High Luminosity B-Factory

Overview - KEK-B version

Luminosity: $10^{35}/\text{cm}^2\text{s}$

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1. Physics
2. Machine
3. Detector/IR

Physics

What can be done with $10^{35}/\mathrm{cm}^2\mathrm{s}$,
and how competitive is it?

What are the requirements on the detector
performances to take advantage of the luminosity?

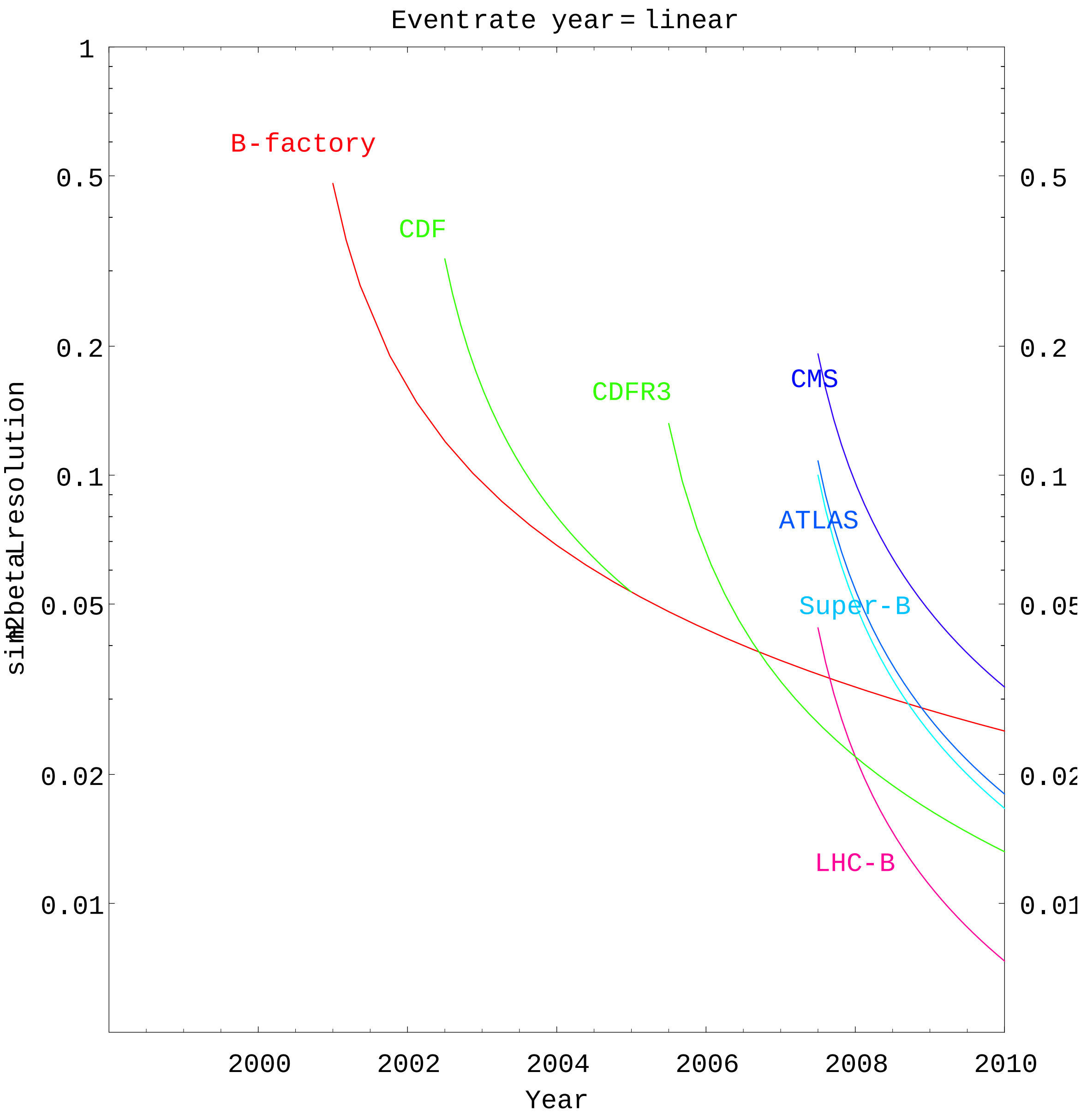
$10^{35}/\mathrm{cm}^2\mathrm{s} \rightarrow 1\mathrm{ab}^{-1}/\mathrm{yr}\ (10^7\mathrm{s})$
10^9 B pairs/yr
(10^{10} B's/5yrs)

Sensitivity of sin2β (rough estimates)

Assume:

- linear increase of luminosity vs time
- design luminosity in 2 years.

Not too competitive wrt LHCb/BTeV (and CDF)



Competitive edges of Super-KEKB
-with respect to the hadron machines-

1. π^0 detection efficiency

2. Smaller background in general

   To take advantage, it requires

   - Hermeticity (incl. π^0)
     Full-reconstruction tagging

   - Good vertexing
     Suppress continuum backgrounds
     Suppress combinatoric backgrounds.

     Practically, $\sigma_z \propto r_{\text{beampipe}}$
     Use a smaller beampipe radius.

Continuum Full reconstruction tagging

Reconstruct as many B's as possible and look at the rest of the event for a signal.

1. Everything left is from a B meson.

2. Particularly useful when ν's are involved.

   Semileptonic decays ($b \to u\ell\nu$), $B \to \mu\nu, \tau\nu$, $b \to s\nu\bar{\nu}$ etc.

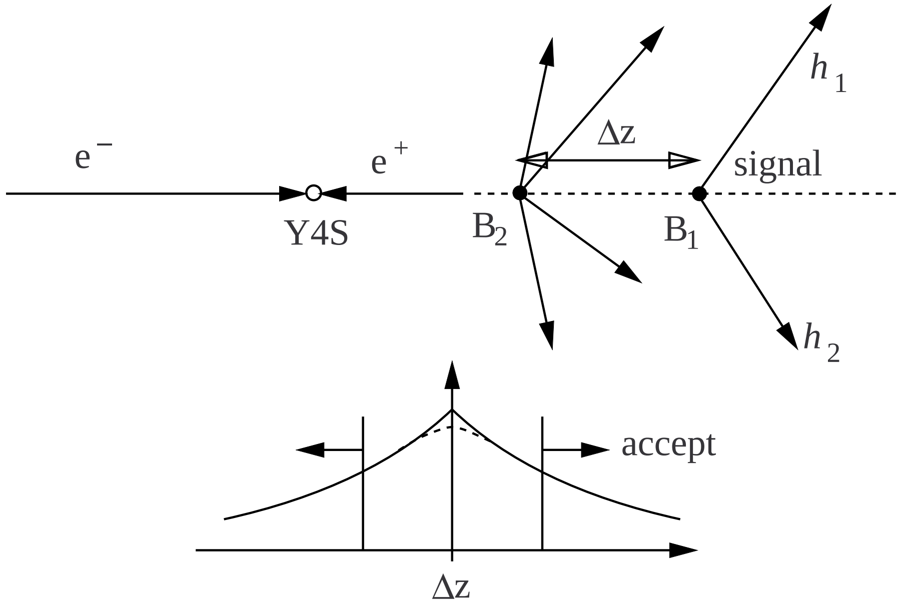
3. Estimated tagging efficiency ~0.004 (Lee and Shipsey).

   Total number of tagged B's $\sim 4\times10^7$/5yrs.

4. Tagging background and its effects?

Continuum suppression by z vertex separation

$$e^+e^- \longrightarrow B_1 B_2$$

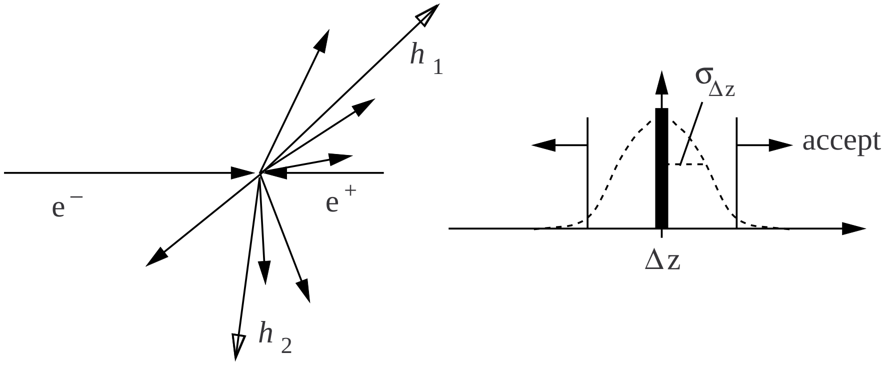


Δz distribution:

$$\propto \exp\left(-\frac{|\Delta z|}{L_0}\right)$$

L_O(B **mean decay length**) $\sim 211\mu(Belle)$

$e^+e^- \to q\bar{q}$ (continuum)



Δz distribution (assume gaussian):

$$\propto \exp\left(-\frac{\Delta z^2}{2\sigma^2_{\Delta z}}\right)$$

$$\sigma_{\Delta z} \sim 100\mu$$

Discovery sensitivity improvement:

$\#\sigma$ probability of background fluctuate up to the signal.

$$\#\sigma = \frac{N_{\text{sig}}}{\sqrt{N_{\text{bkg}}}}$$

The improvement factor for $\#\sigma$ with a Δz cut is then

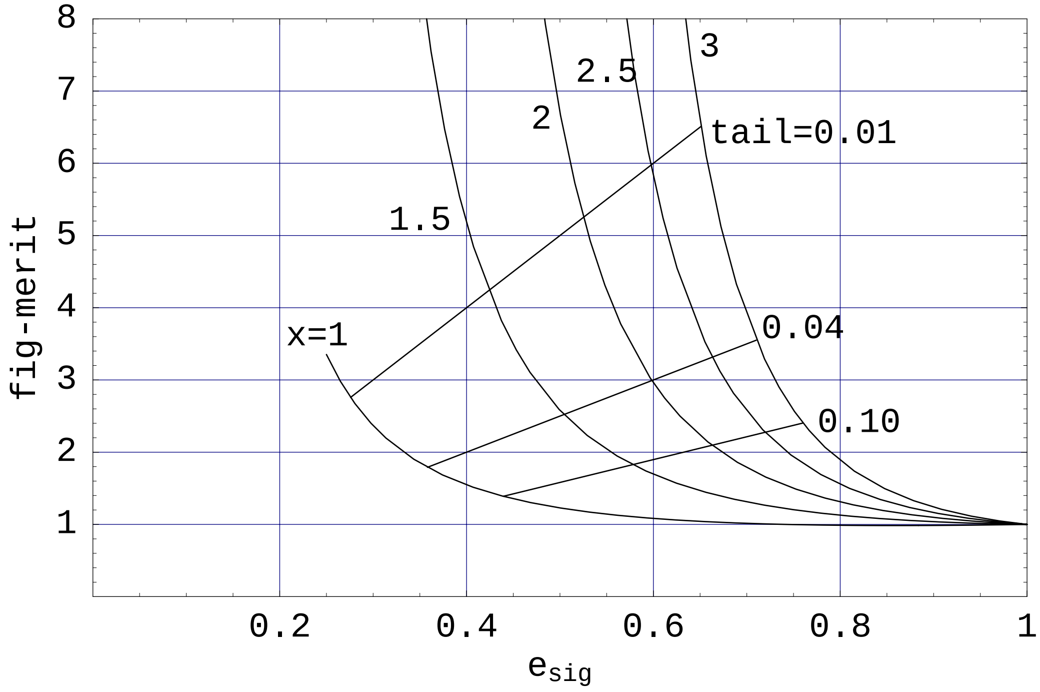
$$\boxed{\text{fig. merit} = \frac{\epsilon_{\text{sig}}}{\sqrt{\epsilon_{\text{bkg}}}}} \qquad \text{(discovery)}$$

Does not depend on $N_{\text{sig}}/N_{\text{bkg}}$ before the vertex separation cut.

Discovery sensitivity improvement:

$x \equiv \sigma_{\triangle z}$ **improvement factor**

$x = 1$ **:** $\sigma_z \sim$ **100** μ**m**



$x = 1$ **is not enough to be effective.**
$x = 2$ **would be very effective.**

Example: Can we find $B^- \to K^{*0}K^-$ if Br is 1/20 of $\rho^0\pi^-$?

CLEO 2.5: $\rho^0\pi^-$ S/N $\sim$ 20/20 @ 5 fb^{-1}

Assume factor of 4 reduction in bkg by PID cut.

$\to K^{*0}K^-$ S/N $\sim$ 1/5 @ 5 fb^{-1}
$\to K^{*0}K^-$ S/N $\sim$ 10/50 @ 50 fb^{-1}

Significance $= 10/\sqrt{50} = 1.4\sigma$: Not a signal.

With $\sigma_{\Delta z} \to 1/2$ and 1% tail,

Significance $\to 1.4 \times 5.2 = 7.3\sigma$: Clear signal.

$K^{*0}K^-$ is an important mode to understand
FSI, annihilation diagram, and $b \to d$ penguin.

There are many important modes at this Br level:
$B^+ \to D^+K_S$: clean annihilation mode.
$B^+ \to D^0K^+$: ADS method for γ, etc. etc.
Many of them play critical roles in direct CP studies.

Machine (Super-KEKB)

Can we achieve $10^{35}/\mathrm{cm}^2\mathrm{s}$? ($25\times$ now)

Basic strategy:
Extrapolation from the current KEK-B configuration
(ref. a talk by Onishi in M2)

Relevant issues:

1. Machine configuration
2. Beam lifetime
3. Injection
4. Implications

Machine configuration for Super-KEKB

Variety of options are being studied.

A possible candidate:

1. ×3 increase of design currents
   $\mathbf{I}_{HER}/\mathbf{I}_{LER}$ = 1.1A/2.6A → 3A/10A (luminosity $\sim \times 10$)

2. Present LER current limit: LER(e^+) vertical blowup due to the electron cloud effect (ECE).
   → LER = e^-, HER = e^+ (i.e. switch them)

3. Use antechambers for HER(e^+) (for ECE)

4. RF: 509 MHz (same as KEKB) → 5000 bunches max.
   (Another possibility is 1.5 GHz → 15000 bunches max.
   A new mahicne, not an upgrade)

5. Crab crossing optional (∼25% increase in luminosity)

Beam lifetime

Sources:

1. Residual gas. (dominant now, a few 100 min)
   Same vacuum pressure → same lifetime.
   (for the same ring acceptance)

   More current → more gas desorption.
   → need a beefed-up vacuum system.

2. Touschek (LER). ($\tau_{\text{Tous}} \sim$ 9 hrs now)
   (depends on the energy acceptance - 1.2% assumed)

   $$\text{Touschek rate} \sim \left\{ \begin{array}{c} \text{Bunch current} \\ \text{1/emittance} \end{array} \right.$$

   → Increase emittance, (reduce β_y^*).
   ϵ_x = 18nm → 54nm.
   (β_y^* = 5mm → 3mm, also ϵ_y/ϵ_x = 5% →1%.).
   → increase the energy acceptance.

3. Collision (radiative Bhabha) (not dominant now)

   Becomes dominant at Super-KEKB
   $\tau_{\text{col}} \sim$ 100 min.

Machine parameters

Smaller β_y^* → smaller σ_z (hour-glass effect)
σ_z = 5.6mm → 3mm.

	KEKB (now)		Super-KEKB	
	LER(e^+)	HER(e^-)	LER(e^-)	HER(e^+)
energy(GeV)	8	3.5	8	3.5
nbunch	1153	1153	5120	5120
$I_{\rm beam}$(A)	0.73	0.55	10	3
$I_{\rm bunch}$(mA)	0.63	0.48	1.95	0.58
ϵ_x(nm)	18	24	54	54
ϵ_y/ϵ_x	0.055	0.041	0.01	0.01
β_x^*(cm)	59	63	33	33
β_y^*(mm)	7	7	3	3
σ_z(mm)	5.6	5.6	3	3
crossing(mRad)	22		30	
L(10^{33}/cm^{2}s)	3		75	

Injection

Apart from the uprade to inject e^+ at 8 GeV,

If the same injection rates as now: $\begin{cases} \frac{dI}{ds}(e^+) = 1.5\text{mA/s} \\ \frac{dI}{ds}(e^-) = 3\text{mA/s} \end{cases}$

Injection time: $\begin{cases} I(e^+) = 3A \rightarrow 34\text{min} \\ I(e^-) = 10A \rightarrow 56\text{min} \end{cases}$

Beam lifetime ∼100 min:

If no improvement in the injection rates,
majority of time will be spent injecting.
(one beam is decaying while another is being injected)

Lifetime $\sim \times 1/3$, currents $\sim \times 3$
$\sim \times 10$ injection rates to obtain the same efficiency.
(Is it possible?)

Implications for detector/IR deaigns

1. Greater luminosity → greater rates (great!)
   → **Detector elements, trigger, DAQ should take it.**

2. ×3 increase of LER bunch current (0.66→1.95mA)
   ×2 decrease of bunch length (6→ 3 mm)
   → $3^2 2^{3/2} = 25\times$ **heating of the IP beampipe.**

3. Possibly larger vacuum pressure.
   Possibly shorter Touschek lifetime.
   → **Larger particle background.**

4. Stronger synchrotron radiation.
   → **SR heating and SR background at the IP beampipe.**

5. Possibly larger crossing angle.
   → **More diffcult for SR and particle background masks.**

6. Smaller β_y^*
   → **final quads closer to IP (space constraint)**

7. Injection background.

Detedctor/IR Issues

I. IR design for Super-KEKB

- Reduce particle background.
- Reduce SR background.
- Reduce HOM heating, image-current heating.
- Better cooling.
- (Mechanical strength - FEA).

Good vertexing resoution → Assume r=1cm.

Particle Background

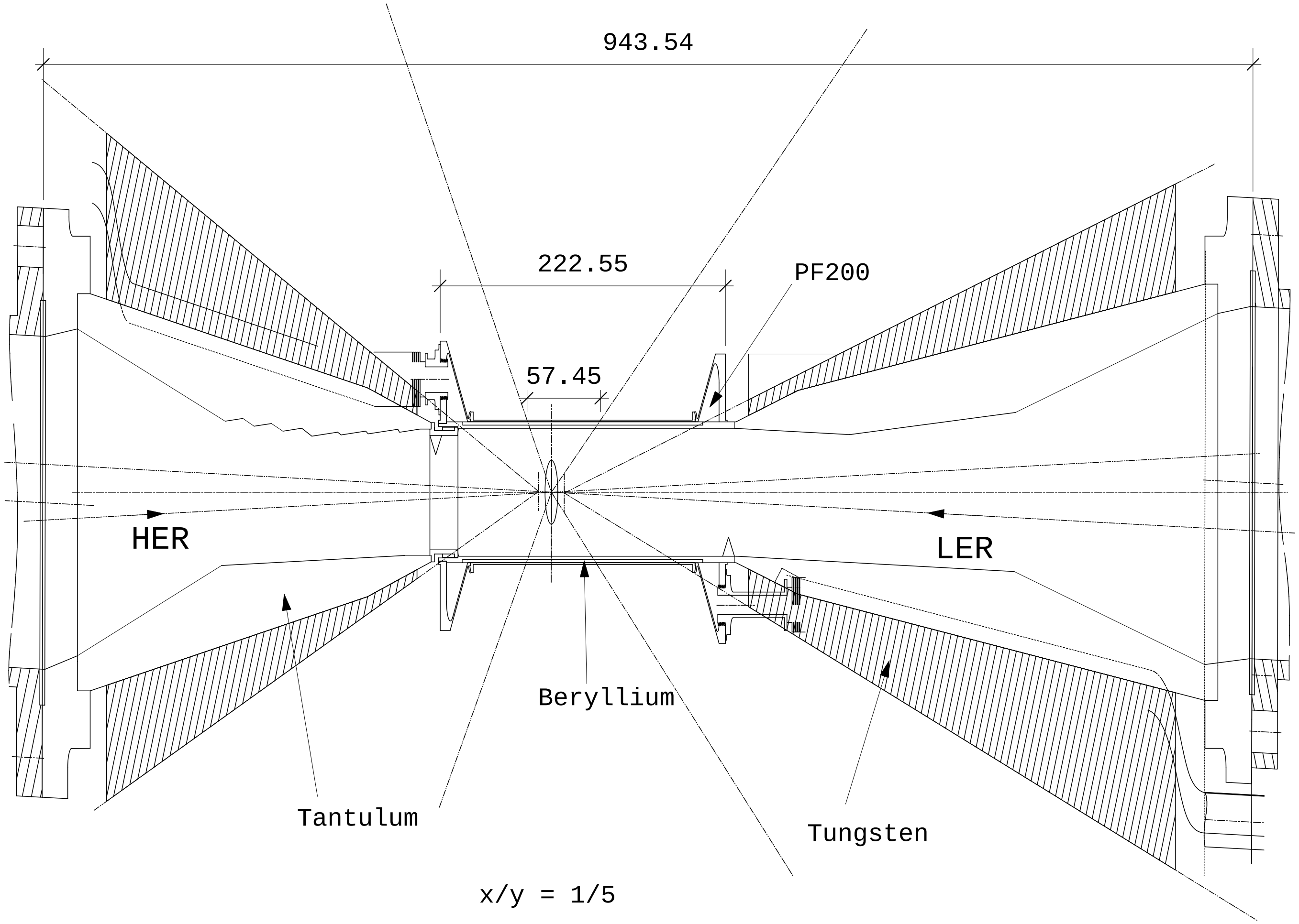
Some design guidelines

- Massive masks around the inner vertex detectors.

  1. At least ~10cm of path for particles hitting the mask.
     → r=1cm cylindrical tunnel on each side of IP along the incoming beam.
     The length limitted by crossing angle and the beam-stay-clear.
  2. Integrated design of the heavy mask and SVD support.

- Systematic covering of upstream beampipes with heavy masks.

- Movable mask placements. Beta phase: not just wrt IP also other weak spots.



Possible r=1cm IP beampipe design

Simulation (by Karim Trabelsi)

1. Assume 1 nTorr (same as now)
   The r=1cm configuartion.

Lyr 1	r= 1.5cm	1.9 MRad/yr
Lyr 2	r= 2.2cm	1.0 MRad/yr
Lyr 3	r= 4.3cm	0.25 MRad/yr
Lyr 4	r= 6.2cm	0.09 MRad/yr

- Occupancy ∼ unity for Lyr 1 (Si strip)
  → pixel (for Lyr 1-2 at least)

  Radiation damage?

2. For r=1.5cm
   (optimized: e.g. longer inner masks)

Lyr 1	r=2.2cm	0.17 MRad/yr
Lyr 2	r=4.3cm	0.04 MRad/yr
Lyr 3	r=6.2cm	0.02 MRad/yr

(KEKB upgrade in 2002 summer is to r=1.5cm)

Synchrotron Radiation Background

- Incoming HER beam.

  1. Sawteeth for outer-x wall.
     Surface scatt. → tip scatt. ($\sim 1/100$)

  2. Use left-side SR mask
     3mm high for 22mRad crossing.
     (if 30mRad, it should be higher → HOM!)

  3. Will be dominated by QC1 SR backscattered from the right-side particle mask (Simulation).

     5 kRad/yr (yoff = 0mm at QC1)
     670 kRad/yr (yoff = 3mm at QC1)
     needs software orbit tracking. → Real-time alarm.

- Incoming LER beam.

  Lower E_c, lower power than HER.
  → in general no severe problems.

  1. No masks (outer-x).
     In order to reduce HOM resonances.
  2. From Q's, weak bends and steerings:
     → Online orbit tracking alarm just in case.

- Outgoing HER at QCSR.

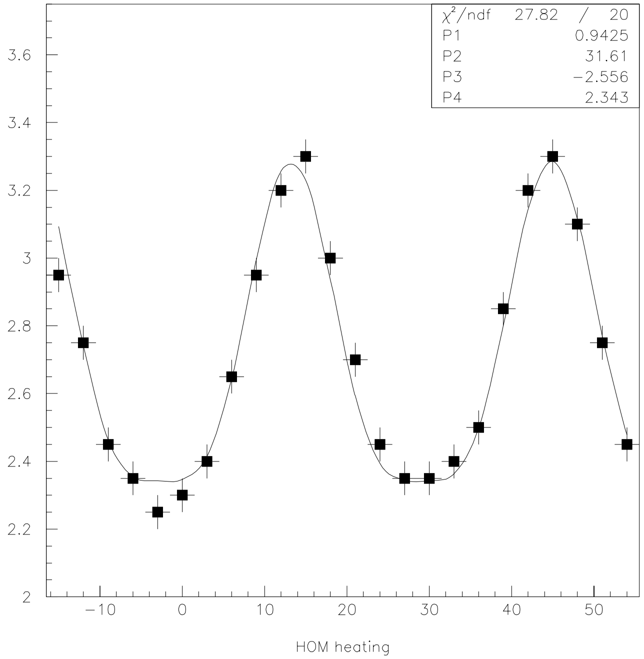
  Large offset (~4cm) → $E_c \sim$ 40keV, 100kW.
  Backscattering from the SR dump (now 8m away)

  1. If no mask: Expect 60 kRad/yr.
     → Move the Cu absorber further away.
  2. With a mask: bkg small.
     One has to avoid HOM resonances.
     (risky but possible - next slide)

Resonant HOM

1. **Simmulation can predict dangerous modes:**

   e^+/e^- RF phase-shift machine study.



Be beampipe temp
vs.
RF phase difference

Period = 31.61±0.2° (TM011: 31.54° expected)

2. **Avoid high-Q resonances:**
   Mask covers only π ('open geometry')
   → only one mode with $Q > 1000$ to worry about.

Beampipe heating and cooling

- Image current heating.

  Au coating, r=1cm, l=20cm → 500 W !

- Incoherent HOM ∼ 1000 W !

  Avoid resonances ← simulation works!

- Needs liquid coolant (probably should be water).
  (Double-wall Be beampipe with 0.5mm cooling channel)

  If H_2O: With 1.5 l/min, outer Be up 14 deg.
  inner Be up 16 deg wrt to outer.
  A bit high, but not a desaster (faster flow).

Can the pixel detector be put inside the beampipe?

1. Needs to be electrically shielded

   Au coated thin Be?

2. Image heat = 500W, HOM heat = 1000W

   Needs to be actively cooled.

3. Needs water coolant (∼0.5mm thick channel).

   Back to the current design.

II. Vertexing

- High occupancy.

  Probably needs a pixel detector.
  (Monolithic CMOS sensor?)

- Radius as small as possible.

  Install on the beampipe.

- Short shaping time.

  1μs(now) $\rightarrow$ 0.5μs(2002) $\rightarrow$ 0.25μs (Super-KEKB)?

II. Other Detector Components

- CDC (Drift chamber).

  2002: 2 inner layers → small-cell chamber
  CDC will probably 'survive' for Super-KEKB.
  The entirely new small-cell chamber (with faster electronics)?

- CsI(Tl) calorimeter.

  Slow (1μs) → Replace with pure CsI? (cost!).
  Wave form sampling?

- KLM (muon chamber).

  RPC is not fast. Already suffers from inefficiency due to local deadtime.
  → replace with wire chambers? (keep the structure)

III. DAQ

- Expected L1 trigger rate:

  Physics: 1kHz
  +Background: 5 kHz typical

- Event size.

  30kB/ev (now) → 100 kB/ev (Super-KEKB)
  (pixel, wave-form sampling for CsI)

- Data flow rate:

  500MB/s (typical), 1GB/s (max)

DAQ considerations:

1. Pipelining needed.

   Asynchronous (a la BaBar) or synchronous (a la CDF)?
   2 ns crossing interval → use asynchronous.

2. Prototyping of pipeline:

   Based on AMT (Atlas muon TDC), now being worked on.

3. Readout from pipeline:

   GbE promissing. + VME?, PCI?, USB2/Firewire? etc.

4. Event building:

   Full, partial, or no event building?

5. Storage.

   Disk, tape?

Summary:

1. The strength of Super-B-factory is its background rejection capabilities.
2. Also, modes that involves π^0's should be studied.
3. A good vertexing and hermeticity are essential. (for background reduction in particular)
4. The competitiveness should be evaluated with realistic estimations of backgrounds in mind.
5. The only way to achieve $\times 1/2$ reduction in vertex resolution seems to be to reduce the beampipe radius by $\times 1/2$. (material reduction has a limit)
6. With a smaller beampipe radius, careful designs are needed for SR backgrounds, particle backgrounds, and cooling of the IR components.