Parameters of SuperKEKB

Luminosity of 10^{35} cm^{-2} s^{-1}

Luminosity of SuperKEKB

- **Luminosity formula:**

$$L = \frac{N_e N_{\bar{e}} f}{4\pi\sigma_x^* \sigma_y^*} R_L$$

- **Beam-beam tune shift parameters:**

$$\xi_{x,ye} = \frac{r_e}{2\pi\gamma_e} \frac{N_{\bar{e}} \beta_{x,ye}^*}{\sigma_{x,y}^* \left(\sigma_x^* + \sigma_y^*\right)} R_{\xi_{x,y}}$$

- **Assumed that "energy transparency" conditions:**

$$\gamma_e I_e = \gamma_{\bar{e}} I_{\bar{e}}\,, \quad \varepsilon_e = \varepsilon_{\bar{e}}\,, \quad \text{etc.}$$

- **Alternative expression for luminosity:**

$$L = \frac{\gamma_e}{2er_e}(1+r)\left(\frac{I_e \xi_y}{\beta_y^*}\right)\frac{R_L}{R_{\xi_y}} \qquad r = \frac{\beta_y^*}{\beta_x^*} = \frac{\varepsilon_y}{\varepsilon_x} = \frac{\sigma_y^*}{\sigma_x^*}$$

"Optimal coupling"

Luminosity of SuperKEKB (cont'd)

- **Design of SuperKEKB is based on:**

$$L = \frac{\gamma_e}{2er_e}(1+r)\left(\frac{I_e\xi_y}{\beta_y^*}\right)\frac{R_L}{R_{\xi_y}} \qquad r = \frac{\beta_y^*}{\beta_x^*} = \frac{\varepsilon_y}{\varepsilon_x} = \frac{\sigma_y^*}{\sigma_x^*}$$

- **Beam-beam tune shift: ξ_y = 0.05**
  - Expectation from our experience (0.04-0.07 @ KEKB)

- **Vertical beta at I.P: β_y* = 3 mm**
  - Bunch length: σ_z = 3 mm to reduce hour-glass effect as possible.

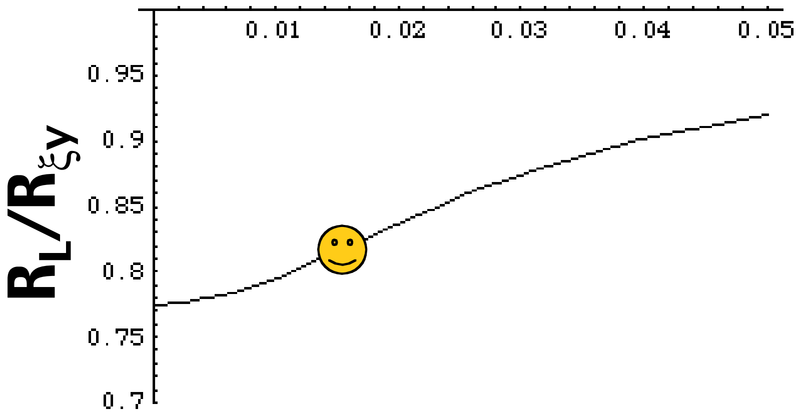
  Constraint of coherent synchrotron radiation

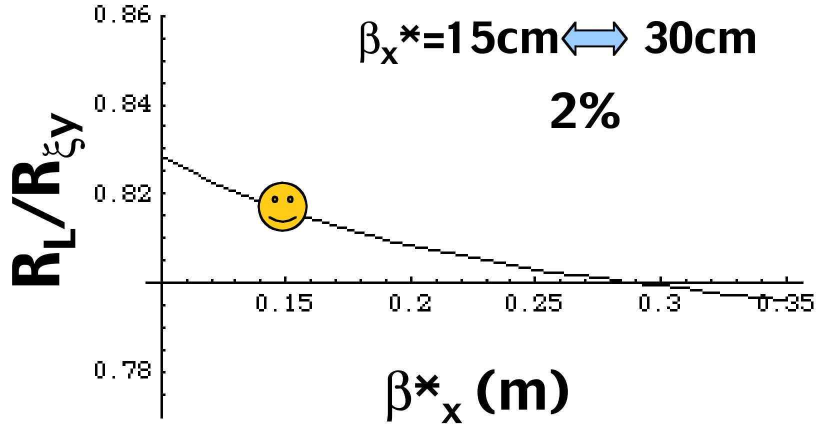
Luminosity reductions

- R_L : Luminosity reduction due to geometrical
- R_ξ : Tune shift reduction
- $R_L/R_{\xi y}$ is a function of crossing angle, beta, emittance, bunch length.
- **Half crossing angle: θ_x = 15 mrad**
- **Horizontal beta at I.P: β_x* = 15 cm**
- **Emittance : 33 nm (6.4 % coupling)**

$R_L/R_{\xi y}$ = 0.82

Half crossing angle (rad)





Beam current

- We choose flat-beam at present.
  - Round beam ? → luminosity gain of factor 2.
  - Lattice design is very difficult.
  - Is it possible to squeeze beta with keeping higher beam-beam tune shift ?
- To achieve 10^{35} $cm^{-2}s^{-1}$:

  9.4 A (LER) x 4.1 A (HER) Huge !

- Idea of 10^{35} $cm^{-2}s^{-1}$ is higher beam current and smaller β at I.P.

List of parameters

Machine Parameters of the SuperKEKB

	LER	HER	
Horizontal Emittance	33	33	nm
Vertical Emittance	2.1	2.1	nm
x-y coupling	6.4	6.4	%
Beam current	9.4	4.1	A
Number of bunches	5018 (2% abort gap)		
Bunch current	1.87	0.817	mA
Bunch spacing	0.6		m
Half crossing angle	15		mrad
Luminosity reduction R_L	0.748		
ξ_x reduction $R_{\xi x}$	0.691		
ξ_y reduction $R_{\xi y}$	0.916		
Bunch length	3	3	mm
Radiation loss U_0	1.23	3.48	MeV/turn
Betatron tune ν_x / ν_y	45.515/43.57 ?	44.515/41.57 ?	
beta's at IP β_x^* / β_y^*	15/0.3	15/0.3	cm
beam-beam parameters ξ_x / ξ_y	0.068/0.05	0.068/0.05	
Beam lifetime	~150	~150	min.
Luminosity	1.0		10^{35}/cm^2/sec

← 1.1 / 0.67 mA@KEKB (Bunch current)

Coherent Synchrotron Radiation

- **Power of coherent synchrotron radiation**

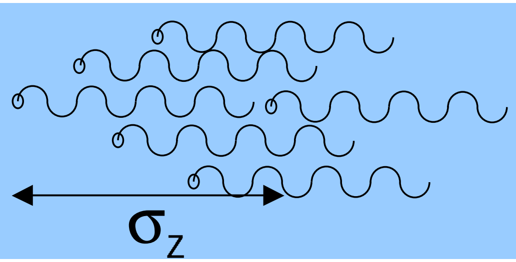
(Kheifets,Zotter)

$$P_{coherent} \approx \frac{\pi N^2 r_e m_e c^2 f_0}{\rho}\left(\frac{\rho}{\sigma_z}\right)^{\frac{4}{3}}\Gamma\left(2/3, x_{th}\right)$$

$$x_{th} = \frac{2}{3}\left(\frac{\pi\rho}{h}\right)^3\left(\frac{\sigma_z}{\rho}\right)^2$$

Particles: Gaussian distribution

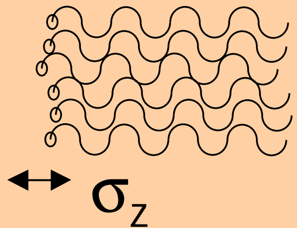
N: particles/bunch
ρ: bending radius
h: height of chamber



- **incoherent**

$E \propto \sqrt{N}$ $\quad P \propto N$

"Statistical fluctuation"



- **coherent**

$E \propto N$ $\quad P \propto N^2$

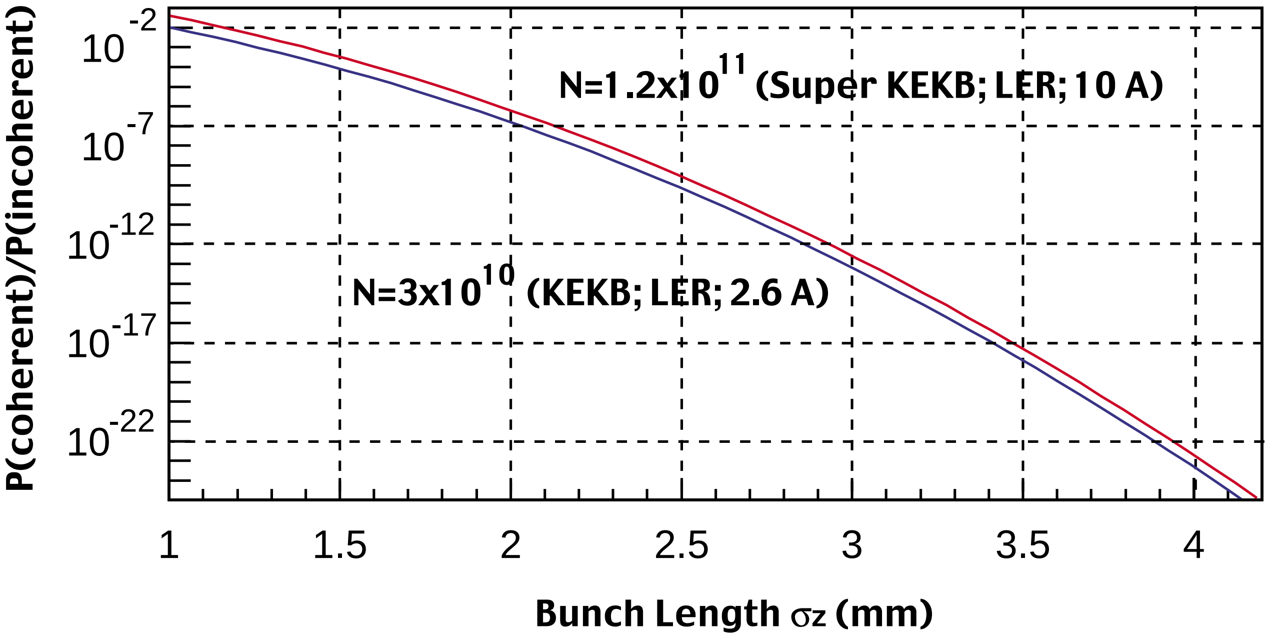
coherent condition

$\sigma_z \leqq \lambda/2\pi$

Coherent Synchrotron Radiation (cont'd)

- **The ratio of coherent power to incoherent:**

$$\frac{P_{coherent}}{P_{incoherent}} = \frac{3N}{4\gamma^4}\left(\frac{\rho}{\sigma_z}\right)^{\frac{4}{3}}\Gamma(2/3, x_{th}) \qquad \left(P_{incoherent} = \frac{4\pi N r_e m_e c^2 f_0 \gamma^4}{3\rho}\right)$$



LER: 3.5 GeV
Bending radius:
ρ = 16.3 m
Chamber height:
h=47mm

2 mm is OK but 1 mm is ?

Coherent radiation can be ignore for 3 mm bunch length.

Lifetime

- Luminosity lifetime
  - dN/dt = $-\sigma L$
  - Cross section of radiative Bhabha: 2.14×10^{-25} cm^2
  - Loss rate : 0.34 mA/s
  - LER/HER : 460/200 min
- Vacuum lifetime
  - ~10 hours (?)
- Touschek lifetime
  - LER/HER : 330/1650 min
- Overall lifetime of LER/HER : > ~150 min
  - Loss rate : 1 mA/s (LER)/ 0.46 mA/s (HER)
- Continuous & Simultaneous injection
  - 5Hz (LER) / 10 Hz (HER) (70% injection efficiency)

Energy exchange (HER:e^+/LER:e^-)

- **Advantage :**
  - Effect of photoelectron cloud can be reduced.
  - Injection time to full current can be reduced.
    - Intensity of injector: $e^- > e^+$
- **Unknown :**
  - Multipactering is no problem for e^+ in HER ?
    - Height of vacuum chamber is smaller than LER.
  - Is fast ion instability safe for e^- in LER ?
- **Major upgrade of injector is needed.**
  - Energy upgrade : C-band or re-circulation scheme
  - Good opportunity for changing linac frequency to: f_{linac}/f_{ring} = integer if C-band is chosen.

Summary

- Machine parameters of SuperKEKB
  - Beam current: 9.4 A (LER) / 4.1 A (HER)
  - Beta at I.P: 15 cm (β_x*) / 3 mm (β_y*)
  - Bunch length: 3 mm
  - Half crossing angle: 15 mrad
- RF system
  - Number of RF units becomes twice of KEKB.
- Vacuum system
  - Ante-chamber, masks, bellows
- Injector will be widely modified to exchange energy and improve beam intensity.

Summary (cont'd)

No brilliant idea
BUT
Integration of many small new idea

HOM dampers in RF,
Photon stops and ante-chambers,
Injection schemes,
Final focusing schemes, …

Cost estimation

• Vacuum	12.2
• RF	9.5
• Facility	5.0
• IR	1.1
• Feedback & monitor	0.9
• Injector	5.0
• SuperBelle	3.5
• Injector for PF,AR	5.0
• Total	42.2 Billion yen