Consideration of Energy asymmetry of Super KEKB

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Introduction

- The Super KEKB is an ultimate e^+e^- collider, we need to collaborate with the accelerator group in order to achieve the luminosity goal.
- The energy asymmetry of 3.5 GeV x 8 GeV has not be reviewed for 15 years.
  - H. Ozaki (KEK) discussed on this issue in KEKB factory feasibility study in 1990.
- Why not review the energy asymmetry issues while the accelerator design is not finalized.
  - Similar discussion is done in the 4th Workshop on Super B-Factory at Villa Mondragone, 13 - 15 Nov. 2006.
    - https://indico.pi.infn.it/conferenceDisplay.py?confId=1

Synchrotron radiation

- The accelerator consumes huge AC power.
  In the Super B factory, significant power is due to the synchrotron radiation (SR), which is proportional to $E^4 \cdot I$
  - What happens if the LER/HER energy asymmetry is reduced.
- LER
  - The power loss due to SR in the ring is small. However, the damping time (Period necessary to forget the effect of previous collisions. It is better damping time in LER and HER is equal.) is too long. Wiggler magnets are inserted so the SR is artificially increased.
  - At higher LER energy, the number of wiggler magnets can be reduced.
- HER
  - The SR power loss in the ring decreases, causing larger damping time. KEKB people like to increase the number of wigglers, although, there are no space left.
- In total, the RF power is reduced at smaller energy asymmetry.

Physics performance and Energy asymmetry

- ICPV related channels.
  - The measurement of B vertex position is essential.
  - Smaller asymmetry directly affect the physics performance.

- For other modes, there might be benefits from the lower asymmetry.
  - Detector acceptance and particle identification is estimated in this talk.

ICPV mode (I)

- A feasibility study of the KEK B factory, July 1990.
- Assumption:
  - R=15 mm, t=0.5 mm Beryllium chamber.
  - Inner most layer is a DSSD at R=17 mm.
    - It is amazing this is same as SVD2, installed in 2003.
- Δz resolution as function of LER energy.
- 20-30 % worse Δz resolution.

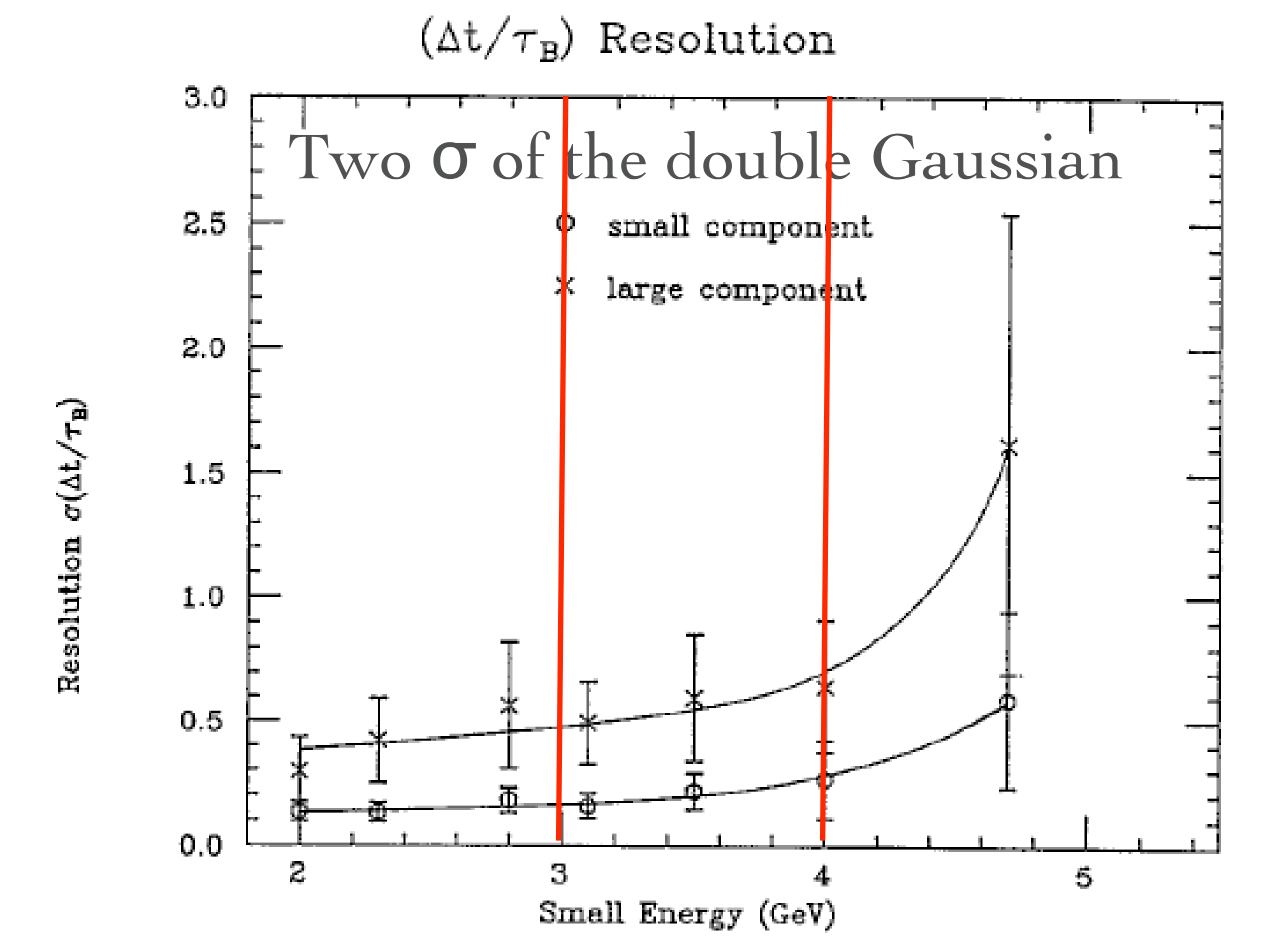


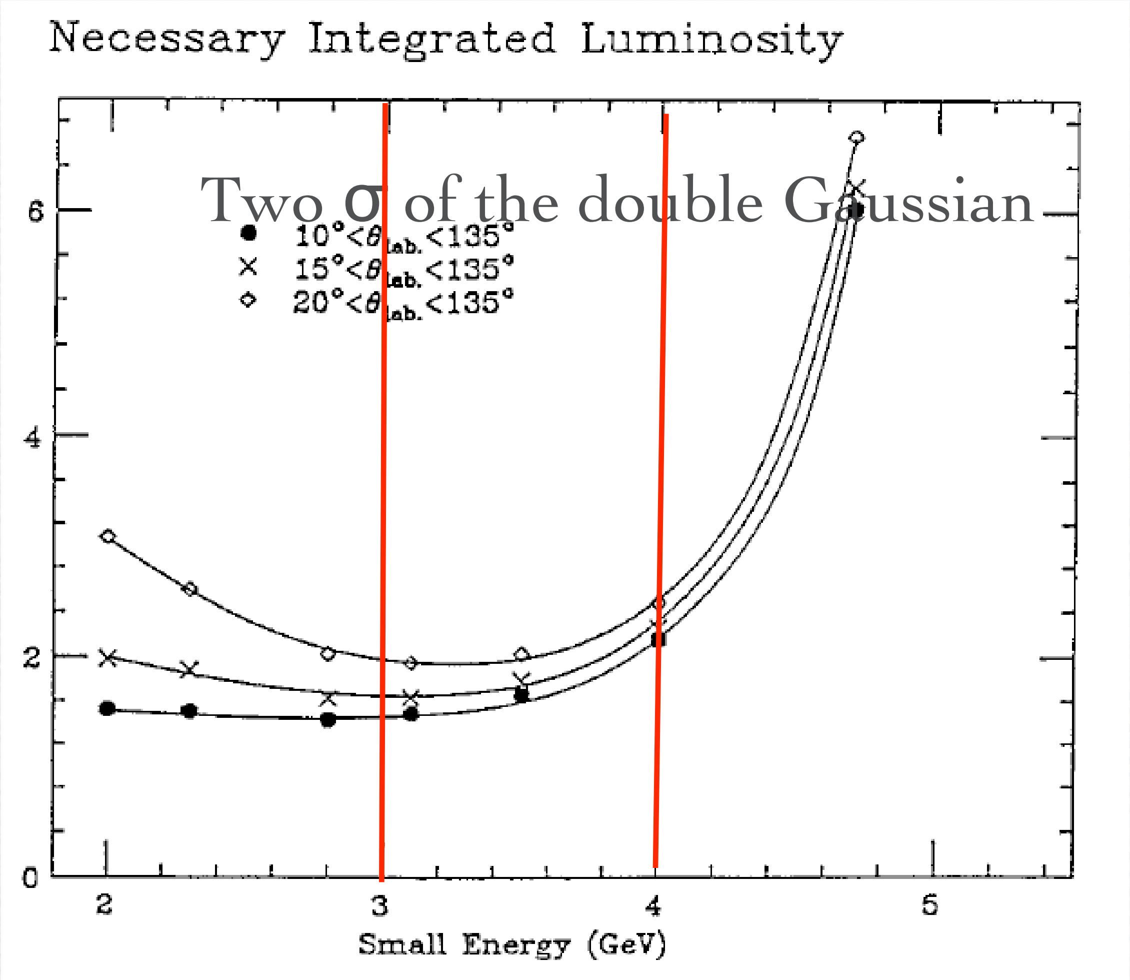
図-17. 時間分解能のエネルギー依存性.

ICPV mode(II)

- Luminosity necessary for *discovering* CP violation in

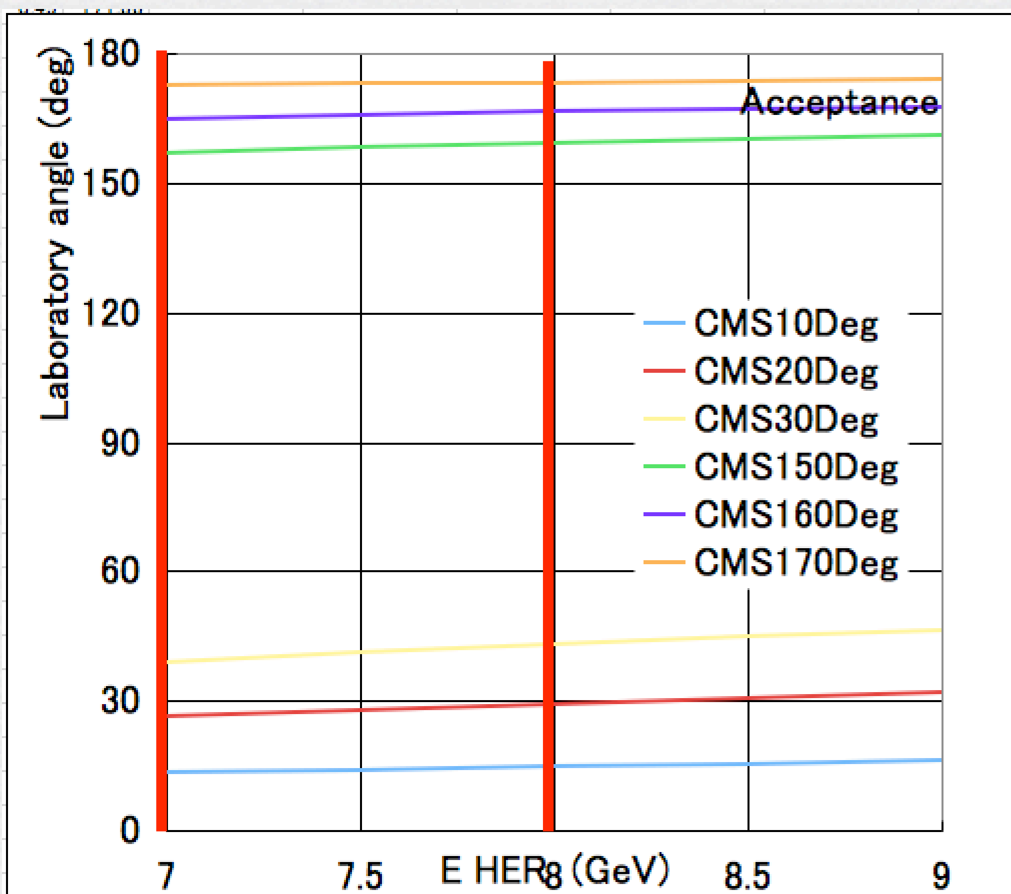
  $B \rightarrow J/\psi\ K_S$

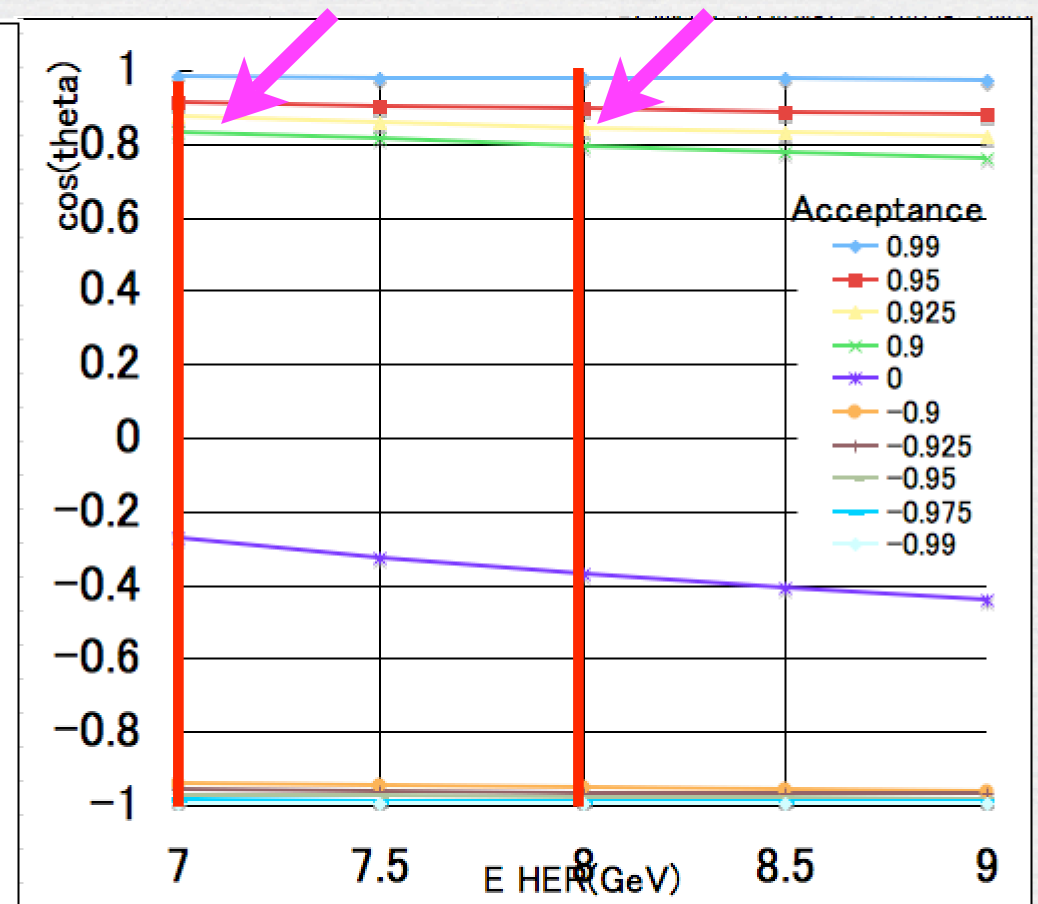
  at the beginning of KEKB.
- 20-30 % more luminosity is necessary if LER energy is 4 GeV.
- Haba mentioned yesterday this situation does not change much even if super-flat beam pipe is introduced.
- No dedicated study for Super KEKB factory.



Detector acceptance

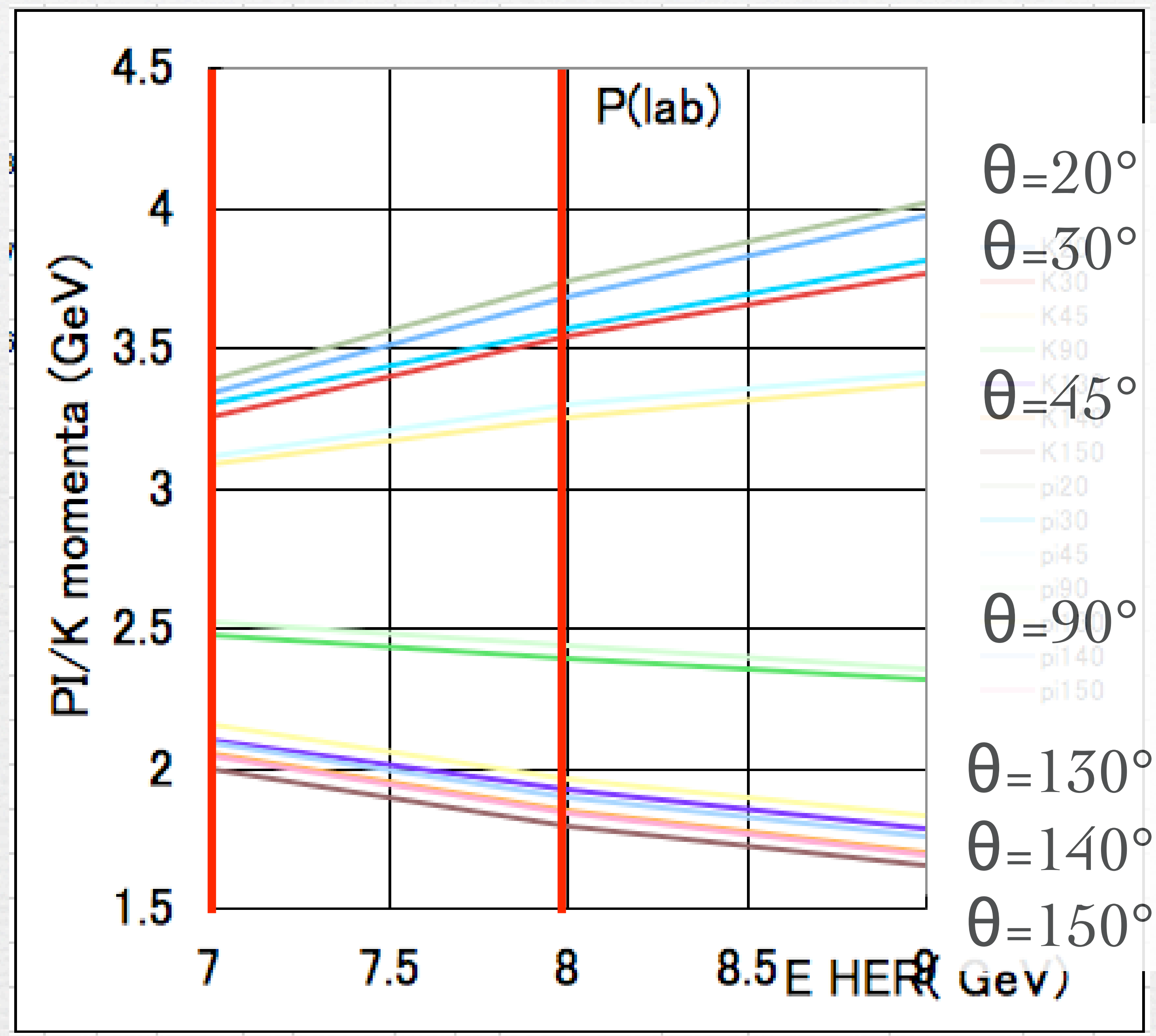
- Following 3 pages are based on kinematics for
- $e^+e^- \rightarrow \Upsilon(4S) \rightarrow BB$, $B \rightarrow \pi\pi$ and $B \rightarrow KK$
- The acceptance (degrees and cosϑ)
- Contrary to my expectation, the gain of acceptance in the forward region is <5%.
- Could be better for the slower particles from generic B decays.





PID for two-body decay modes

- Laboratory momentum of pions and kaons from $B \to \pi\pi$ and $B \to KK$ is shown at several laboratory angles, θ.
- In the forward region, the requirements to the PID can be reduced significantly.
- In the central and backward region, the momentum is larger.
- Separation between K and π does not change.



What we learn

- In ICPV mode, the resolution is determined by the tagging side.
- 20 % worse resolution results in 20 % more luminosity.
  - Ozaki's prediction is made 15 years ago and his interests were to "observe" the ICPV.
  - Dedicated study for SuperB case is not done.
  - More impacts would come if the super-flat IP chamber and a pixel sensor can be used in the innermost layers.
- Detector acceptance is not significantly improved.
- The laboratory momentum of the two-body decay of B is much smaller. This will reduce the requirements to PID in the forward region.

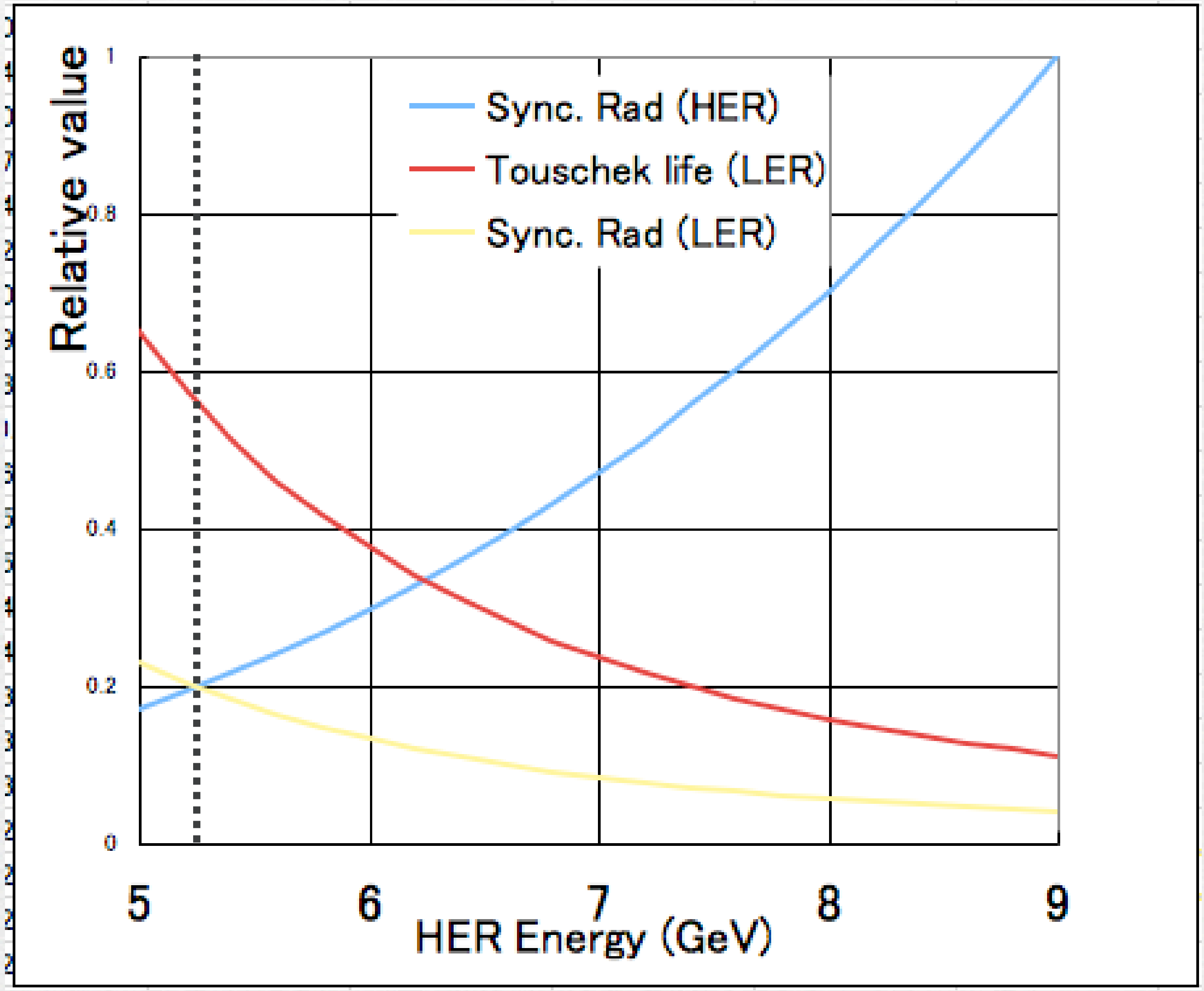
Accelerator issues

- To achieve $8\times10^{35}/cm^2/sec$,
  - LER: 9.4A
  - HER: 4.1A
- Power consumption in RF system~73 MW.
  - synchrotron radiation $\propto E^4$.
- Reduction of the HER beam current reduces the difficulties of KEKB.
- Reduction of operation cost is also serious issue.

		with beam-beam	unit
Beam current (LER/HER)	I	9.4/4.1	A
Beam energy (LER/HER)	E	3.5/8.0	GeV
Emittance	ε_x	130	nm
Horizontal beta at IP	β_x^*	1.9	cm
Vertical beta at IP	β_y^*	2.4	mm
Horizontal beam size	σ_x^*	50	μm
Vertical beam size	σ_y^*	1.0	μm
Beam size ratio	$r = \sigma_y^*/$	2.0	%
Crossing angle (30 mrad crab crossing)	θ_x	0	mrad
Luminosity reduction	R_L	0.82	
ξ_x reduction	$R_{\xi x}$	0.98	
ξ_y reduction	$R_{\xi y}$	1.16	
Reduction ratio	R_L/R	0.70	
Horizontal beam-beam (estimated with S-S simulation)	ξ_x	0.030	
Vertical beam-beam (estimated with S-S simulation)	ξ_y	0.187	
Luminosity	L	4.0×10^{35}	$cm^{-2}s^{-1}$

Synchrotron radiation power

- Synchrotron radiation (SR) in HER and LER.
- SR in LER is essentially small.
- In order to reduce damping time, they put wiggler magnets. Which results in huge power loss.
- Touschek effects is proportional to $1/E^3$.
- However, the effect is much smaller than INFN design since bunch size is larger.



Consideration of Energy Asymmetry

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Parameter Considerations

Beam current:

Luminosity : $L \propto E{\cdot}I$

$E{\cdot}I$ should be kept to obtain the same luminosity

Damping time (synchrotron radiation loss):

Energy loss/turn $U \propto E^4$

Damping time: $\tau_x = \tau_y = 2\tau_s = 2E{\cdot}T/U$

U can be increased by adding wiggler magnets.

Bunch length:

Bunch length: $$\sigma_z = \frac{C\alpha_p}{2\pi\nu_s}\sigma_\delta \propto \sqrt{\frac{E^3}{V_{RF}}}$$

If σ_z and α_p are fixed, V_{RF} should be lager for the larger E.

Energy spread: $$\sigma_\delta = \gamma\sqrt{\frac{C_q}{2\rho}} \propto E$$

σ_δ can not be controlled.

$$C_q = \frac{55}{32\sqrt{3}}\frac{\hbar}{mc}$$

Synchrotron tune: $$\nu_s \propto \sqrt{\frac{V_{RF}}{E}}$$

Smaller ν_s is preferable.

Parameter Considerations (cont'd)

Touschek lifetime for LER:

$$\tau_{Touschek} \propto \frac{\gamma^3}{N_p}$$

Fast ion instability

*Betatron tune shift:

$$\Delta\nu_\beta \propto \frac{1}{\gamma}$$

Electron cloud

*Betatron tune shift:

$$\Delta\nu_\beta \propto \frac{\rho}{\gamma} \propto 1$$

ρ: Electron density is proportional to energy. (w/o multipacting)

*Tune shift is an indication for instabilities.

HOM loss:

$$P_{b,HOM} = T \cdot \kappa(\sigma_z)\frac{I^2}{n_b}$$

Parameter Considerations (cont'd)

KEKB Linac Injector

e- beam: E = 8 GeV (2 unit STB)
e+ beam: E = 3.5 GeV (5 unit STB)

→

e- beam: E_{max} = 8.16 GeV
e+ beam: E_{max} = 4.14 GeV
with 1 unit STB

1 unit = 160 MeV

Possible energy asymmetry is 4 GeV(e+) x 7 GeV(e-)

Parameter Table

α_p is fixed.

		LER	HER	LER	HER	comment
Energy	E (GeV)	3.5	8	4	7	
Current	I (A)	9.4	4.1	8.2	4.7	Keep ExI
Energy loss/turn	U (MeV)	1.24	3.48	1.42	2.05	Less wiggler magnets in LER No wiggler magnets in HER
Transverse Damping time	$\tau_{x,y}$ (ms)	57	46	57	68	
Bunch length	σ_z (mm)	3	3	3	3	
No. cavities	ARES+SCC	28+0	16+12	20+10	13+6	SCC in LER
Rf voltage	V_{RF} (MV)	15	20	22.4*	13.4*	ARES:0.5 MV/SCC:1.3 MV
Radiation loss	P_{Rad} (MW)	11.7	14.3	11.6	9.6	I x U
HOM loss	P_{HOM} (MW)	7.0	1.7	5.4	2.2	LER: 40 V/pC, HER: 50 V/pC
Total beam power	P_b (MW)	18.7	16.0	17.0	11.8	Rad + HOM
Cavity wall loss	P_c (MW)	6.5+0	2.4+0	4.6+0	2.0+0	ARES:233 kW(LER) /150 kW(HER)
Total AC power	P_{tot} (MW)	40+0	23+10	29+8	19+5	ARES(LER):930kW/65% ARES(HER):850kW/59% SCC:480kW/57.6%
	P_{AC} (MW)	73		61		RF system only

Memo by Ohnishi

The table is made under the following condition.

1. In HER, there are no space for wiggler magnets. The damping time of 7 GeV HER is larger than that for 8 GeV case.
2. In LER, the wiggler magnets can be removed. The damping time for 4 GeV LER can be same as that for the 3.5 GeV case.
3. Luminosity is believed to be proportional to

   $$E(beam)\cdot I(Beam)$$

   Therefore, the beam current is larger for HER and smaller for LER in the less-asymmetric case.
4. The AC power for the RF system can be 12 MW saved.

Summary (I)

- Lower energy asymmetry reduce the construction and running cost of the accelerator.
  - Less hardwares for the RF source, vacuum system and cooling.
  - If luminosity is kept, we might reduce the total cost of Super KEKB operation.
    - Less AC power.
    - Less accidents in the RF/vacuum/cooling system.
- If cost is kept, we might have larger average luminosity. (I do not guarantee.)

Summary (II)

- Impact to the Detector design:
  - More symmetric detector
  - Less sensitivity gap, larger acceptance
  - Lower backgrounds, effective radiation shield.
    - Should be evaluated qualitatively.
  - Requirements to PID in the forward region is relaxed.
- Impact to the physics:
  - 10 % more luminosity is necessary for the ICPV physics.
  - For the other channels, symmetric design might be beneficial.
  - Optimization for rare decay processes of B meson and τ may be necessary.

Proposal

- Please give some attention to the cost of the experiment.
- If you are doing a physics case study, please simulate both 3.5 GeV+8 GeV case and 4 GeV+7GeV case.
- If 4 GeV + 7 GeV case is found to be tolerable or even better, we should discuss on this issue more seriously.
- Comments
  - With a super-flat IP chamber, we could farther reduce the energy asymmetry.
  - I hope this kind of effort is appreciated by the government and the Super KEK B factory is approved sooner.