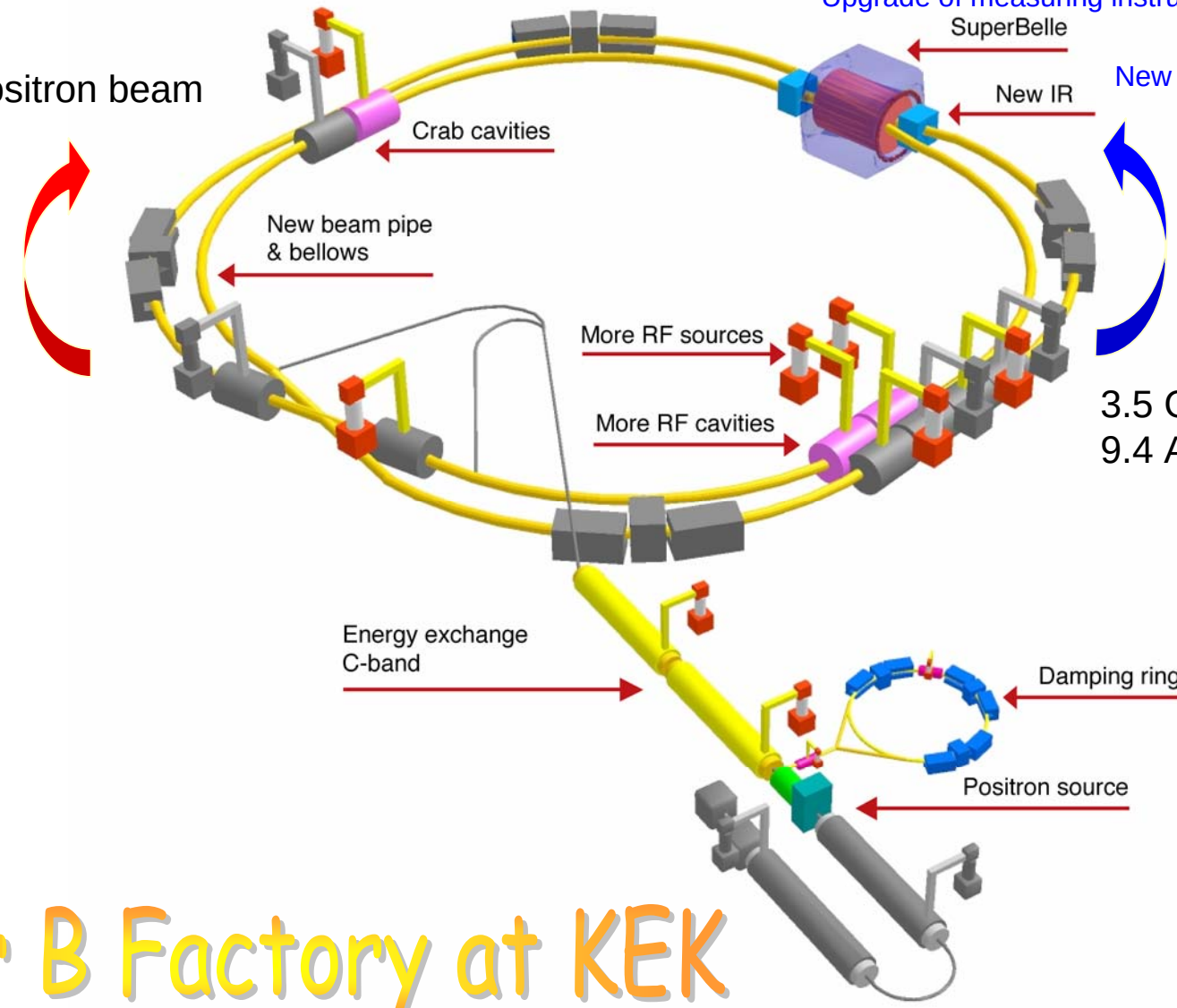
Super KEKB Overview

Upgrade of measuring instrument

8 GeV positron beam
4.1 A



New collision point design

3.5 GeV electron beam
9.4 A

Super B Factory at KEK

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Parameters for Super KEKB

Super KEKB

	KEKB		Super KEKB	
	LER	HER	LER	HER
Current [A]	1.616	1.210	9.4	4.1
Bunches	1388		5018	
Spacing [m]	1.8 or 2.4		0.6	
Emittance ε_x [nm]	18	24	24	
β_x^* [cm]	59	56	20	
β_y^* [cm]	6.5	5.9	3	
Hor. Size@IP [μm]	103	116	69	69
Ver. Size@IP [μm]	1.7	1.7	0.73	0.73
ξ_x	.106	.068	.152	.152
ξ_y	.105	.060	0.215	0.187
Luminosity [/nb/s]	16.52		400	
Bunch length [mm]	6		3	
RF voltage [MV]	8	15	15	20

Parameters to decide Luminosity

Stored current:
1.36/1.75 A (KEKB)
→ 4.1/9.4 A (SuperKEKB)

Beam-beam parameter:
0.059 (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:
0.16×10^{35} $cm^{-2}s^{-1}$ (KEKB)
4×10^{35} $cm^{-2}s^{-1}$ (SuperKEKB)

Vertical β at the IP:
6.5/5.9 mm (KEKB)
→ 3.0/3.0 mm (SuperKEKB)

Higher current and low β and higher beam parameter will provide 400 /nb/s.

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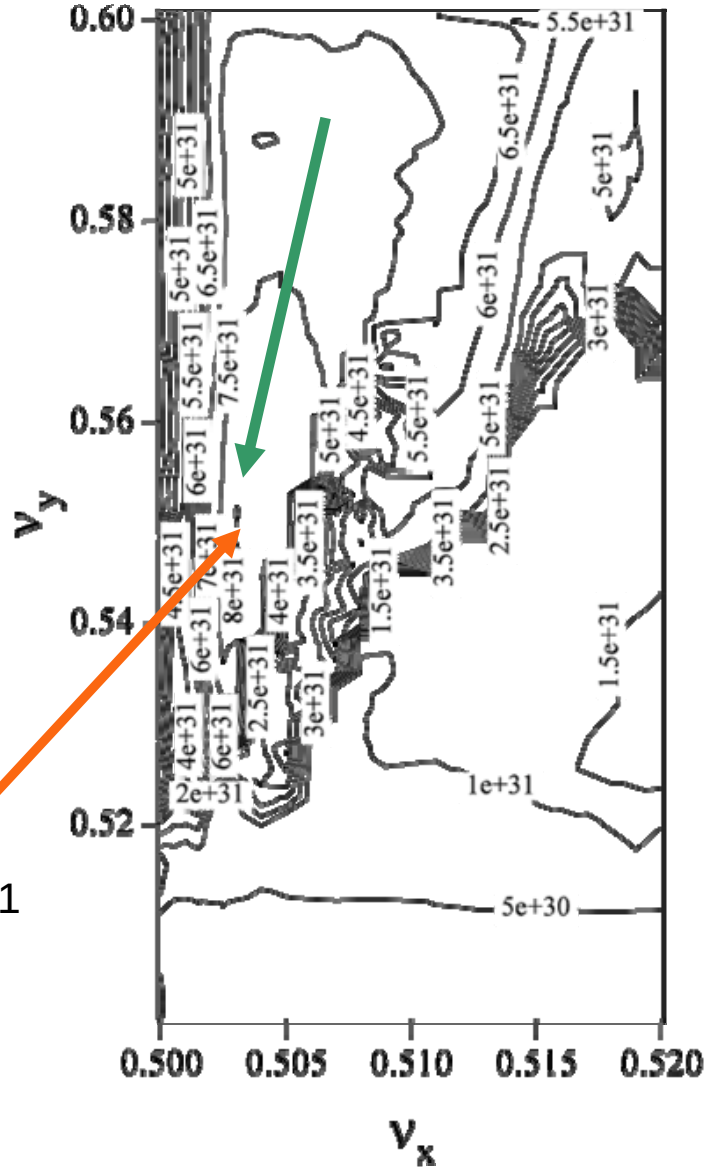
Beam-Beam Simulation

Tune scan

- Bunch luminosity v.s. tune
- Total luminosity = 5000 x bunch luminosity
- Green line sketches the progress of KEKB.

$L_{total} = 4 \times 10^{35}\ cm^{-2}\ s^{-1}$



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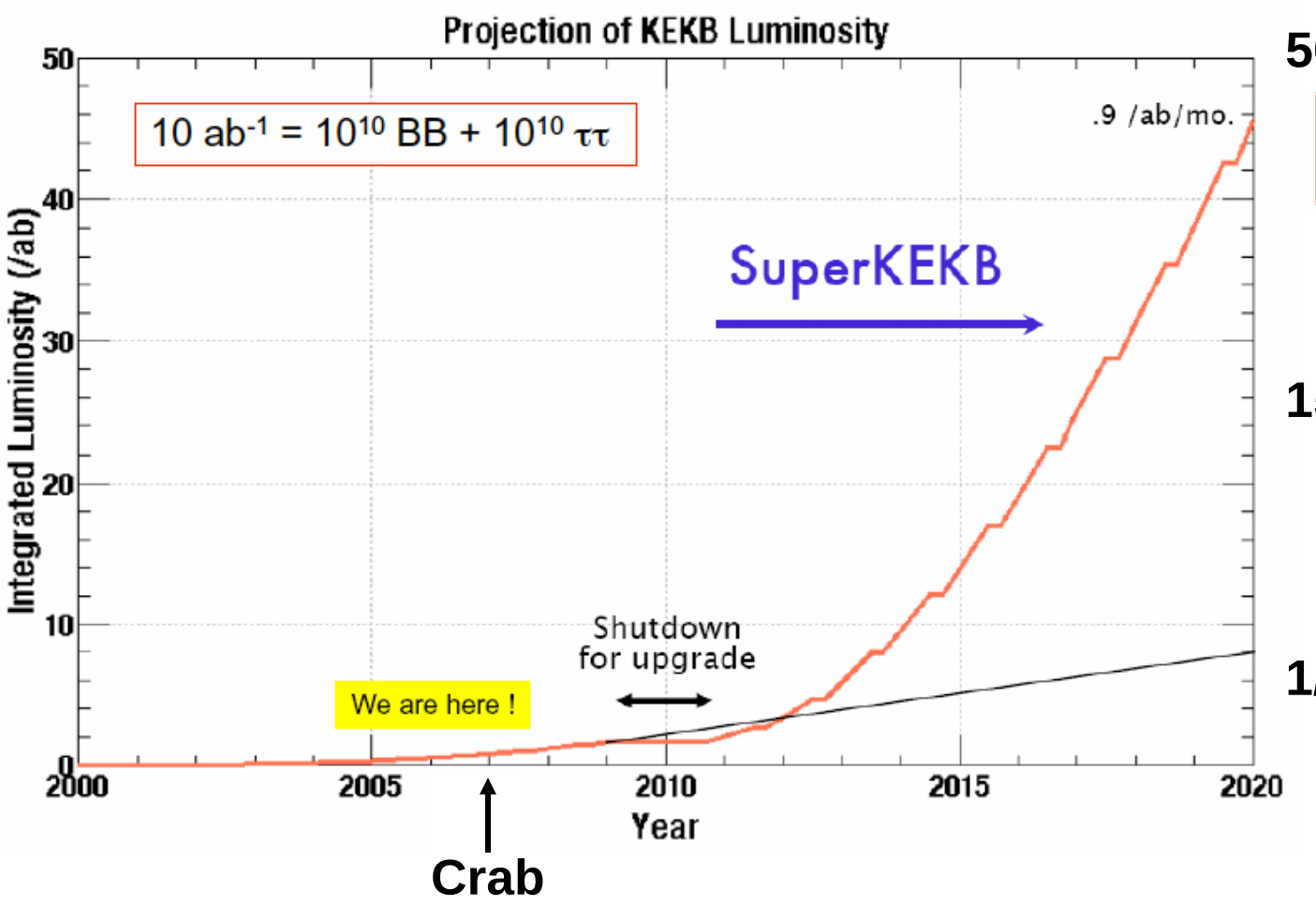
Expected Luminosity

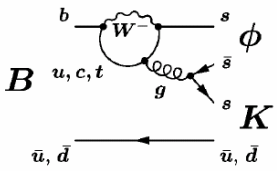


50/ab :

Discoveries of
$B \to K\nu\nu$

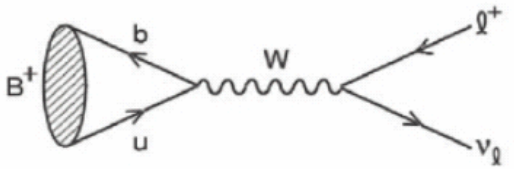
15/ab :

Discovery of
new *CP* violation
in $B^0 \to \phi Ks$



1/ab :

Discoveries of
$B^0 \to D\tau\nu$, $\tau\nu$



Upgrade Items for SuperKEKB

Accomplishment of higher luminosity

- For Higher beam currents
  - Large number of RF cavities and stations to obtain RF power
  - 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
- For Smaller beta function at IP
  - New QCS+special magnets at IR
  - Need short bunch length (Cure of CSR should be necessary.)
- For Higher beam-beam parameter

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RF Upgrade for High Current

ARES upgrade for SuperKEKB

- For Larger detuning

⇒ Change energy ratio :
Us/Ua = 9 →15

Small modification on the window size of A-cav

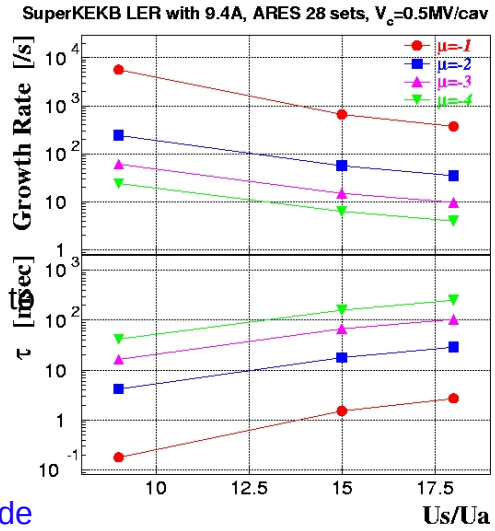
-1 mode growth time :
0.3 ms to 1.6 ms.

Then the -1 (and -2) modes related to the fundamental

mode will be suppressed by a FB system in the RF

control system.

(need bunch-by-bunch FB to suppress ARES HOM & 0/π mode instability)



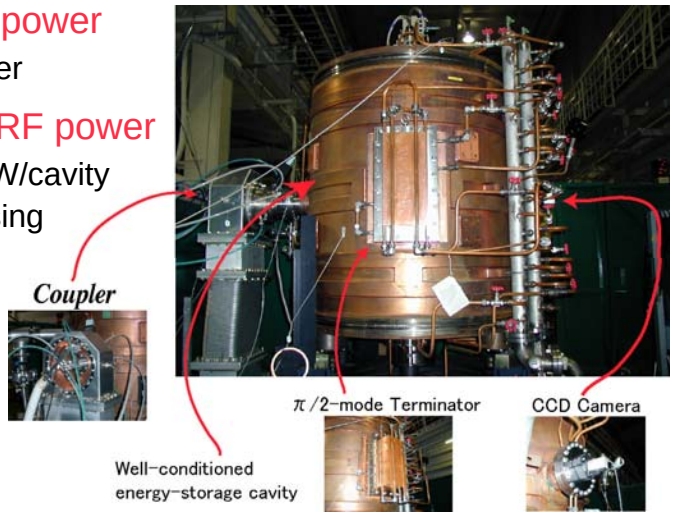
- For Higher HOM power

Upgrade of HOM damper

- For Higher input RF power

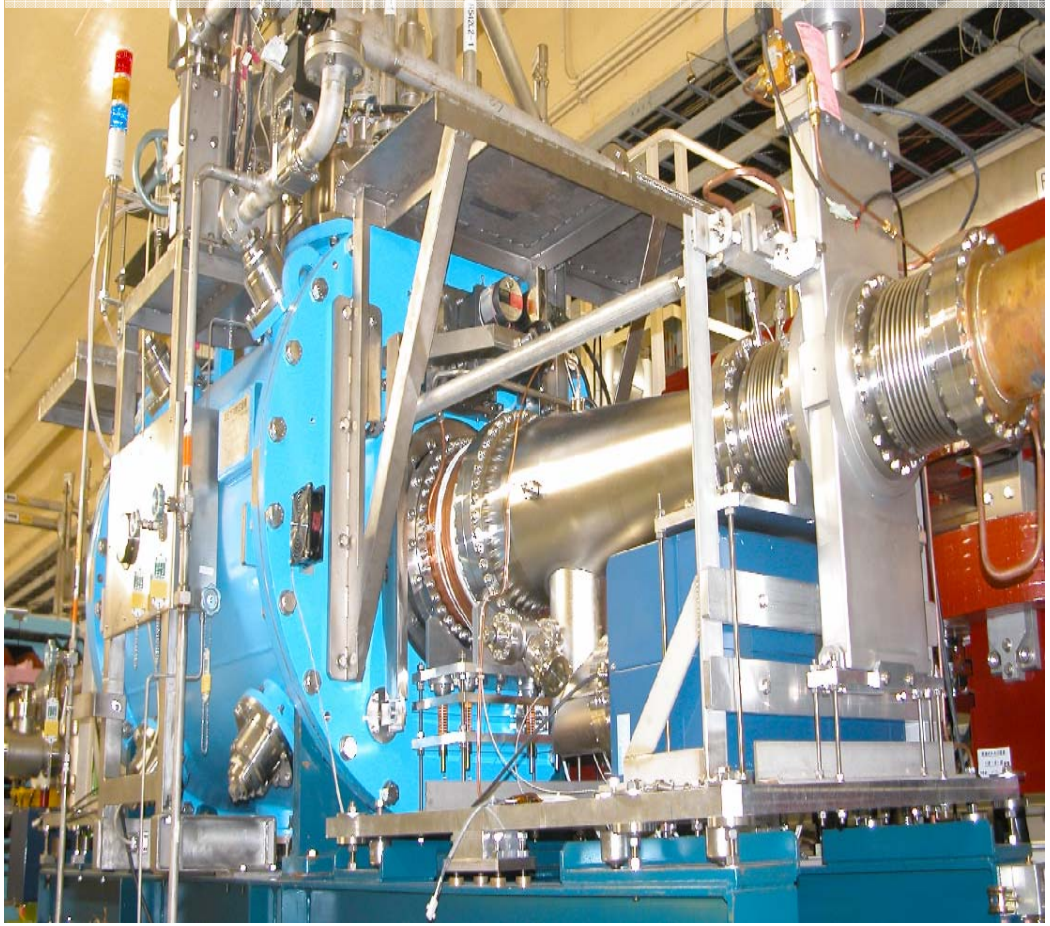
400 kW/cavity -> 800 kW/cavity

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



Superconducting Cavity

Storing world's highest beam current of 1.4A. Input coupler has been operated up to 380kW. Ferrite Higher Order Mode (HOM) absorber working at 10 kW (has achieved 12kW at 1.2 A).
SuperKEKB challenges: The expected power load to the HOM absorber becomes 50 kW/cavity at 4.1 A, (even) with a larger beam pipe of 220 mmφ. HOM damper upgrade may be needed.



Vacuum Components for High Current

- High luminosity requires high stored current in Super KEKB.

- The history of KEK was a history of fight against high current, which caused

Heating of components, by synchrotron light and higher order modes

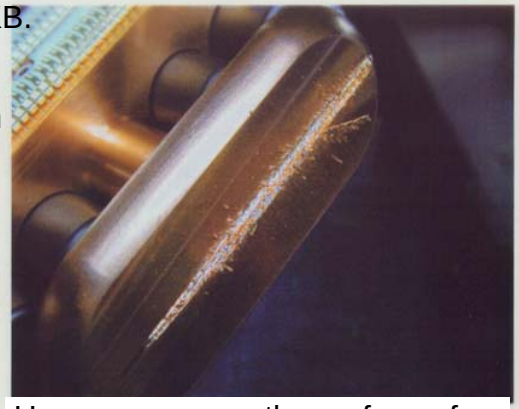
Discharge and melt down

Vacuum leak

Displacement due to thermal expansion

-Endless upgrades of components have been done on vacuum chambers/movable masks/bellows/pumps/abort windows, etc.

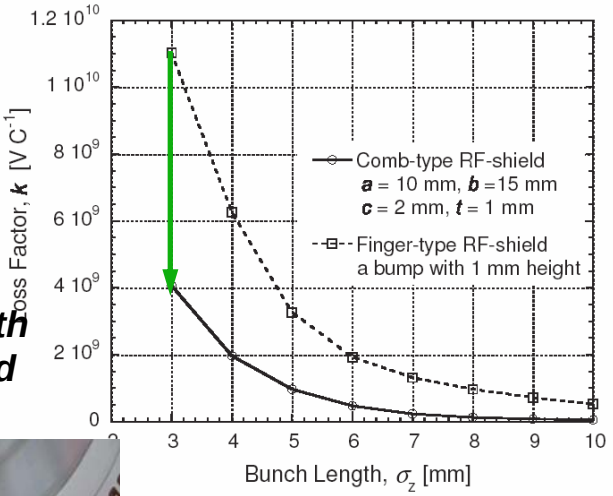
- Machine protection system with fast beam abort has been developed to reduce the possible damage.



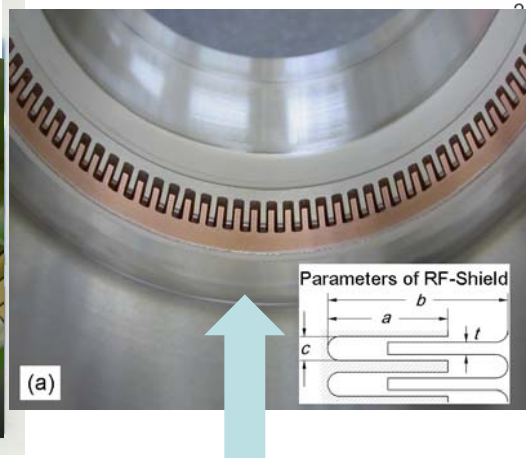
Heavy groove on the surface of a copper movable mask in HER.

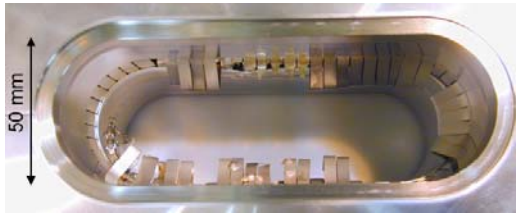
Thermal deformation of the fingers for rf shield of bellows.

Presented by Y.Suetsugu (MOOPMA05)



Bellows chamber with comb type RF-shield



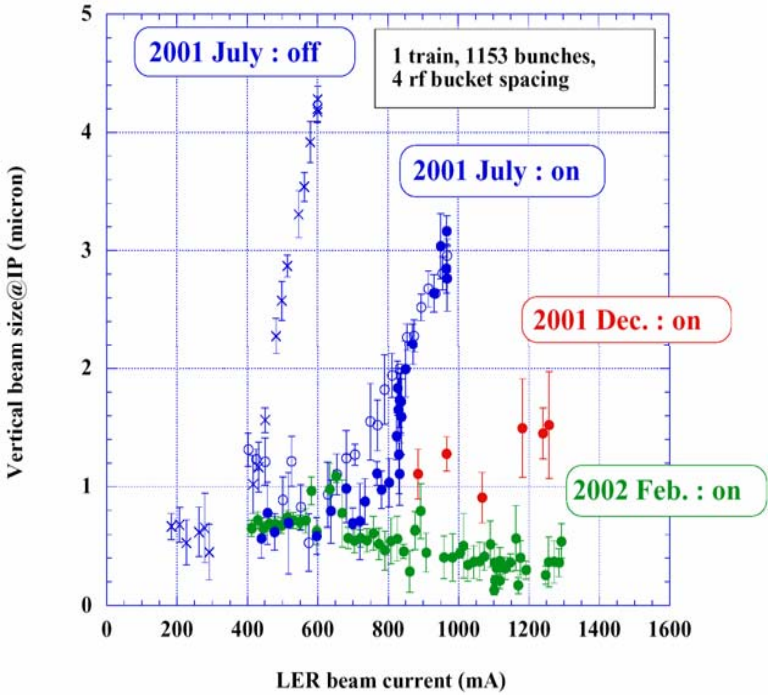


- High thermal strength
- Low impedance
- No sliding contact on the surface facing the beam

Comb-type bellows were installed in the LER.

Electron Cloud

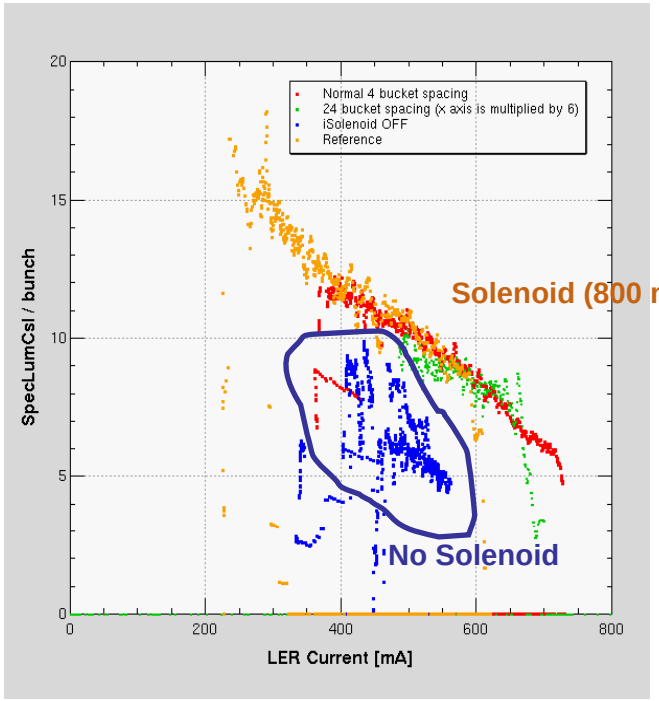
For KEKB: Solenoids are so effective to reduce electron cloud.



Vertical beam size @ IP vs. LER current

Blow-up of the vertical beam size in LER has been suppressed by solenoid windings.

The coverred length of solenoids reached 2,300 m raised the threshold to 1.8 A.



Presented by Fukuma (TUZH103)

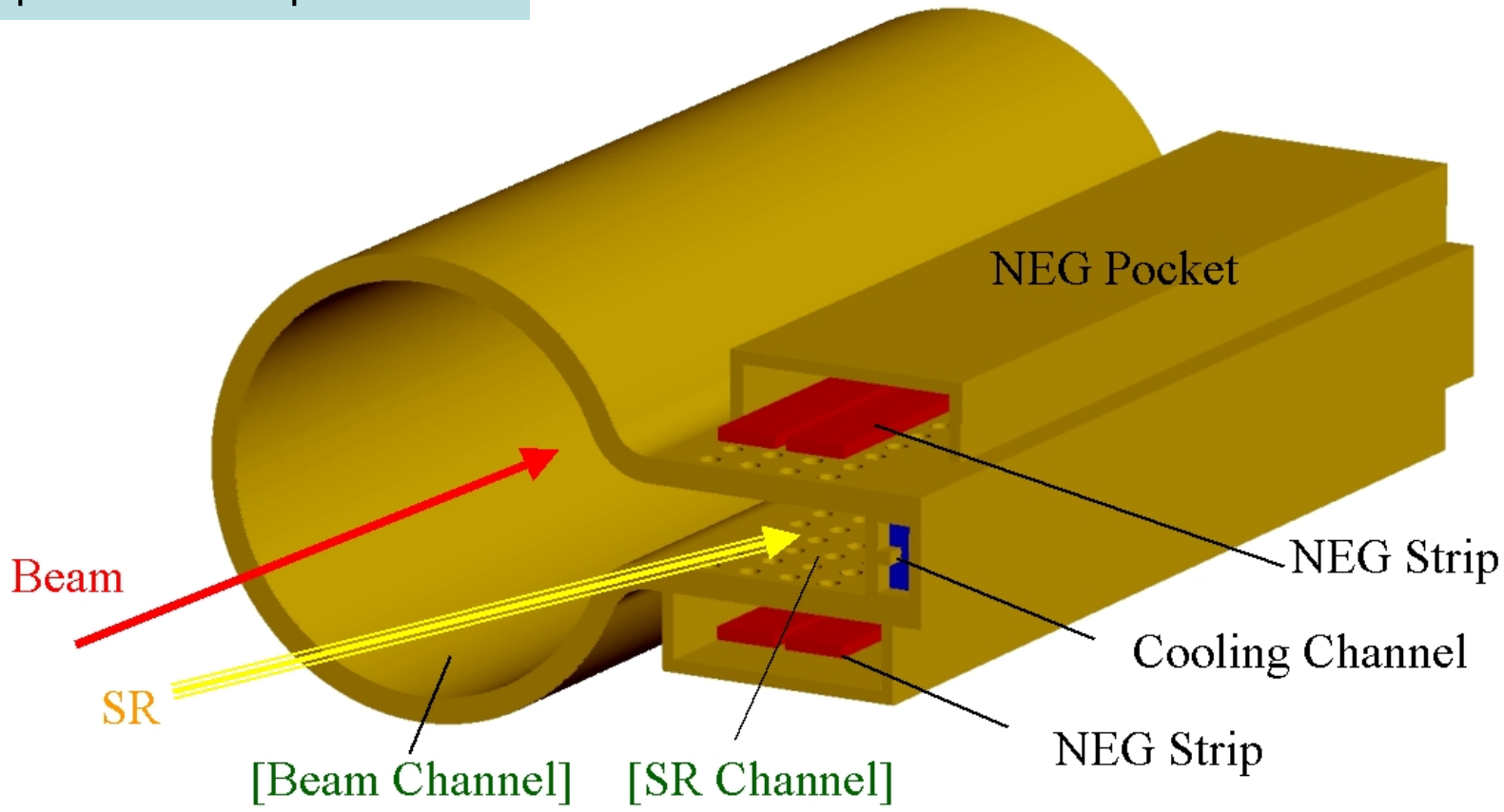
Specific luminosity vs. LER current.

Solenoids are just so effective.

For SuperKEKB: Much higher current, and bunch spacing should be reduced.

Ante Chamber

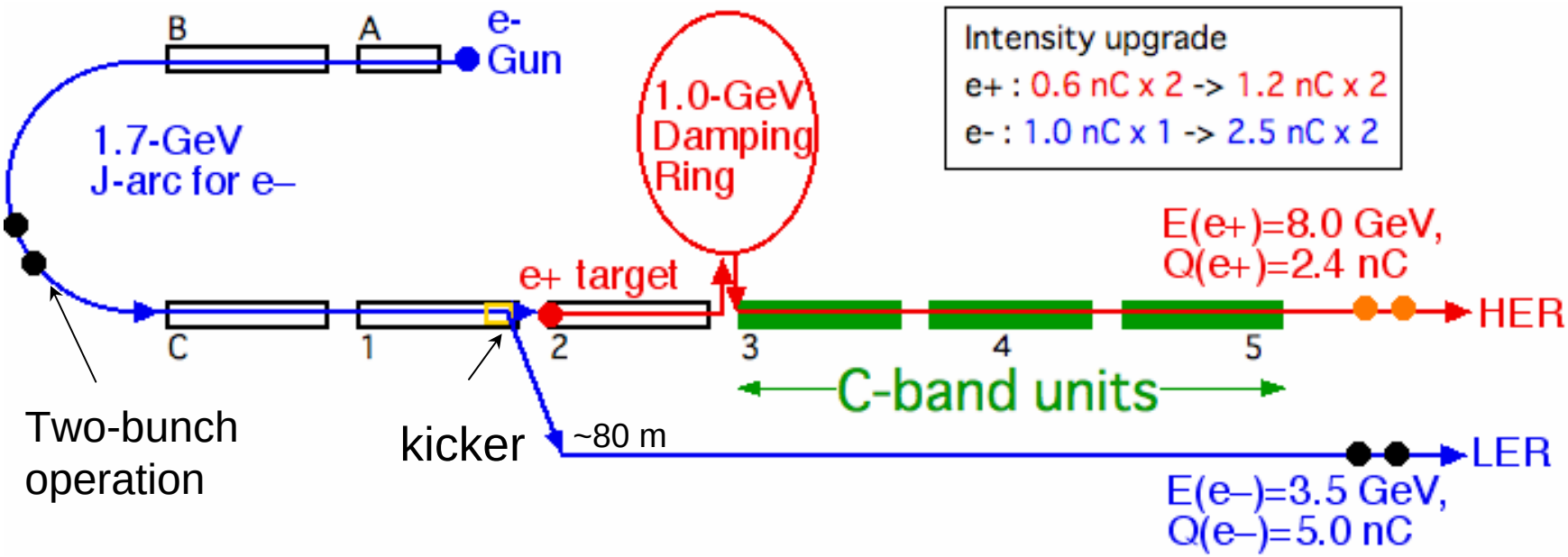
Smaller SR Power Density
Lower photoelectron production



Prototype ducts were installed in the LER

Energy Switch

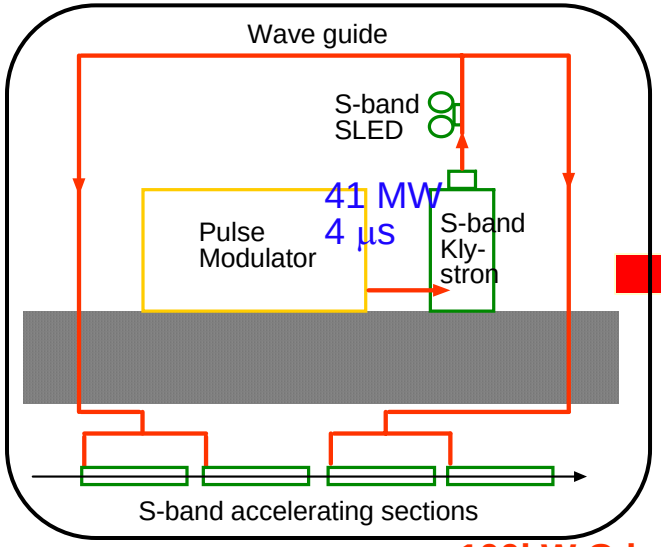
8 GeV e^- / 3.5 GeV e^+⇒8 GeVe^+ / 3.5 GeVe^-



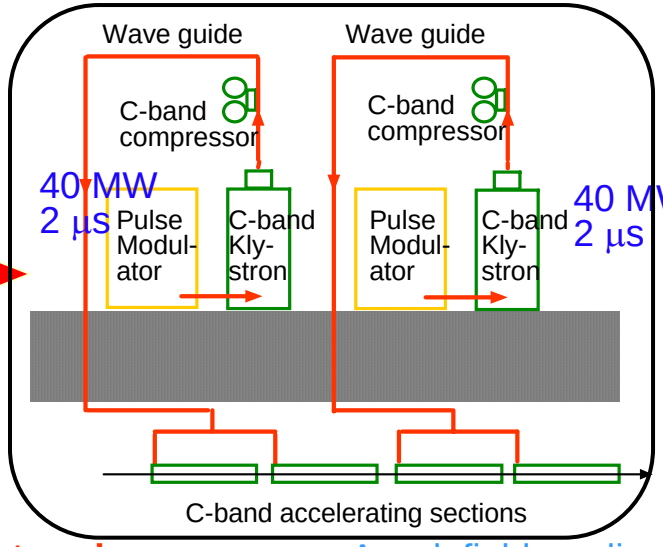
- S-band (2856 MHz) ⇒C-band(5712 MHz)
- Higher stored energy density in the acceleration structure
  ⇒ higher acceleration field

C-band Acceleration Units

Present S-band accelerator module



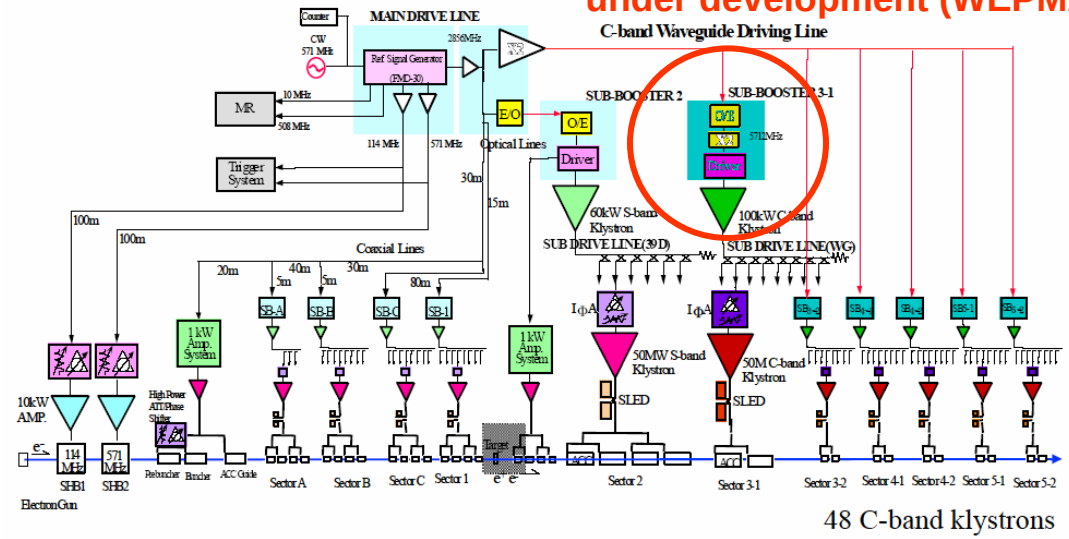
New C-band accelerator module

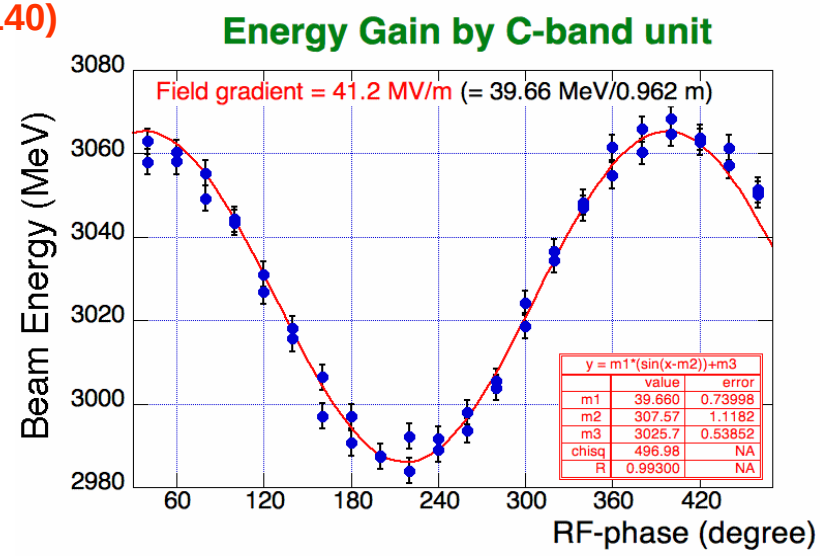


Accel. field gradient = 21 MV/m

100kW C-band multi beam klystron is under development (WEPMA140)

Accel. field gradient = 42 MV/m





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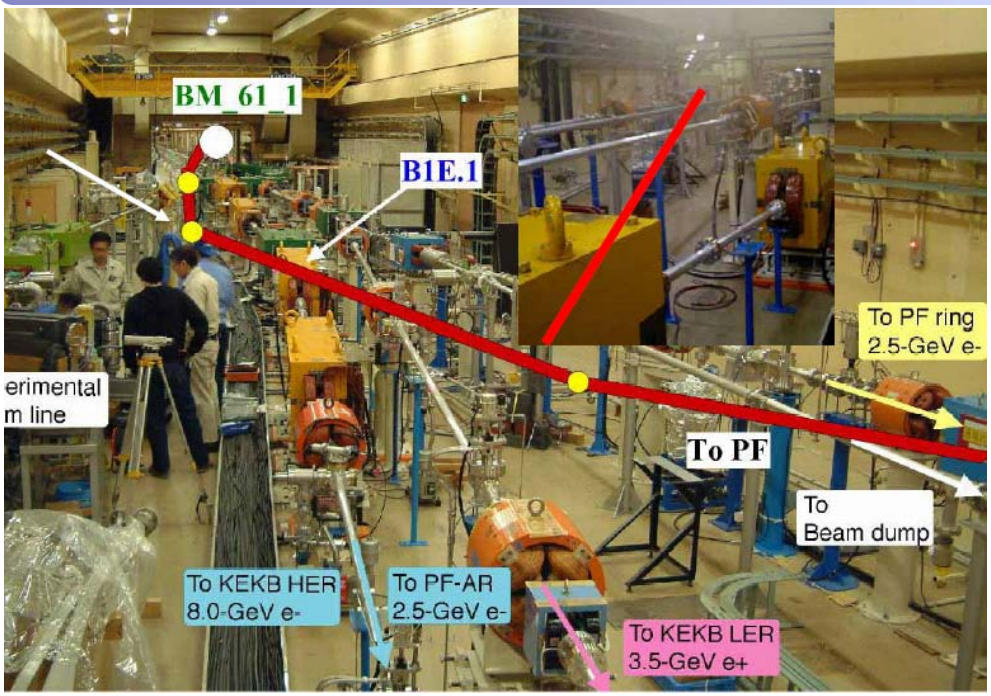
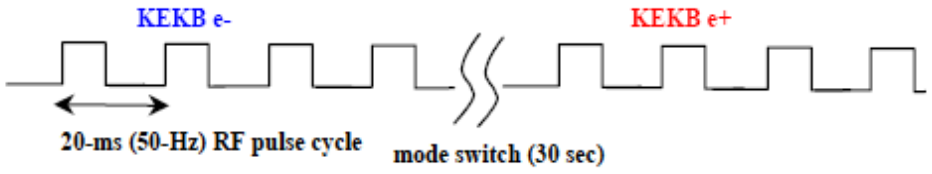
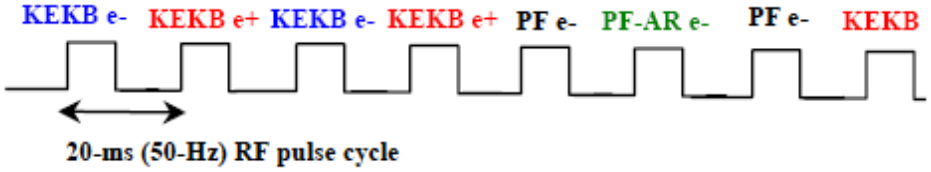
Fast Beam Mode Switch



(A) Present Continuous injection mode



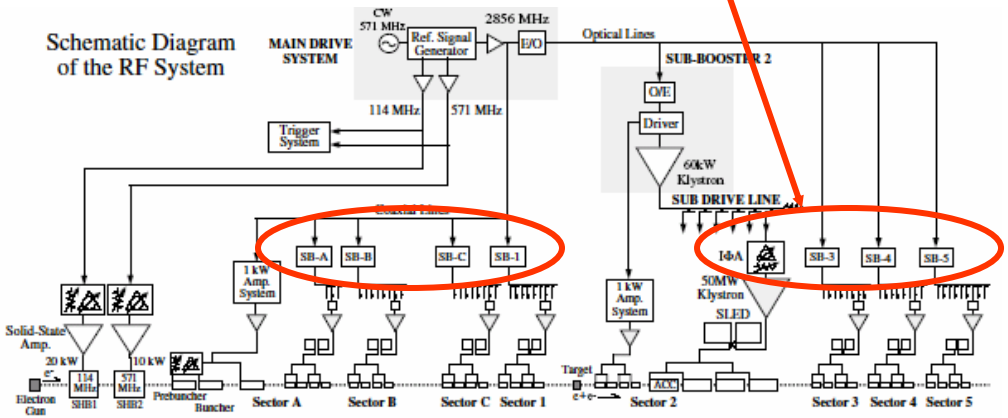
(B) High-speed beam mode switch



Phase-I (2005):
- **New PF-BT line bypassed energy compression system for e+**

Phase-II (2006):
- **Multi-energy optics**
- **Fast phase switch for SB Klystron**

Phase-III (2007):
- **Bypass line or e+ target with hole**
- **Pulse bend**



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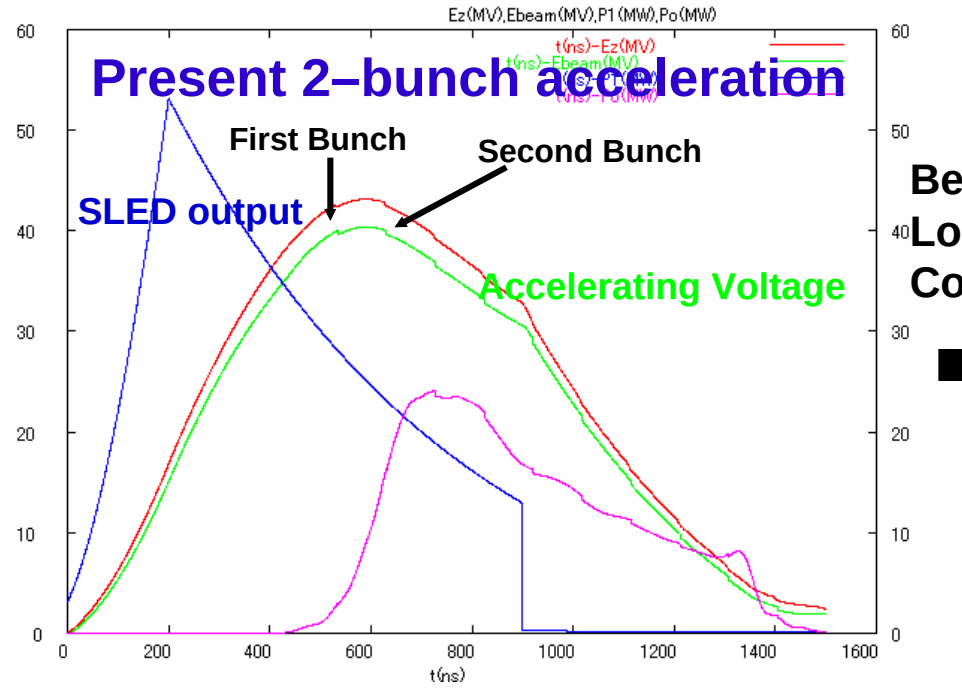
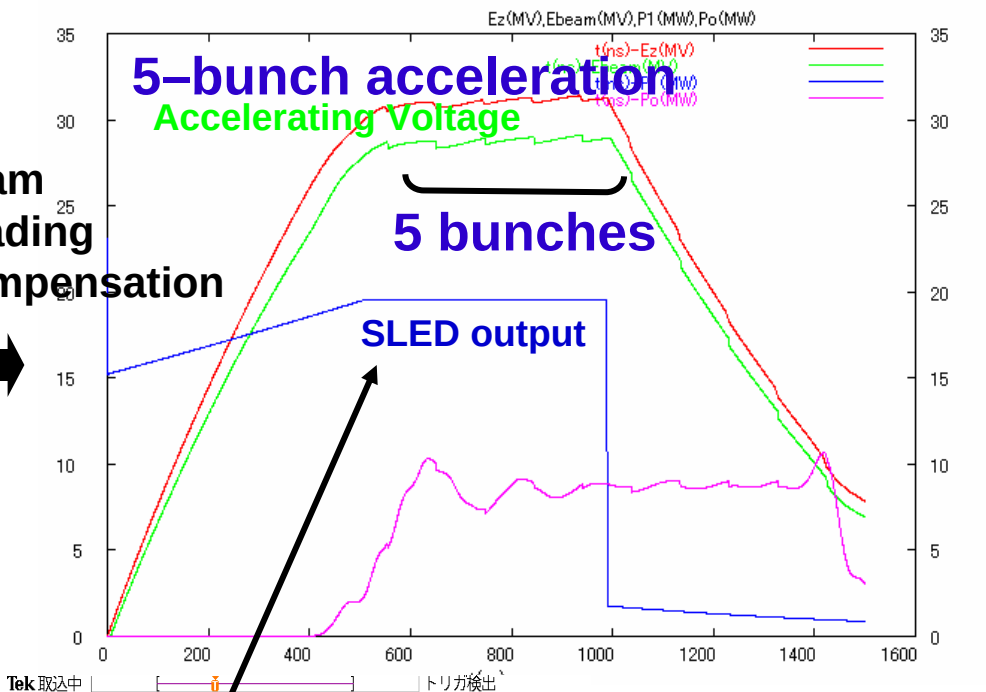
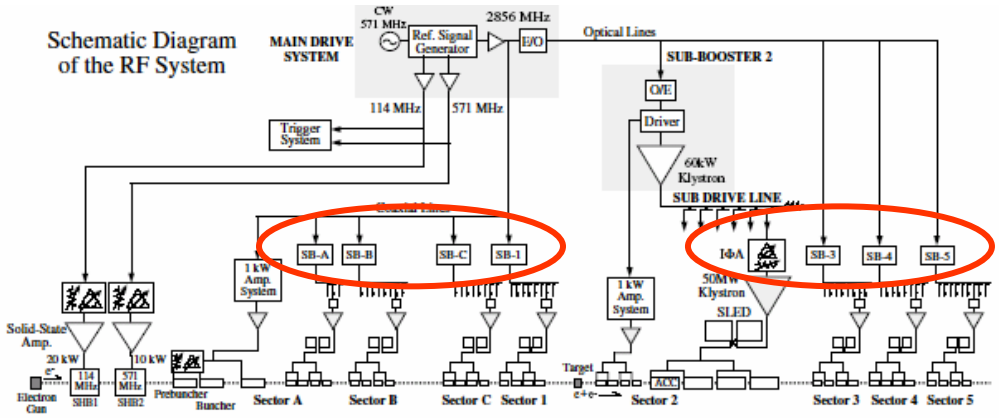
Multi-Bunch Acceleration

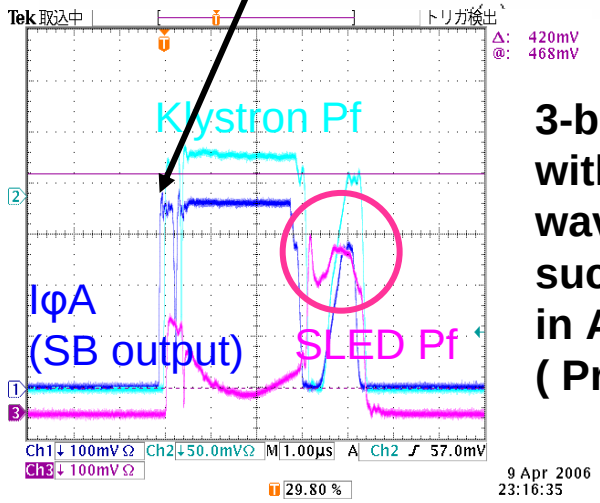


Beam Loading Compensation





IQ circuit using FPGA will be installed



3-bunch acceleration with 5-bunch ready waveform was successfully tested in April 2006. (Presented@LINAC06)

Another Idea for Super B

Long bunch approach was proposed by P.Raimondi et al, for L = 1 x 10^{36} using ILC damping ring concept.

Short Bunch

$$L \sim \frac{N^2}{\sqrt{\varepsilon_x \beta_x \varepsilon_y \beta_y}}$$

$$\xi_x \sim \frac{N}{\varepsilon_x}$$

$$\xi_y \sim N \sqrt{\frac{\beta_y}{\varepsilon_x \beta_x \varepsilon_y}}$$

$$\beta_y > \sigma_z$$

$$\times \frac{\sqrt{\varepsilon_x \beta_x}}{\theta \sigma_z} \quad (<1)$$

Overlap factor

Long Bunch

$$L \sim \frac{N^2}{\theta \sigma_z \sqrt{\varepsilon_y \beta_y}}$$

$$\xi_x \sim \frac{N}{\theta \sigma_z} \sqrt{\frac{\beta_x}{\varepsilon_x}}$$

$$\xi_y \sim \frac{N}{\theta \sigma_z} \sqrt{\frac{\beta_y}{\varepsilon_y}}$$

$$\beta_y > \frac{\sqrt{\varepsilon_x \beta_x}}{\theta}$$

Crab waist or traveling focus makes less emittance blow up.

Bunch length must be less than βy.
Operating point closed to half integer.

Small beta and emittance are required

Adopting this idea to KEKB is under consideration.

Summary

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- **Peak luminosity is increasing even after the design luminosity (10/nb/s) was obtained up to May 2005. The present peak luminosity is 17.12/nb/s.**
- **Present integrated luminosity is 710/fb.**
- **Crab cavities were installed and machine study will begin soon.**
- **SuperKEKB project is proposed. Designed peak luminosity is 400/nb/s.**