Detector for Super KEKB

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Representing the Belle collaboration

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Plan

1. Machine
2. Beambackground and IR design
3. Vertexing
4. Central tracker
5. Particle Identification (Cerenkov)
6. EM Calorimeter
7. DAQ/Trigger $\rightarrow$ M. Tanaka's talk

(Possible) Machine configuration for Super-KEKB (Start 2007)

1. RF: 509 MHz (same as KEKB) $\rightarrow$ 5000 bunches max.

2. $\times$3 increase of design currents
   I_{HER}/I_{LER} = 1.1A/2.6A $\rightarrow$ 3A/10A (luminosity $\sim \times 10$)

3. LER(e^+) electron cloud effect (ECE).
   $\rightarrow$ LER = e^-, HER = e^+ (i.e. energy switch)

4. Use antechambers for vacuum pipes.
   (for SR heating and ECE)

5. Continuous injection (physics run tried with success)

6. Crab crossing optional ($\sim$25% increase in luminosity)

Beam lifetime

1. Residual gas. (dominant now, a few 100 min)
   More current $\longrightarrow$ more gas desorption.
   $\longrightarrow$ need a beefed-up vacuum system.

2. Touschek (LER).
   ($\tau_{\rm Tous} \sim$ 9 hrs now for 1.2% energy acceptance)
   Touschek rate $\sim$ Bunch current/emittance
   $\longrightarrow$ Increase emittance, (reduce β_y^*).
   ϵ_x = 18nm $\longrightarrow$ upto 54nm.
   (β_y^* = 5mm $\longrightarrow$ 3mm, also ϵ_y/ϵ_x = 5% $\longrightarrow$1%.).
   $\longrightarrow$ increase the energy acceptance.

3. Collision (radiative Bhabha) (not dominant now)
   Becomes dominant at Super-KEKB
   $\tau_{\rm col} \sim$ 100 min.

Machine parameters

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

	KEKB (now)		Super-KEKB	
	LER(e^+)	HER(e^-)	LER(e^-)	HER(e^+)
energy(GeV)	8	3.5	8	3.5
nbunch	1223	1223	5120	5120
$I_{\rm beam}$(A)	1.33	0.82	10	3
$I_{\rm bunch}$(mA)	1.09	0.67	1.95	0.58
ϵ_x(nm)	18	24	$\sim$54	$\sim$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)	6.6		100	

Implications for detector/IR deaigns

1. Greater luminosity $\longrightarrow$ greater rates (great!)
   $\longrightarrow$ Detector elements, trigger, DAQ should take it.

2. $\times 2$ increase of LER bunch current (1.09$\rightarrow$1.95mA)
   $\times 2$ decrease of bunch length (6$\rightarrow$ 3 mm)
   $\longrightarrow 2^2 2^{3/2} = 11\times$ heating of the IP beampipe.

3. Possibly larger vacuum pressure.
   Possibly shorter Touschek lifetime.
   Possible continuous injection.
   $\longrightarrow$ Larger particle background.

4. Stronger synchrotron radiation.
   $\longrightarrow$ SR heating and SR background at the IP beampipe.

5. Possibly larger crossing angle.
   $\longrightarrow$ More diffcult for SR and particle background masks.

6. Smaller β_y^*
   $\longrightarrow$ final quads closer to IP (space constraint)

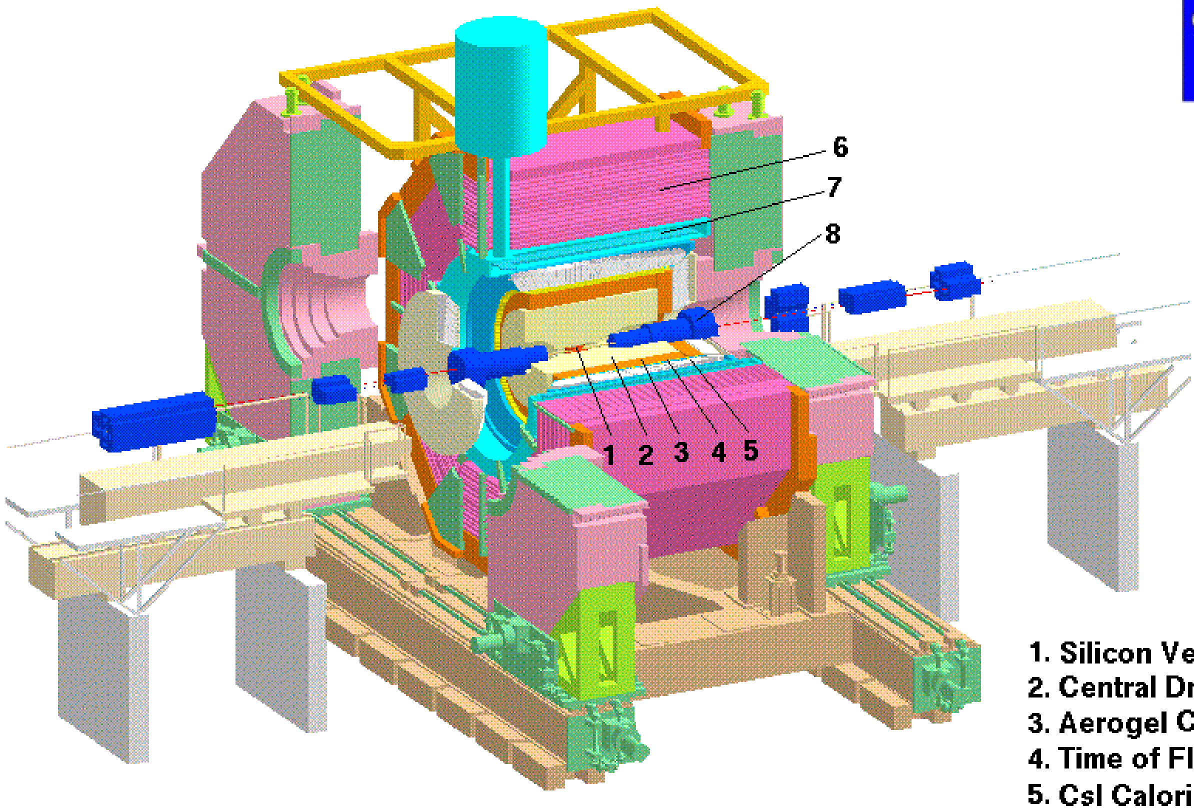
Studies for the 2002 upgrade

IR beampipe radius: 1cm and 1.5cm studied.
To be conservative $\longrightarrow$ 1.5cm taken for 2002.
1cm version: a good starting point for Super KEKB.

(vretex resolution $\propto r_{\mathrm{beampipe}}$)

Do all necessary minimum upgrades to current Belle

BELLE Detector



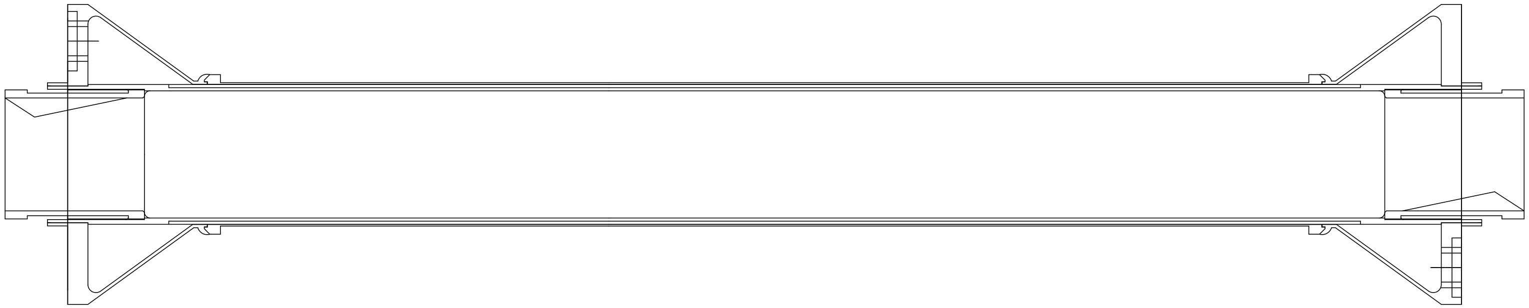
1. Silicon Vertex Detector
2. Central Drift Chamber
3. Aerogel Cherenkov Counter
4. Time of Flight Counter
5. CsI Calorimeter
6. KLM Detector
7. Superconducting Solenoid
8. Superconducting Final
   Focussing System

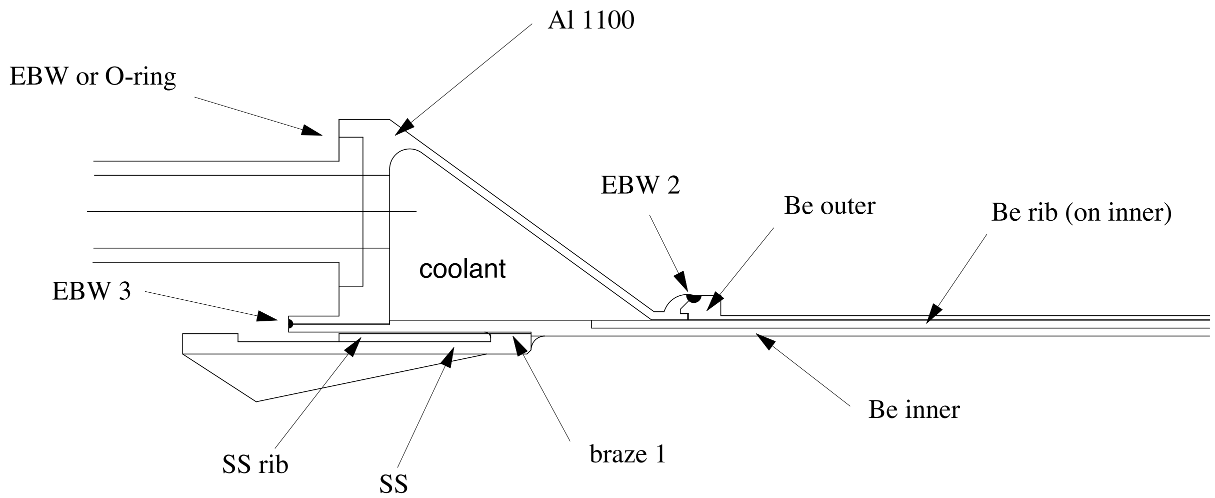
IR design

IR beampipe heating and cooling

- Image current heating.
  Au coating, r=1cm, l=20cm → 500 W !
- Incoherent HOM (hard to predict) ∼ 1000 W !
  Avoid resonances ← simulation works!
- Needs liquid coolant (probably should be water).
  (Double-wall Be beampipe with 0.5mm cooling channel)
  With H_2O 1.5 l/min, outer Be up 14 deg.
  inner Be up 16 deg wrt to outer. OK.

Actively-cooled double-wall Beryllium beampipe





Synchrotron Radiation Background

- Incoming HER beam.

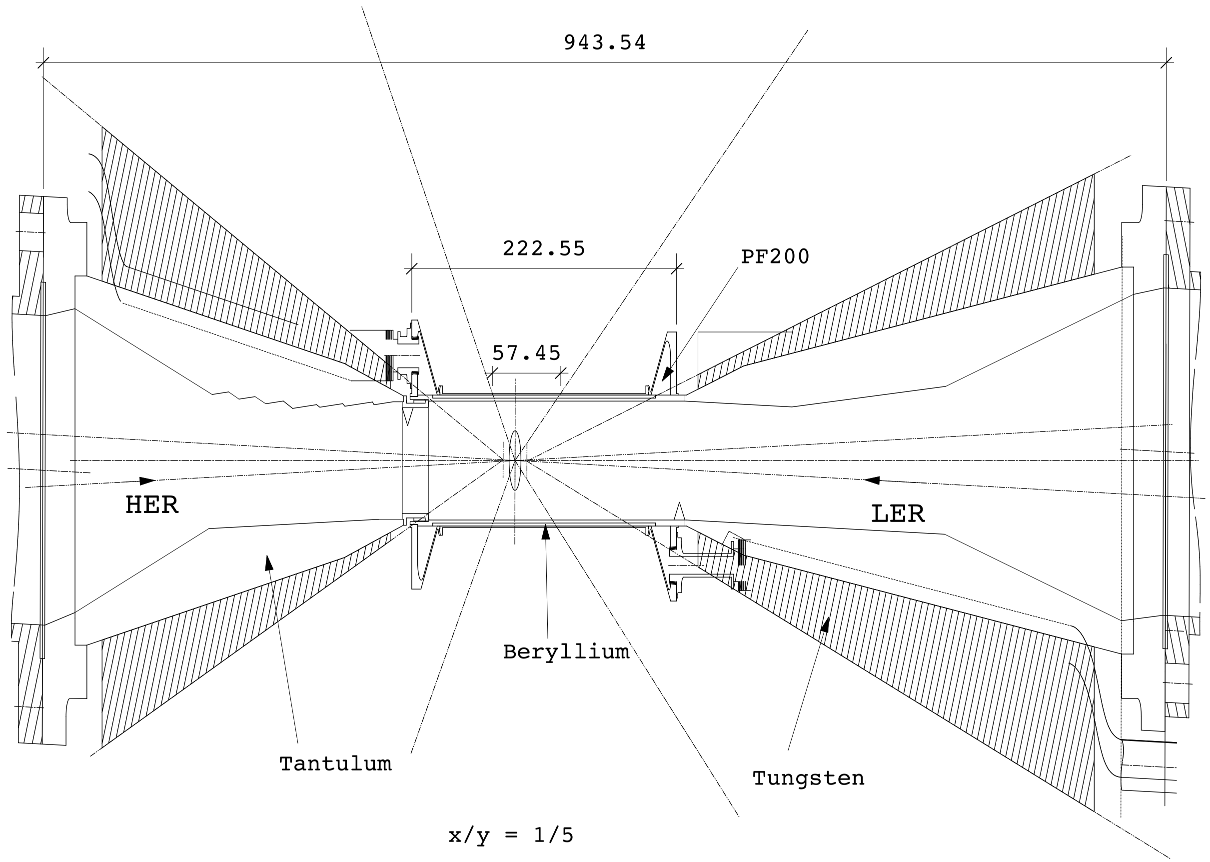
1. Thin heavy-metal (Au) coating inside Beryllium.
   $\sim 1/100$ dose reduction.

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

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

4. Depends on orbit: 5(670) kRad/yr for 0(3) mm orbit offest at QC1. $\rightarrow$ Real time orbit tracking.

Possible r=1cm IP beampipe design



- Incoming LER beam.
  Lower E_c, lower power than HER.
  $\longrightarrow$ in general no severe problems.

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

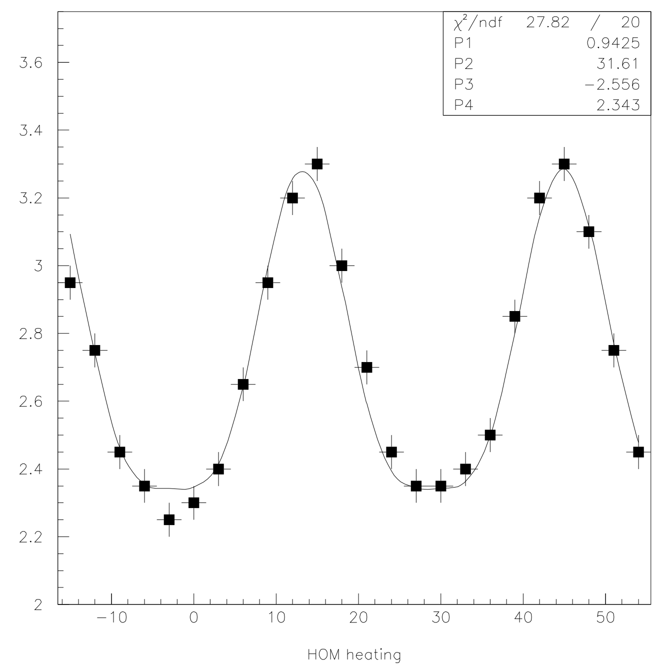
- Outgoing HER at QCSR.
  Large offset ($\sim$4cm) $\longrightarrow E_c \sim$ 40keV, 100kW.
  Backscattering from the SR dump (now 8m away)

  1. If no mask: Expect 60 kRad/yr.
     $\longrightarrow$ 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

Simmulation can predict dangerous modes:
e^+/e^- **RF phase-shift machine study.**

Be beampipe temp
vs.
RF phase difference



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

Particle Background

Some design guidelines

- Massive masks around the inner vertex detectors. r=1cm cylindrical tunnel on each side of IP along the incoming beam. The length limitted by crossing angle and the beam-stay-clear.

- Systematic covering of upstream beampipes with heavy masks.

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

MC Simulation Results for KEKB (Karim Trabelsi)

Silicon Lyr1 doses

(kRad/yr=10^7s) for (1nTorr CO, 1.1A/2.6A)				
Version	Data	MC(now)	MC(2002)	MC(2002)
r(b.p.)	2cm	2cm	1cm	1.5cm
r(lyr1)	3cm	3cm	1.5cm	2.2cm
HER Brem		6	28	13
HER Coul		35	35	13
HER sum	24	41	63	26
LER Brem		20(9)	67(63)	13(9)
LER Coul		15	52	14
LER Touschek		57(7)	474(464)	29(9)
LER sum	82	92(31)	593(579)	56(32)
Total	106	133(72)	655(641)	82(58)

( ): ignore bkg from just outside beampipe at QC2.

Extrapolation to Super-KEKB

Beam current $\sim \times 4$, Lifetime $\sim \times 1/3$, Same vacuum (true?).

Lyr1 doses

(MRad/yr=10^7s) for (1nTorr CO, 3A/10A)				
	Conservative		Optimistic	
r(b.p.)	1cm	1.5cm	1cm	1.5cm
HER sum	0.5	0.2	0.2	0.1
LER sum	6.8	0.6	2.3	0.2
Total	7.3	0.8	2.5	0.3

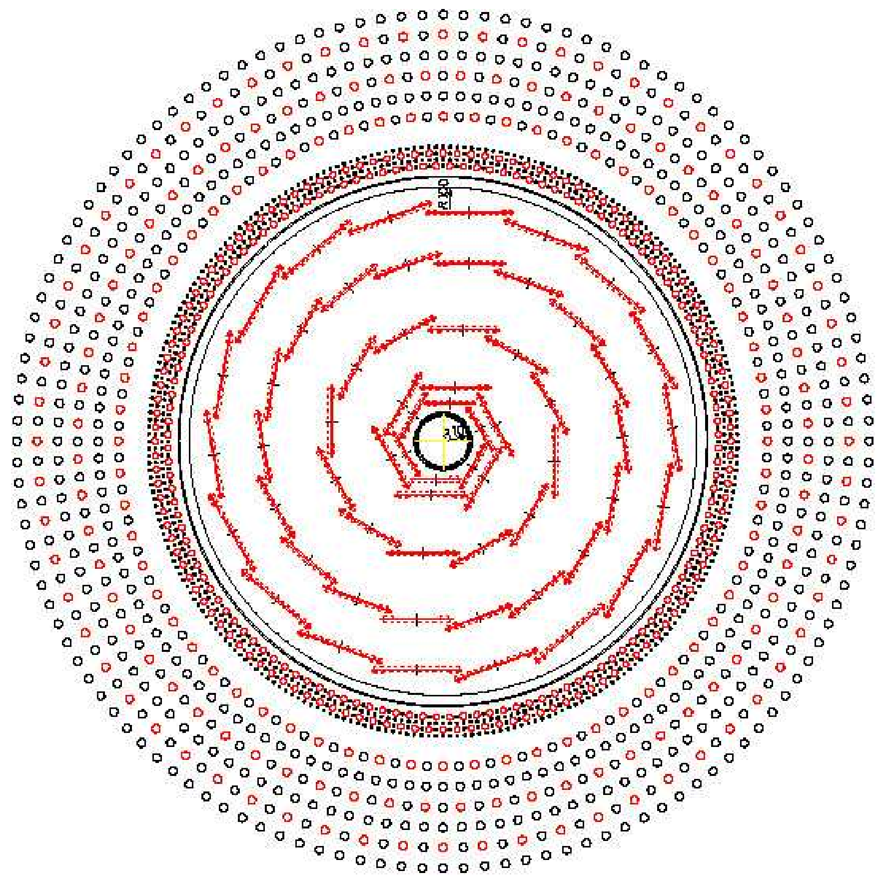
Conservative: scales with (beam current)/(lifetime).
Optimistic: scales with (beam current).

Vertexing

- Try $r_{\text{bampipe}} = 1$cm.

- Radiation dose.
  7.3 MRad/yr expected.
  2002 upgrade FE chip:
  OK at 20 MRad.
  Radhardness is OK.

- Occupancy.
  Silicon strip detector
  occupancy ~ 1.
  Need a pixel device for
  inner layers.



Pixel detector

- Occupancy $< 1\%$
  No significant impact param res.

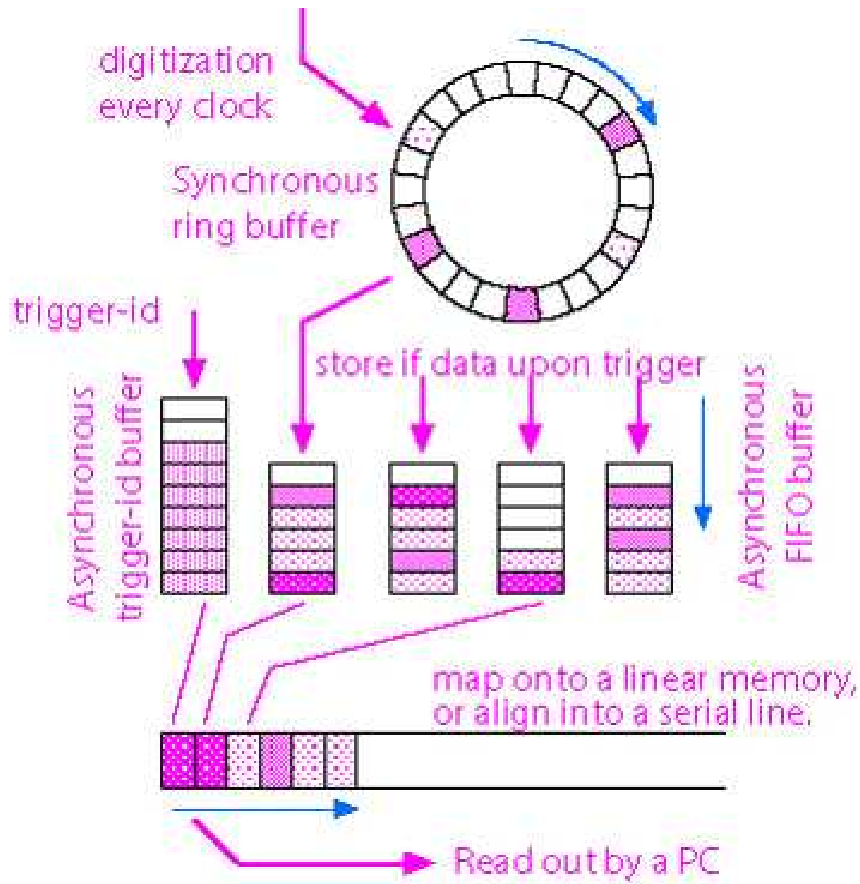
  $\rightarrow$ pixel size $< 50\text{x}100\mu m^2$.

- Trigger rate $\sim$ 5 kHz expected.

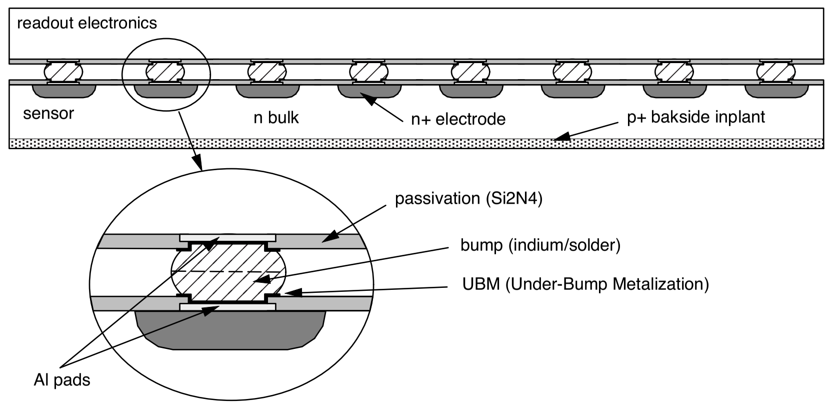
  Trigger latency $\sim 10\mu s$ (hard)
  or pipeline.

- Candidates

  Hybrid pixel.
  CMOS monolithic pixel.
  CCD.



Hybrid pixel

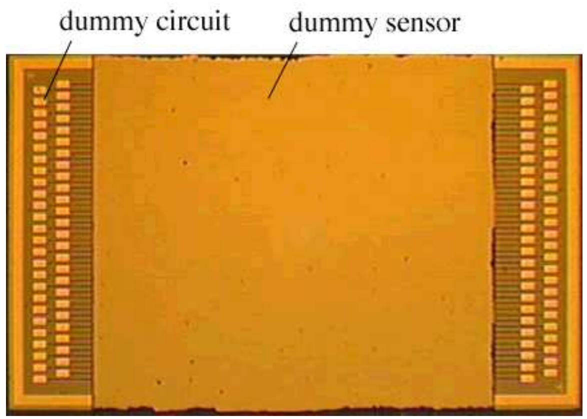


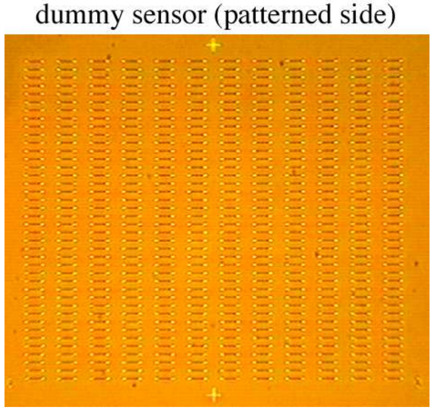
1. Large pixel: $50 \times 300 \mu\mathrm{m}^2$ (ATLAS), $150 \times 100 \mu\mathrm{m}^2$ (CMS)
2. Need chage sharing for position resolution
   $\longrightarrow$ A good candidate: CMS analog readout
3. Thinning necessary (200μm total or less?)
4. Heat generation and cooling $\longrightarrow$ more material.
   (40μW/pixel for LHC operation. For B-factory?)

Realistic candidate: $50 \times 300 \mu\mathrm{m}^2$ pixel with a CMS electronics

Thin Die Bump Bonding Test (U. Hawaii)

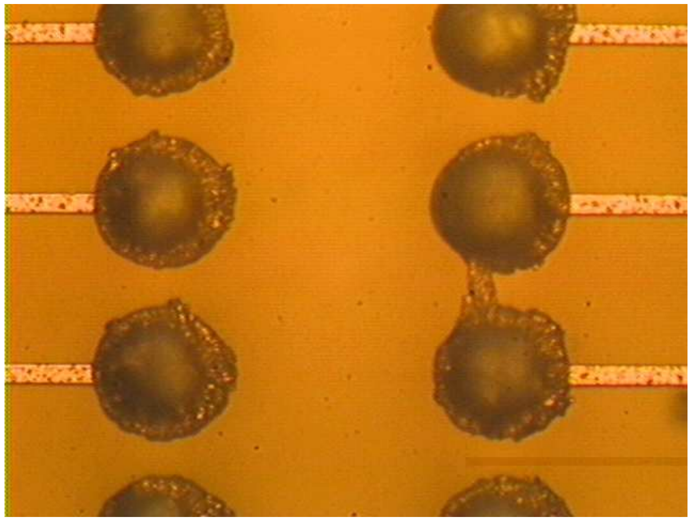
1. Dummy sensors and dcuircuit chips fabricated at SNF.
   - 100μm thick. • 40×24 array, 50×100μm^2 pitch
2. Indium-bump-bonded by AIT (Hong Kong)



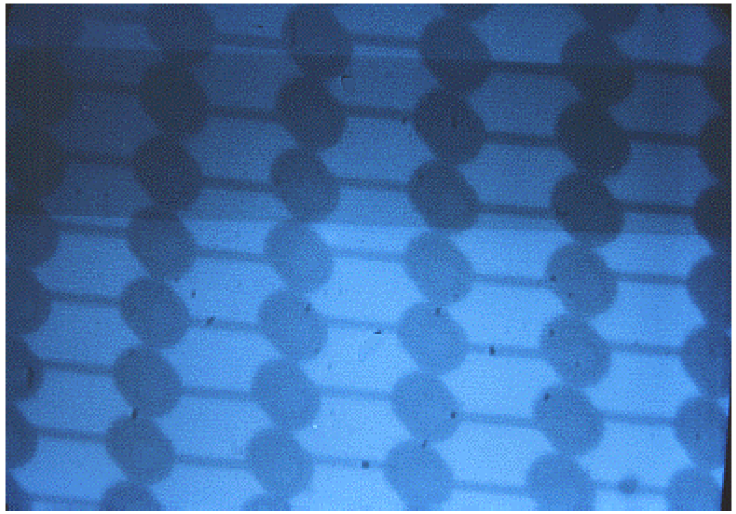


3. 5 samples inspected by IR microscope and tested for misconnecction&shorts
   - No misconnection.
     Shorts: ~2% (Run A), $\sim 10^{-3}$ (Run B)
   - ~100Ω/bump

Optical microscope image of a die before bonding. There is a UBM short.



IR miscroscope image. Misalignment is seen. (no shorts resulted)



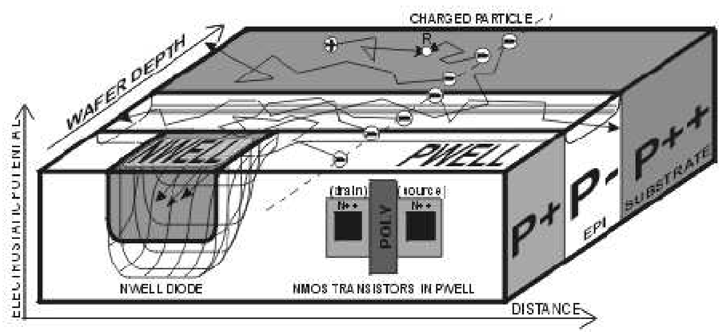
Monolithic Active Pixel Sensor (MAPS)

CMOS camera

Commercial technology

Use dEdx in epi layer

$\sim$150ns collection time



1. MIMOSA chips (Strasburg)
2. 4-6 arrays 64×64 each.
3. $20 \times 20\mu$m^2 pixel.
4. $\sigma = 1.4\mu$m achieved.
5. Rad-tolerant design done.
   $\sim$40% charge loss at 5E11 30MeV p ($\sim$ 7MRad dedx)
   More or less OK.
6. Read-out speed still slow.
   (25 MHz $\rightarrow$ 10ms/cm^2)
   Larger pixel size?
   Column-parallel readout?

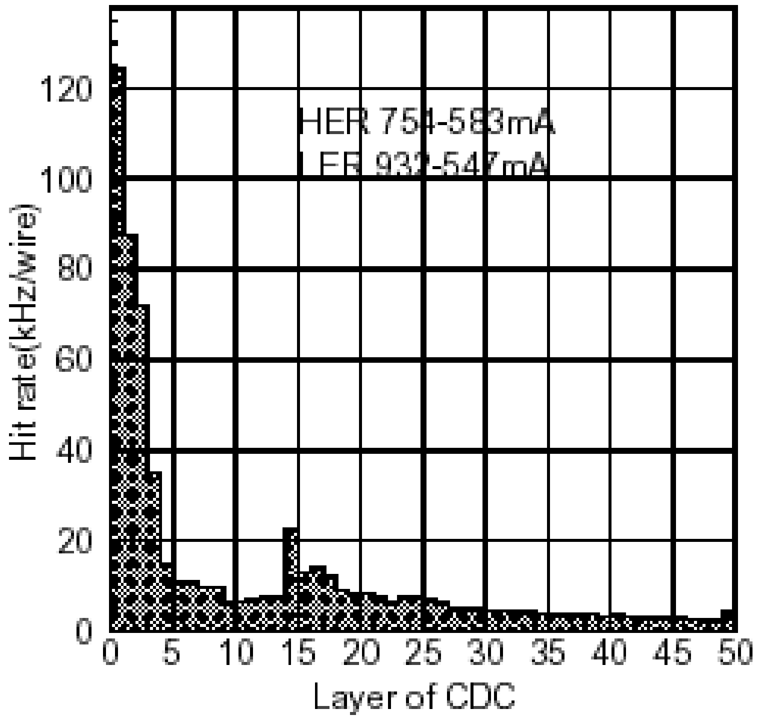
We keep watching its progress.

CCD

1. TESLA CCD project ongoing (C. Damerrell et. al.)
2. $20 \times 20\mu\text{m}^2$ pixel.
3. Needs to be cooled (Liq.N2).
   Rad hard enough?
4. Slow read out at present.
   R&D: Column-parallel readout at 50 MHz.
   (Good enough when realized)
5. Continous readout.

Hope they will make it soon.
(Soon enough for Super KEKB?)

Central Trackers

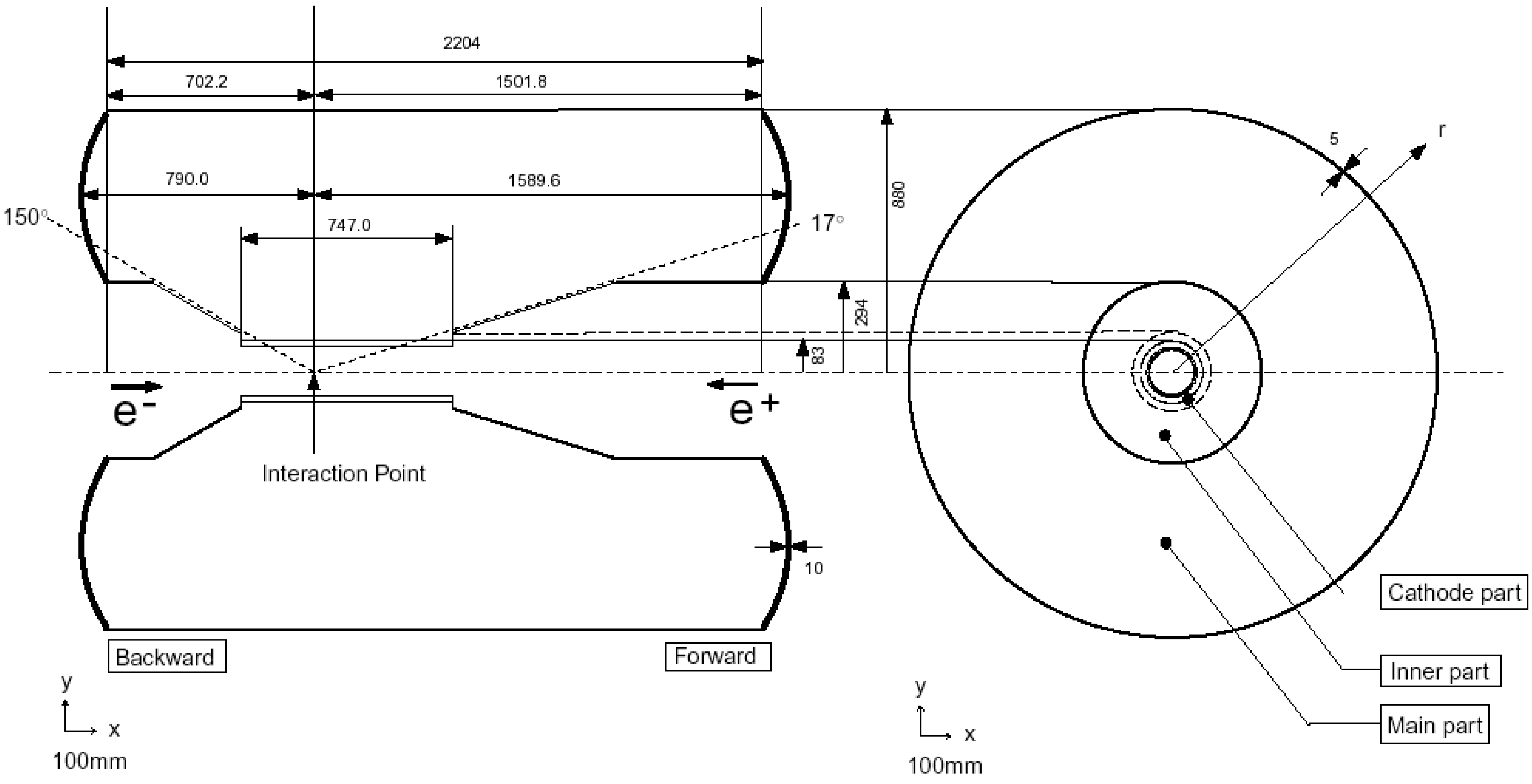


- Innermost CDC: $\sim$100 kHz now. ($\sim$10% inefficiency)
- Inner layers (upto r=15cm) to be replaced by SVD.
- Rest of the CDC:

  A small-cell chamber (5mm cell) with a faster gas (e.g. CH_4).

  Super-B deadtime $\rightarrow$ a few %.

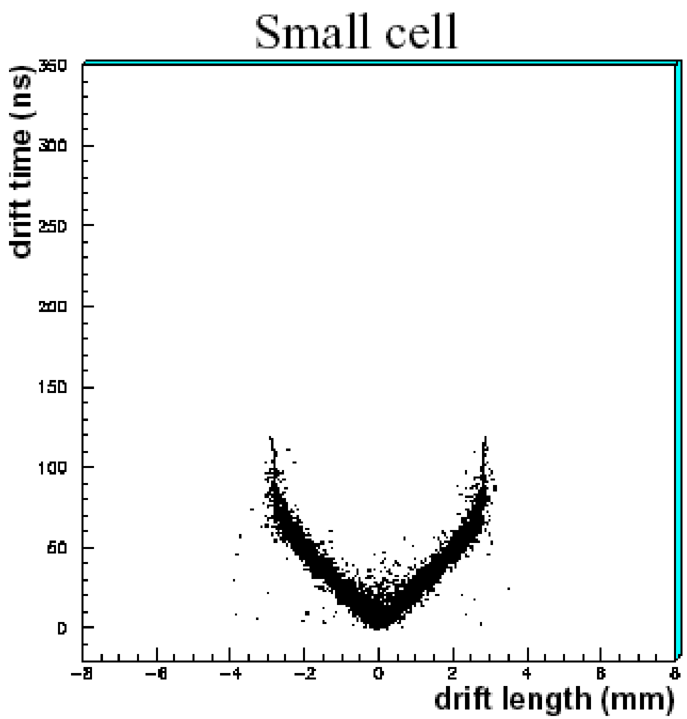
Belle Central Drift Chamber



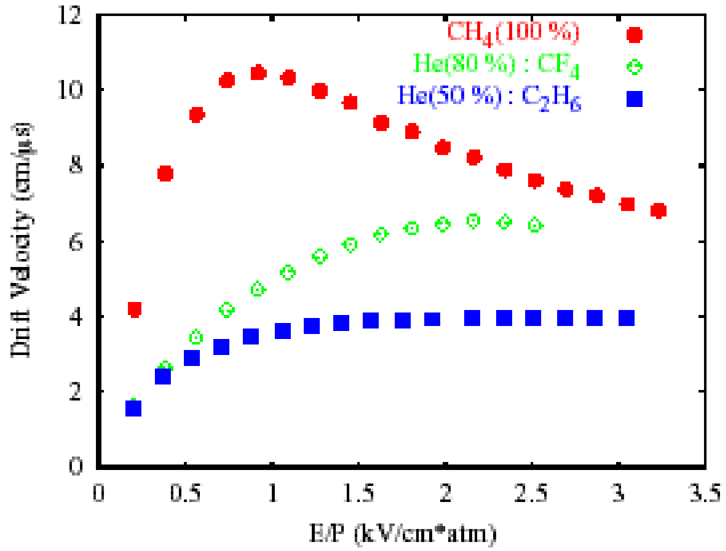
Prototype small-cell chamber

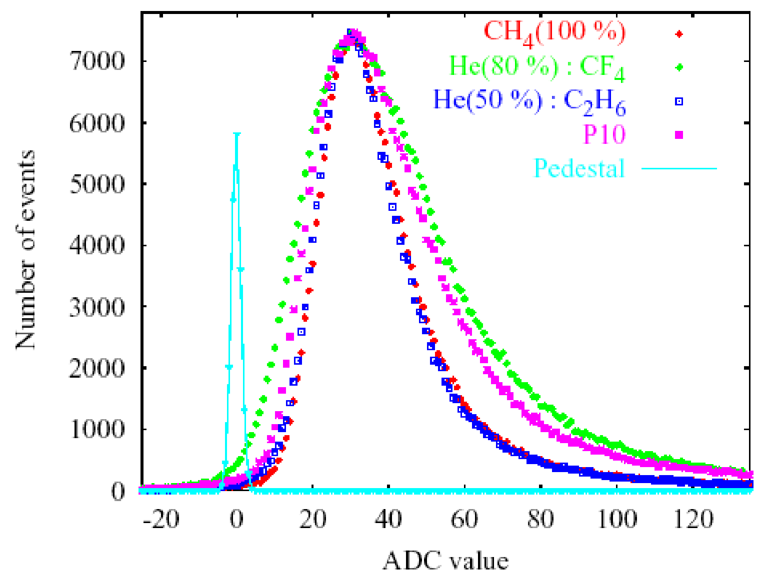
Inner layers: 5mm cell
Outer layers: ‘normal’ cell

Drift time vs distance



CH_4: a fast gas candidate

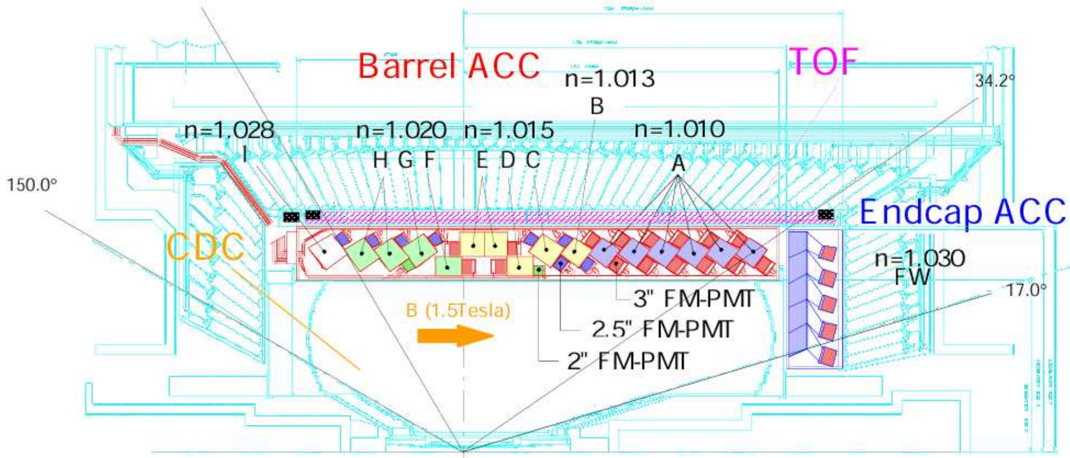


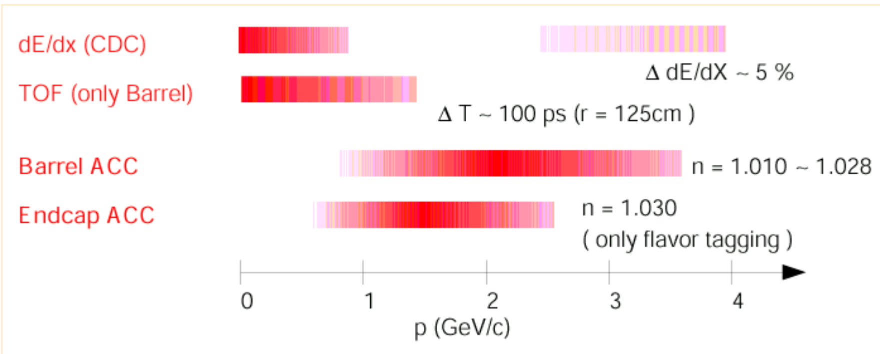


A possible problem: rad hardness - R&D in progress

Particle Identification

Belle PID π/K separation



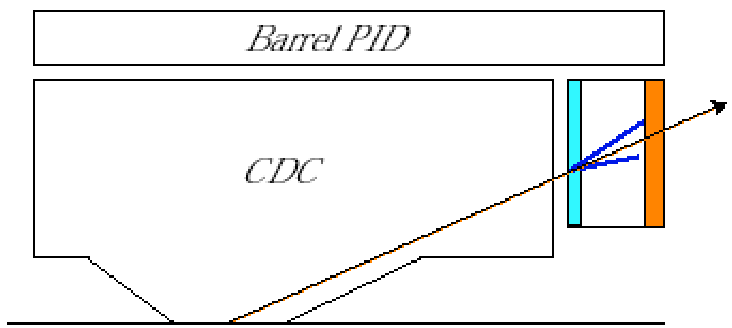


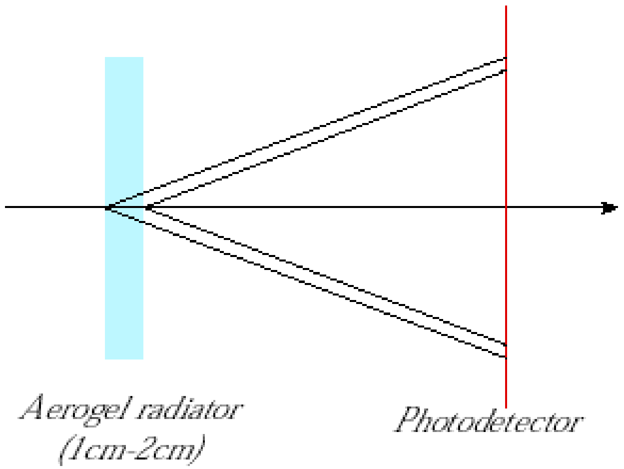
Better π/K separation.
More noise hits
at higher luminosity.
$\longrightarrow$ Ring-Imaging

2 candidates:

- Ring-imaging aerogel. (End Cap)
- TOP counter. (Barrel)

Aerogel-RICH



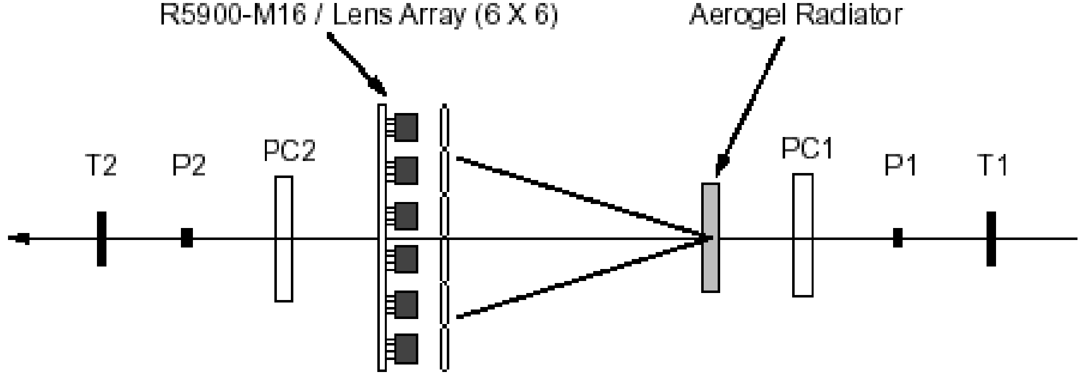


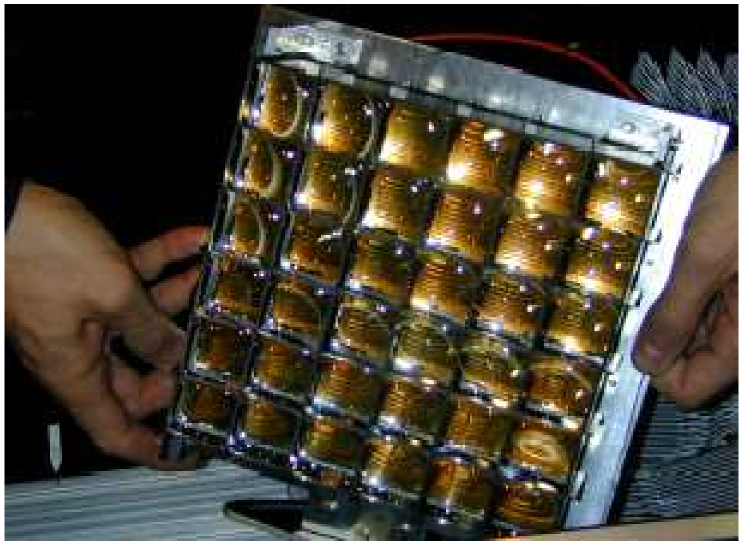
n=1.029/1.050 tried.

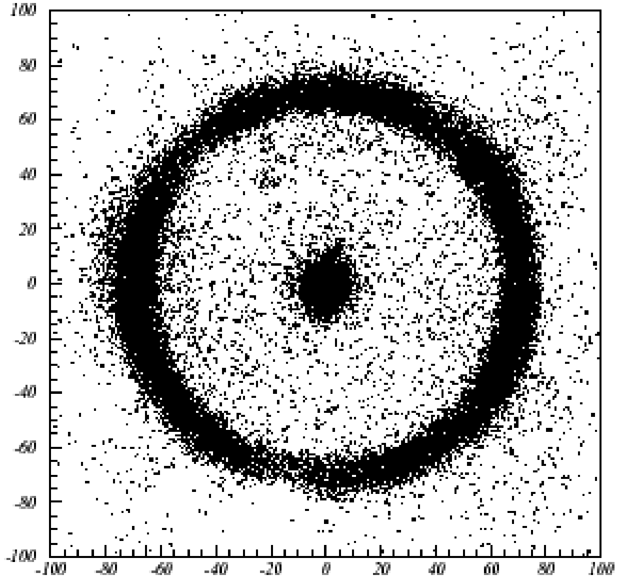
6×6 Multi-anode PMT's.
4 outputs/PMT
(4 cathodes combined)
Focusing lens on each PMT.

Cosmic ray test:
J.Stephan Inst., June-Oct,01.
Beam test:
KEK, Nov-Dec,01.

Beam test of Aerogel-RICH







Aerogel-RICH beam test results

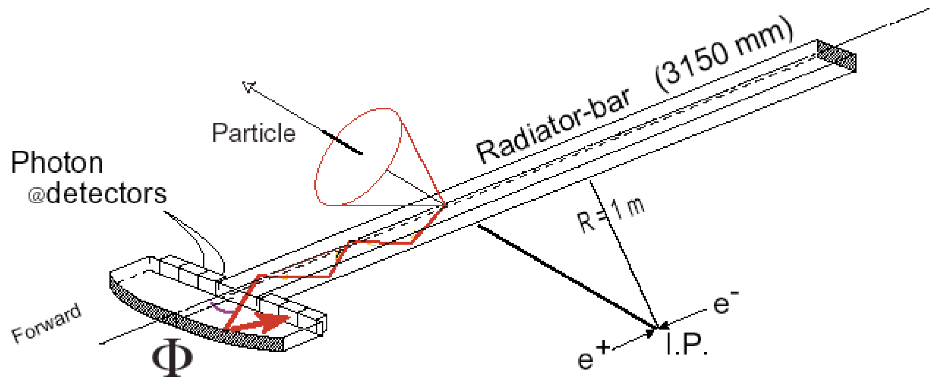
n	$N_{p.e.}$ w/o lens	$N_{p.e.}$ w/ lens	$\delta\theta_c$
1.029	2.21 (3.78)	3.90	12.8
1.050	2.25 (4.06)	3.34	15.9

( ): MC expectation

1. Finer-grain PMT readout (16 outputs/PMT): 10-20% improvement of $\delta\theta_c$.
2. Novosibirsk aerogel: 80% increase of $N_{p.e.}$
3. Flat-pannel Hybrid (Avalanche) Photodiode (H(A)PD) under study.

Time of Propagation (TOP) counter

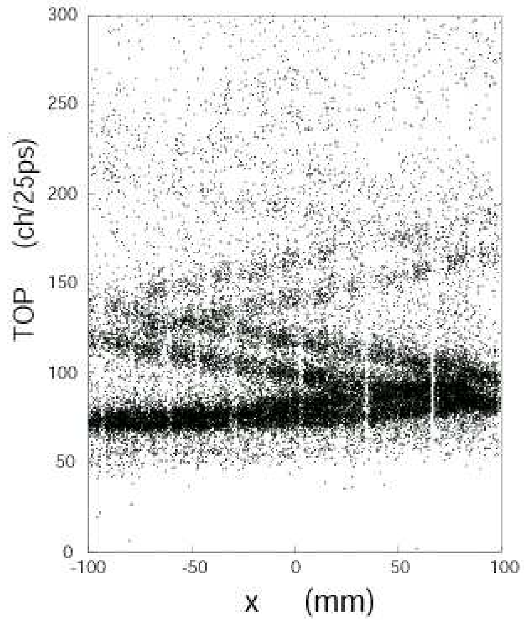
Top counter concept



- Fused silica radiator.
- 2D position of p.e.:
  x (horizontal hit pos.)
  t (time of propagarion)
- Discrete ambiquity in x.
- $\delta t \sim 100$ps photon detector in 1.5T field.

TOP counter prototype

Beam test with 2.5 GeV/c pions (KEK).



- $N_{p.e.} \sim 30$.
- Fused silica polish is critical.
- Multi-anode PMT used. But not in 1.5T field.

EM Calorimeter

- Current system: 8376 CsI(Tl) blocks. Q and T readout.

- Barrel: 1kRad/3000fb^{-1} expected. 5-10% light loss.
  ($\sim$ OK)

- Endcap: Pure CsI ($\times 100$ faster decay time, $\times 10$ rad.hard).
  R&D at BINP (with photo triode/tetrode)
  Noise~ 1MeV$\rightarrow$0.2MeV expected.

- Wave-form samp. and shorter shaping time. $\rightarrow \sigma_{\text{pileup}} \times 0.5$.
  Installing FADC (from BINP) for a few channels for study.

- Pipeline readout.

Summary:

1. IR beampipe radius of 1cm should be pursued as 1.5cm as a fall-back design.
2. Beam backgrounds and IR heatings seem manageable.
3. The tracking system can be configured as a new pixel device at the center, an expanded DSSD layers, and a small-cell drift chamber.
4. The particle ID devices will have ring-imaging capability for both barrel and endcap sections.
5. The barrel EM cal could use CsI(TI), but the endcap EM cal may need pure CSI.
6. Faster shaping and pipeline readouts are needed for most detector elements.
7. A detector for Super-KEKB at $10^{35}/cm^2s$ can be designed as a reasonable upgrade of the current Belle detector.