Nano-Beam Scheme for SuperKEKB

15th KEKB Accelerator Review
Feb. 15, 2010

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14^{th} KEKB Accelerator Review Committee

- In order to significantly increase the luminosity of KEKB, there are two possible approaches: increase the current (more intense beams), or decrease the emittance (brighter beams). ….. It is recommended that the KEKB team evaluate the low emittance option to see whether it would provide a suitable basis for SuperKEKB.

- A great deal of component R&D has been carried out over the last few years and great strides have been made. Most of this R&D would be applicable to both design solutions, so this work should carry on.

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- However, it is suggested that the machine design work concentrate on the low emittance option for the next few months, with a focus on identifying any possible showstoppers. The design should be brought to a point where an informed decision between the two options can be made.

- We have started intensive design works on the Nano-Beam scheme, and have decided to select that scheme for SuperKEKB.

Issues on High-Current Scheme

- Although a new luminosity record has been achieved with skew sextupole magnets, the vertical beam-beam parameter still remains ~0.09 at crab crossing after two years of intensive tuning.

- The bunch length $\sigma_z^* = 3$mm is difficult in LER due to CSR. The minimum bunch length has been estimated as 5 mm. (K. Oide, 14th KEKB ARC)

- Realistic IR design for $\beta_x^* = 20$ and $\xi y = \sim 0.3$ has not yet been found.

- The construction and operation costs should be decreased.

HOW much is the IMPACT ON the LUMINOSITY?

ν_x	β_x^* (cm)	$\sigma_{z,\mathrm{LER}}$ (mm)	$\mathcal{L}$ (10^{35})	
0.503	20	3	8	Original
0.505	40	3	5	+ Possible IR design
0.505	40	5	3	+ CSR
0.505	40	5	4	+ Travel Focus
0.503	20	5	5.5	+ Recovery of the IR design

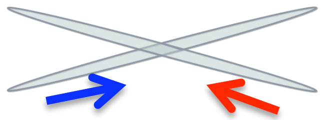
* All luminosities assume that Crab Crossing works perfectly.

No technical solution has been found yet.

K. Oide, 21 May 2009 @ HEPAP

Nano-beam Scheme

- The scheme proposed by P. Raimondi and SuperB Group.

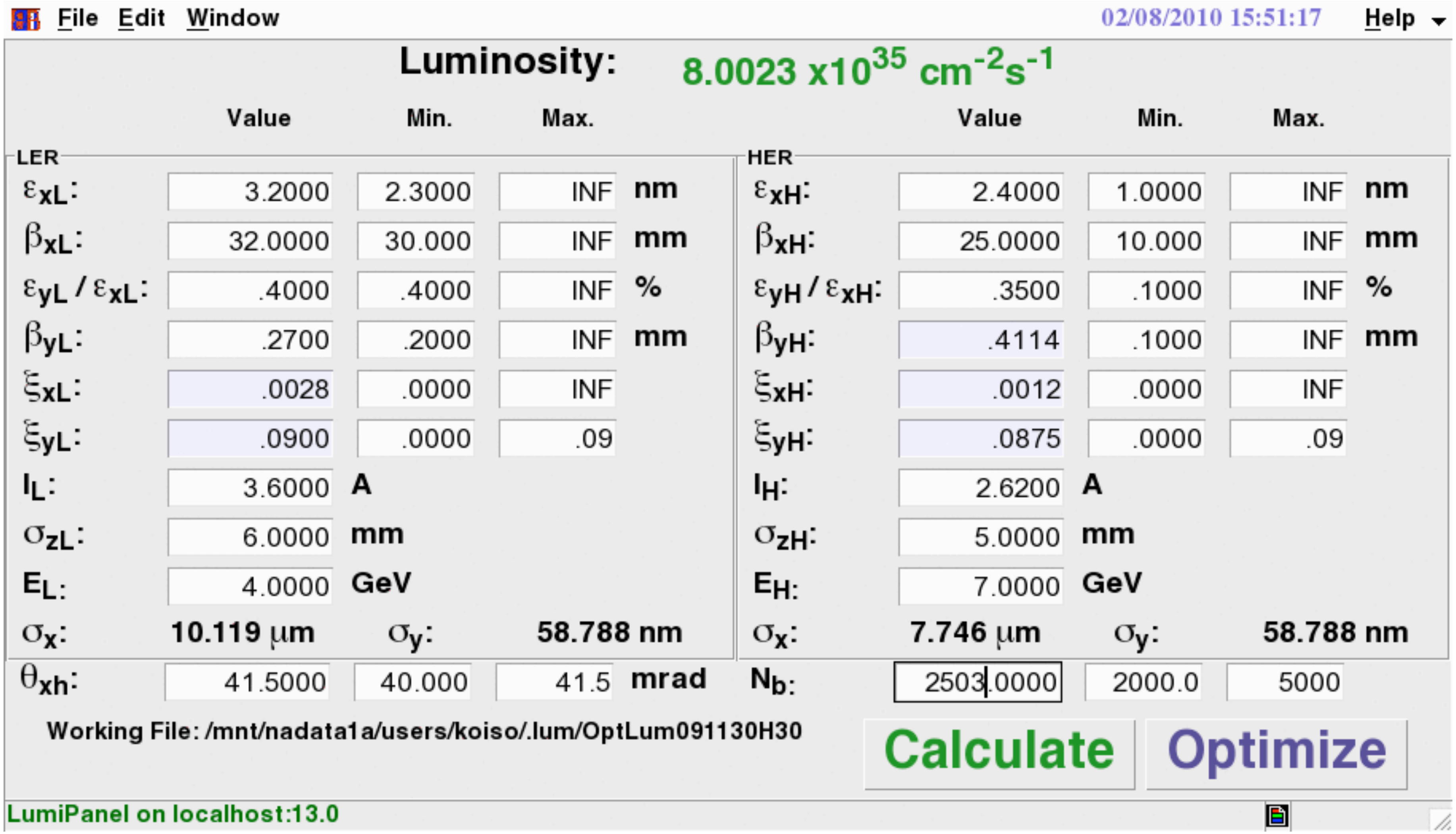


- Squeeze β_y^* as small as possible: 0.27/0.41 mm.

- Assume beam-beam parameter = 0.09 which has been already achieved at KEKB.

- Change beam energies 3.5 / 8 -> 4 /7 GeV to achieve longer Touschek lifetime and mitigate the effect of intra-beam scattering in LER.

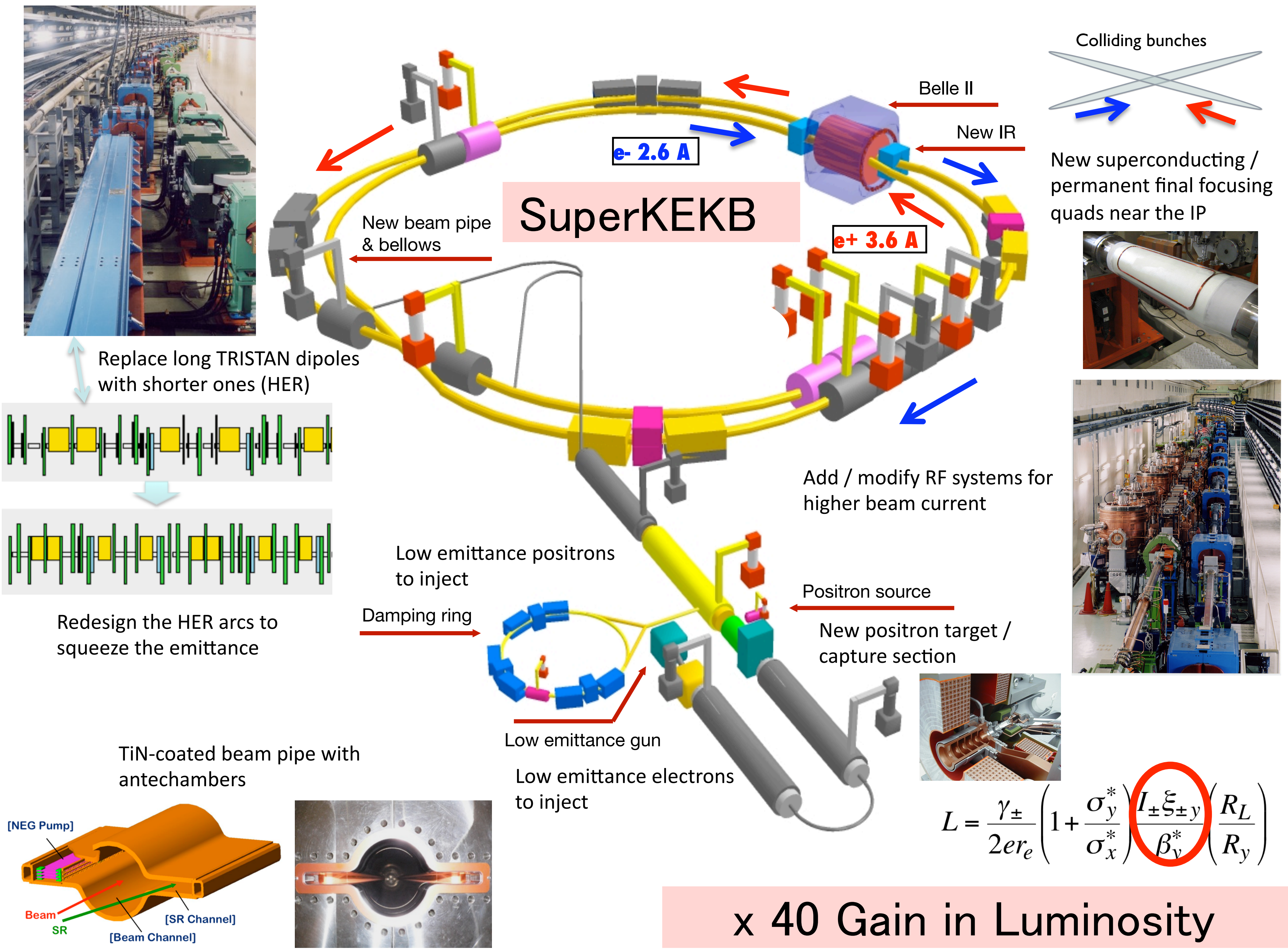
Parameter Optimization



Main parameters can be quickly optimized with this panel.

Beam Parameters

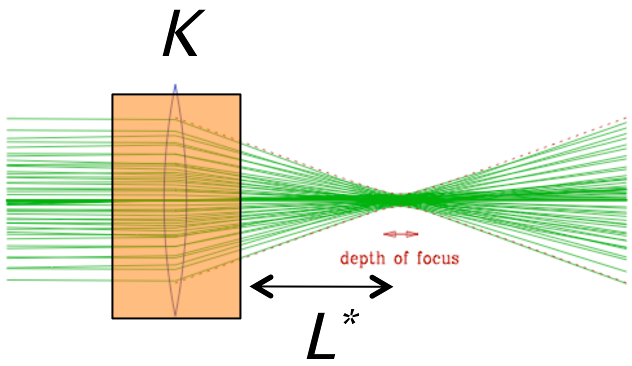
	KEKB Design	KEKB Achieved : with crab	SuperKEKB High-Current	SuperKEKB Nano-Beam
Energy (GeV) (LER/HER)	3.5/8.0	3.5/8.0	3.5/8.0	4.0/7.0
β_y^* (mm)	10/10	5.9/5.9	3/6	0.27/0.42
ε_x (nm)	18/18	18/24	24/18	3.2/2.4
σ_y(μm)	1.9	0.94	0.85/0.73	0.059
ξ_y	0.052	0.129/0.090	0.3/0.51	0.09/0.09
σ_z (mm)	4	~ 6	5/3	6/5
I_{beam} (A)	2.6/1.1	1.64/1.19	9.4/4.1	3.6/2.6
$N_{bunches}$	5000	1584	5000	2503
Luminosity (10^{34} cm^{-2} s^{-1})	1	2.11	53	80



SuperKEKB
Colliding bunches
Belle II
New IR
e- 2.6 A
e+ 3.6 A
New superconducting / permanent final focusing quads near the IP
New beam pipe & bellows
Replace long TRISTAN dipoles with shorter ones (HER)
Redesign the HER arcs to squeeze the emittance
Add / modify RF systems for higher beam current
Low emittance positrons to inject
Damping ring
Positron source
New positron target / capture section
Low emittance gun
Low emittance electrons to inject
TiN-coated beam pipe with antechambers
[NEG Pump]
Beam
SR
[SR Channel]
[Beam Channel]
$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$
x 40 Gain in Luminosity

Nonlinear Terms around IP

$$J_{y0} = \frac{\beta_y^{*2}}{\left(1 - \frac{2}{3} K L^{*2}\right) L^*} A(\mu_y)$$



Phys. Rev. E47, 2010 (1993)

LER		**KEKB L**	**KEKB R**	**SuperKEKB L**	**SuperKEKB R**
β_y^*	(mm)	5.9		0.27	
K	(1/m²)	-1.777	-1.778	-4.425	-6.003
L^*	(m)	1.332	1.762	0.7269	0.7680
J_{y0} / A	(μm)	8.425	4.221	0.03919	0.02825

Summary

- We have made great progress in the Nano-beam scheme:
  - Lattice: solutions exist, preserving the present tunnel. Optimization of dynamic aperture is going on.
  - IR: large crossing angle, independent quadrupoles for both beams.
  - Electron cloud mitigation has been studied at KEKB.
  - RF system will be added and modified to store beam currents twice as those of present KEKB.
  - Design of e+ damping ring has been done.
  - Low-emittance electron gun will be installed in linac.

- So far we have not found showstoppers. We still have issues to be solved, but have been making steady progress in all of them.

Backup

Machine Parameters of SuperKEKB

2010/Feb/08

(): zero current parameters		LER	HER	
Emittance	ε_x	3.2(2.7)	2.4(2.3)	nm
Coupling	$\varepsilon_y/\varepsilon_x$	0.40	0.35	%
Beta Function at IP	β_x^* / β_y^*	32 / 0.27	25 / 0.41	mm
Horizontal Beam Size	σ_x^*	10.2(10.1)	7.75(7.58)	μm
Vertical Beam Size	σ_y^*	59	59	nm
Bunch Length	σ_z	6.0(4.9)	5.0(4.9)	mm
Half Crossing Angle	ϕ	41.5		mrad
Beam Energy	E	4	7	GeV
Beam Current	I	3.60	2.62	A
Number of Bunches	n_b	2503		
Energy Loss / turn	U_0	2.15	2.50	MeV
Total Cavity Voltage	V_c	8.4	6.7	MV
Energy Spread	σ_δ	8.14(7.96)x10^{-4}	6.49(6.34) x10^{-4}	
Synchrotron Tune	ν_s	-0.0213	-0.0117	
Momentum Compaction	α_p	2.74x10^{-4}	1.88x10^{-4}	
Beam-Beam Parameter	ξ_y	0.0900	0.0875	
Luminosity	L	8x10^{35}		$cm^{-2}s^{-1}$