B factories and Super KEKB

October 20, 2005

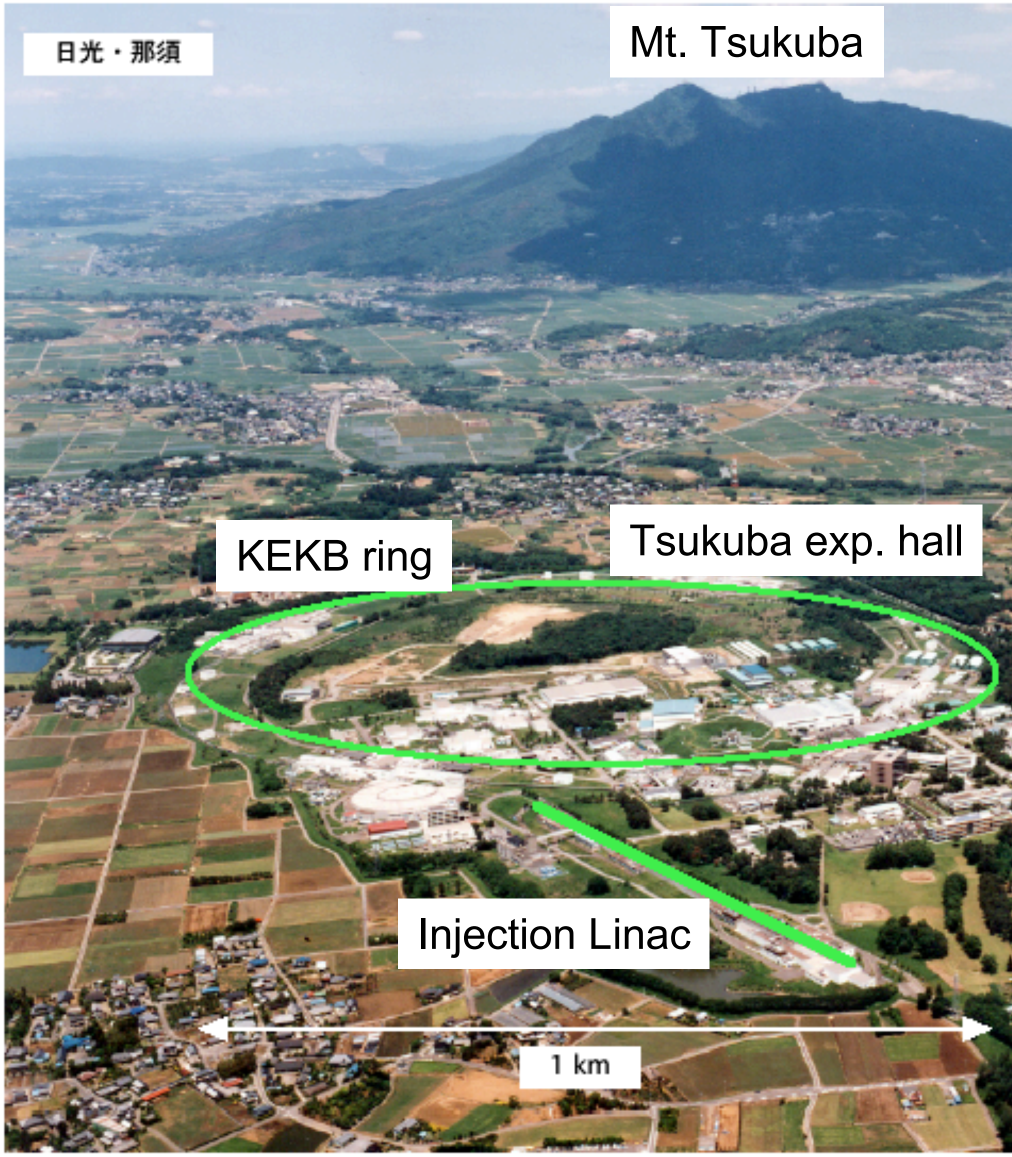
Seminar at Frascati

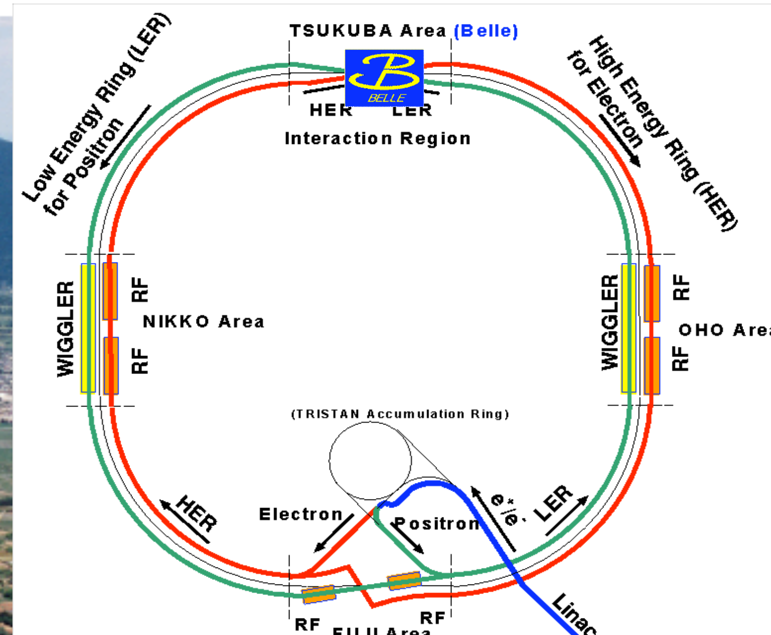
Masa Yamauchi
KEK

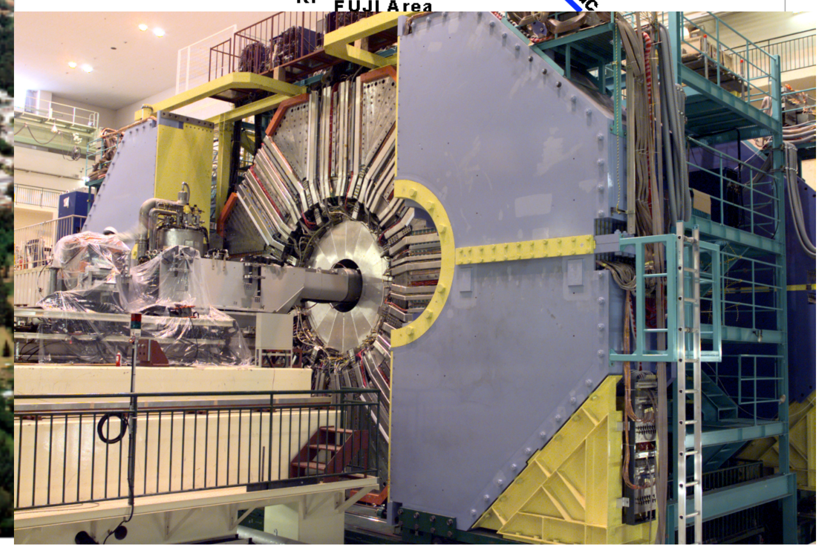
Outline

- Introduction
- Scientific achievements of the *B* factories
- Fundamental questions and *B* physics' approach to them
- Super KEKB physics
- Super KEKB machine, detector and schedule
- Summary

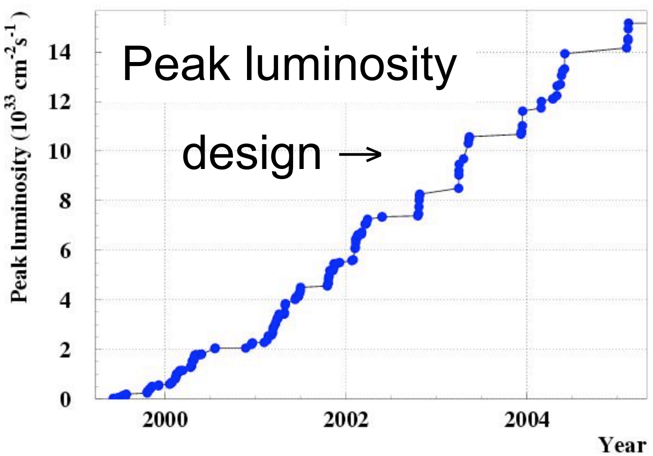
KEKB

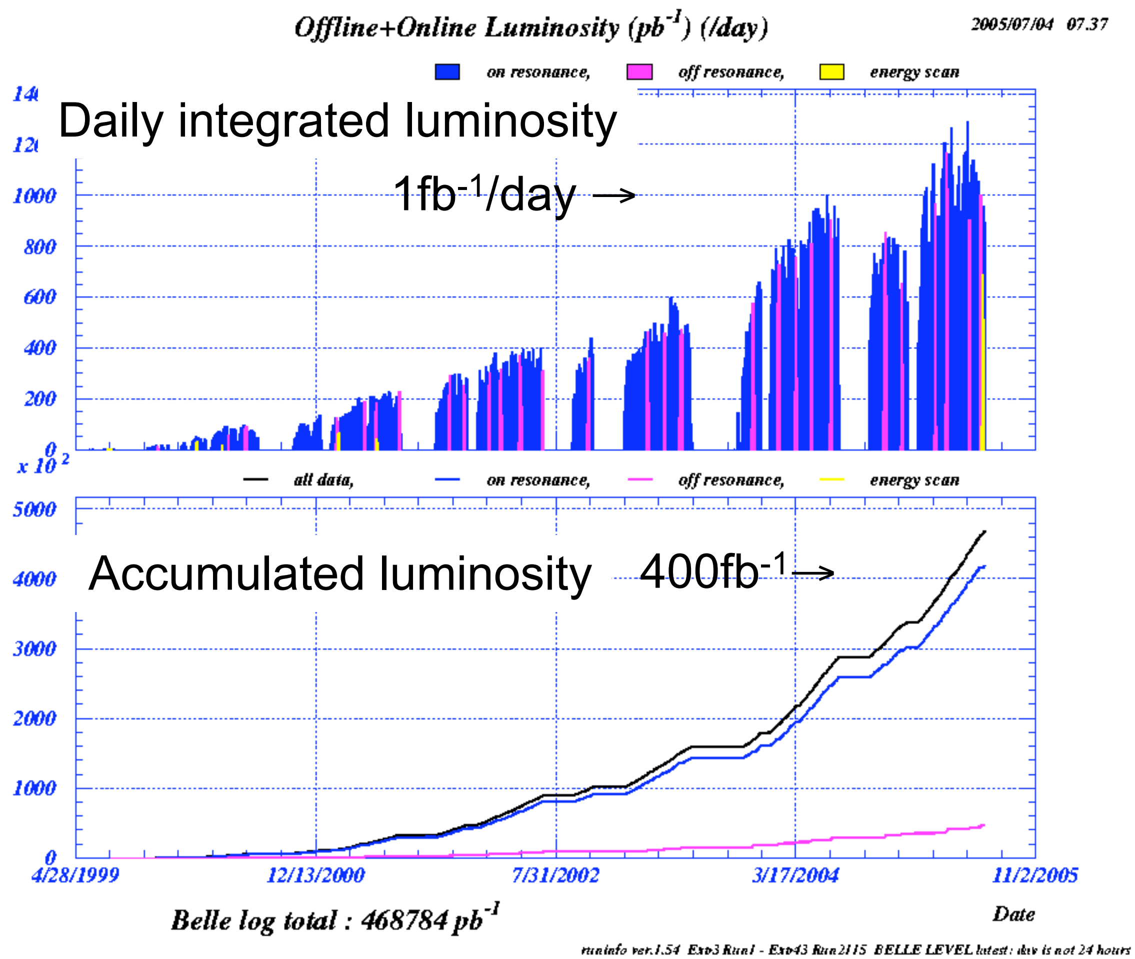

日光・那須
Mt. Tsukuba
KEKB ring
Tsukuba exp. hall
Injection Linac
1 km


TSUKUBA Area (Belle)
HER
LER
Interaction Region
Low Energy Ring (LER)
for Positron
High Energy Ring (HER)
for Electron
WIGGLER
RF
RF
NIKKO Area
WIGGLER
RF
RF
OHO Area
(TRISTAN Accumulation Ring)
HER
Electron
Positron
LER
Linac
RF
FUJI Area
RF



Luminosity





- World record of the peak luminosity ~1.5×10^{34}/cm^2/s
- ~500M *BB* and ~400M $\tau^+\tau^-$ events have been recorded.

Belle Collaboration

Aomori U.
BINP
Chiba U.
Chonnam Nat'l U.
U. of Cincinnati
Ewha Womans U.
Frankfurt U.
Gyeongsang Nat'l U.
U. of Hawaii
Hiroshima Tech.
IHEP, Beijing
IHEP, Moscow

IHEP, Vienna
ITEP
Kanagawa U.
KEK
Korea U.
Krakow Inst. of Nucl. Phys.
Kyoto U.
Kyungpook Nat'l U.
EPF Lausanne
Jozef Stefan Inst. / U. of Ljubljana / U. of Maribor
U. of Melbourne

Nagoya U.
Nara Women's U.
National Central U.
Nat'l Kaoshiung Normal U.
National Taiwan U.
National United U.
Nihon Dental College
Niigata U.
Osaka U.
Osaka City U.
Panjab U.
Peking U.
U. of Pittsburgh
Princeton U.
Riken
Saga U.
USTC

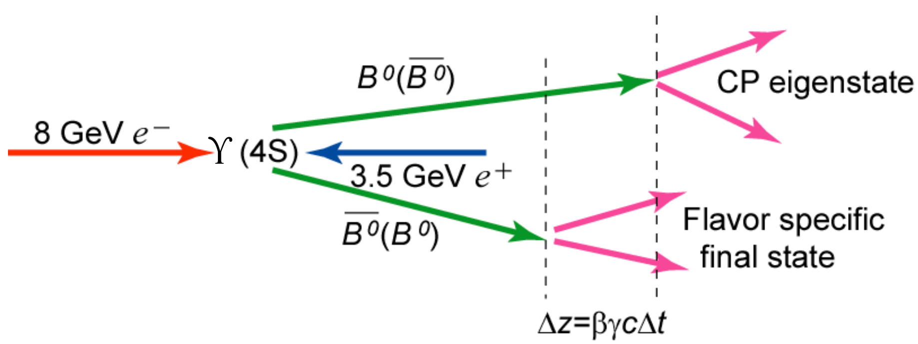
Seoul National U.
Shinshu U.
Sungkyunkwan U.
U. of Sydney
Tata Institute
Toho U.
Tohoku U.
Tohuku Gakuin U.
U. of Tokyo
Tokyo Inst. of Tech.
Tokyo Metropolitan U.
Tokyo U. of Agri. and Tech.
Toyama Nat'l College
U. of Tsukuba
Utkal U.
VPI
Yonsei U.

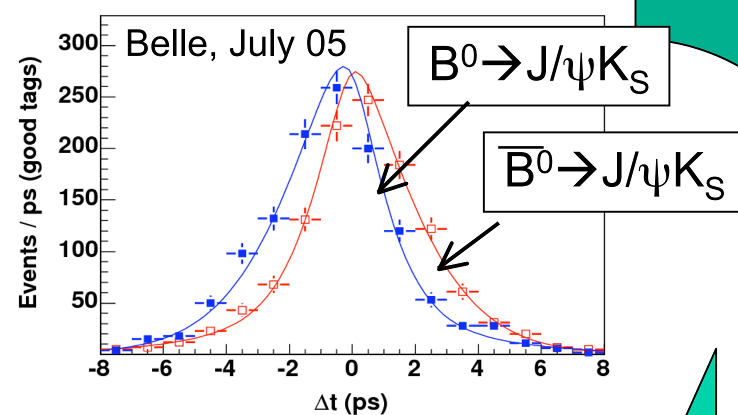
13 countries, 57 institutes, ~400 collaborators

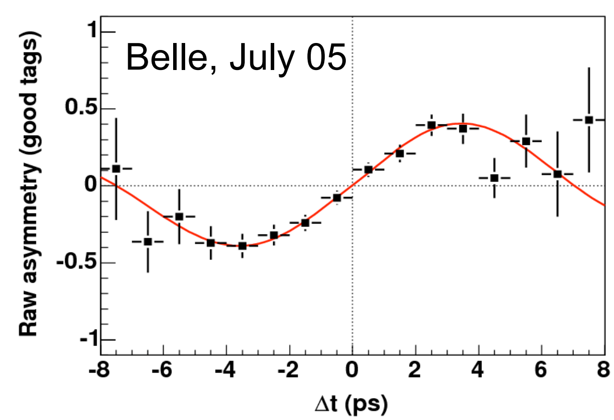
Scientific Achievements of *B* Factories (1)

Observation of CPV in the *B* meson system

$$A_{CP}(t) = \frac{\Gamma(\overline{B} \to f_{CP};t) - \Gamma(B \to f_{CP};t)}{\Gamma(\overline{B} \to f_{CP};t) + \Gamma(B \to f_{CP};t)} = A_f \cos\Delta mt + S_f \sin\Delta mt$$







$A_f \sim 0$

$S_f = 0.652 \pm 0.039 \pm 0.020$

Consistent with BaBar's meas.

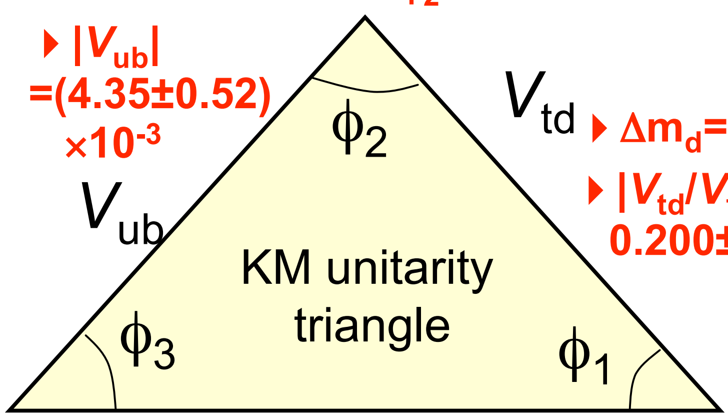
Observation of CPV in the *B* meson system

- Its impact on particle physics
  - Second evidence for CPV 40 years after the first observation by Fitch, Cronin *et al*.
  - CPV is not a very special phenomenon restricted to the neutral *K* system.
- Citations: 926 (Belle)

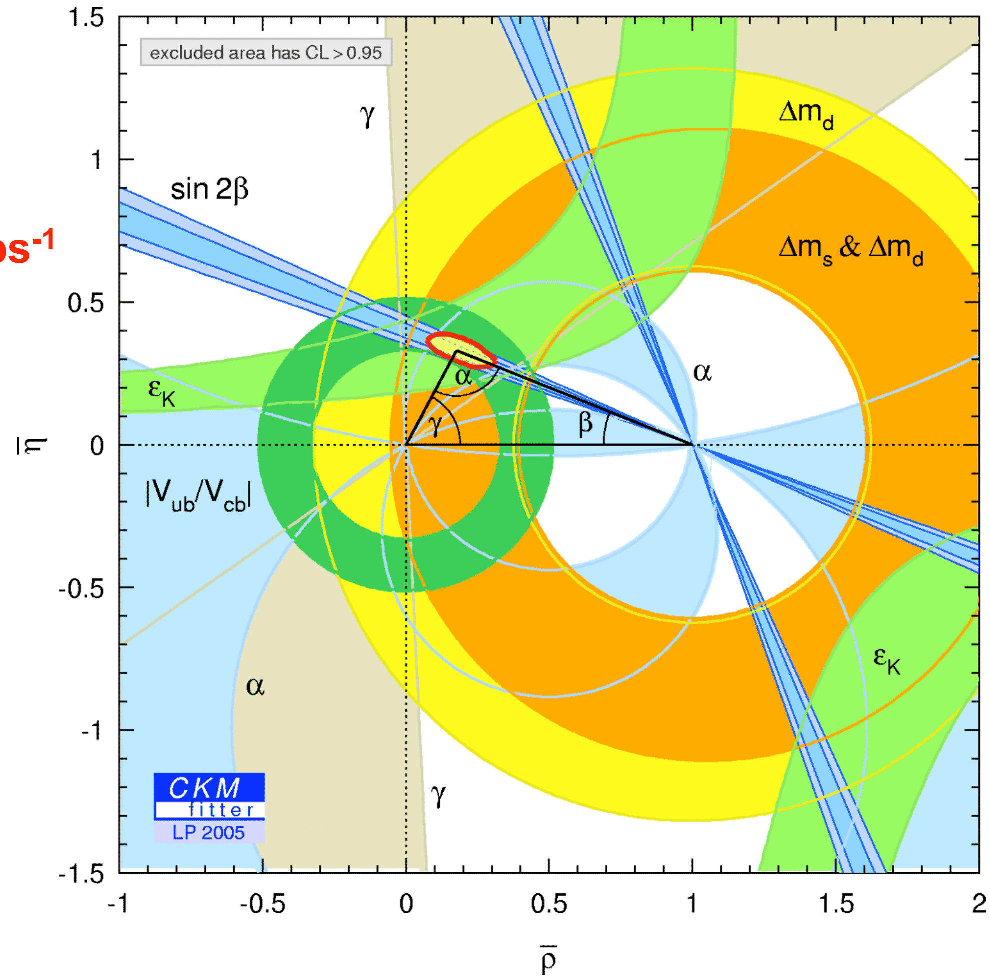
Scientific Achievements of *B* Factories (2)

Quantitative confirmation of the KM theory

- $75° < \phi_2 < 113°$
- $|V_{ub}|=(4.35\pm0.52)\times10^{-3}$



- $\Delta m_d=0.511 ps^{-1}$
- $|V_{td}/V_{ts}|=0.200\pm0.046$
- $22°<\phi_3<113°$
- $\sin2\phi_1=0.728\pm0.061$
- $|V_{cb}|=(4.08\pm0.27)\times10^{-2}$



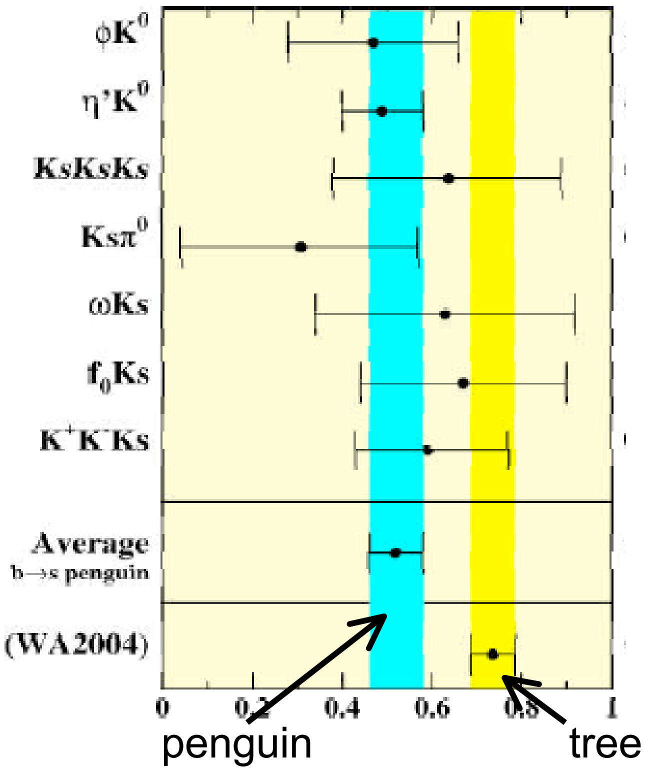
Quantitative confirmation of the KM theory

- Its impact on particle physics
  - Confirmed that Kobayashi-Maskawa model describes CPV at the weak scale.
  - KM matrix was determined including its complex phases. SM acquired predictive power.

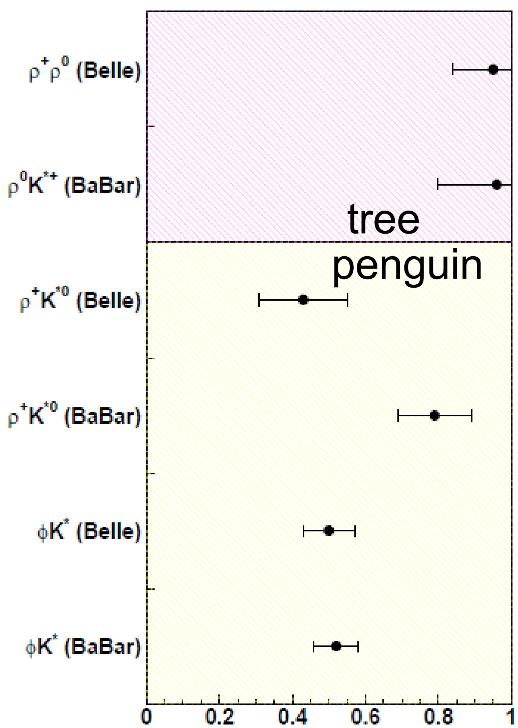
Scientific Achievements of *B* Factories (3)

Hints for new physics?

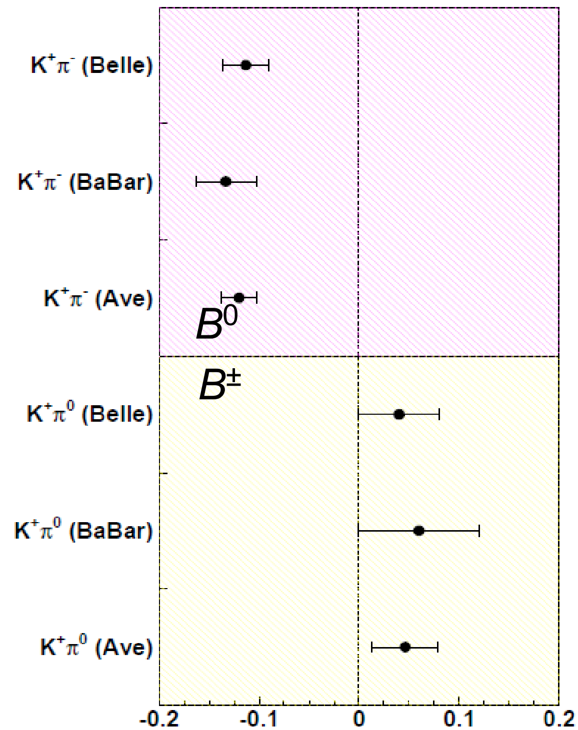
CPV(tree)~CPV(penguin) if only SM is assumed.



f_L (B→VV) ~ 1 in SM



A_{CP}(B→Kπ) is equal between *B*± and *B*⁰.



These hint at new physics contributing to b→s penguin processes.

Hints for new physics

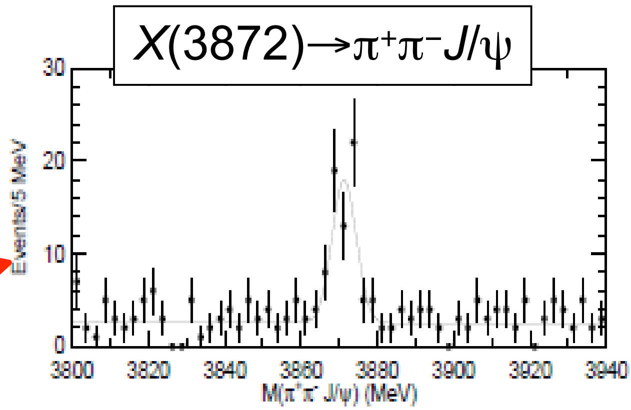
- Their impact on particle physics
  - Signature of the long-awaited new physics beyond the standard model (if confirmed).
    - Modern high energy physics experiments are all driven by new physics!
    - If new physics is present at a TeV scale, it is unlikely that it does not show up in *B* decays.
    - Weak interaction was understood well before *W* and *Z* were discovered at the energy frontier experiments.

Scientific Achievements of *B* Factory (4)

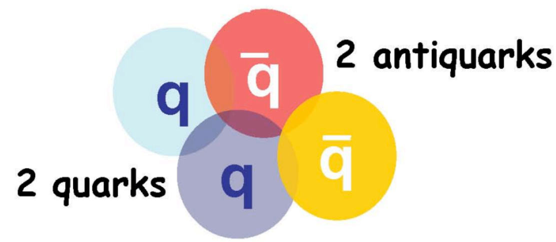
Unanticipated new resonances

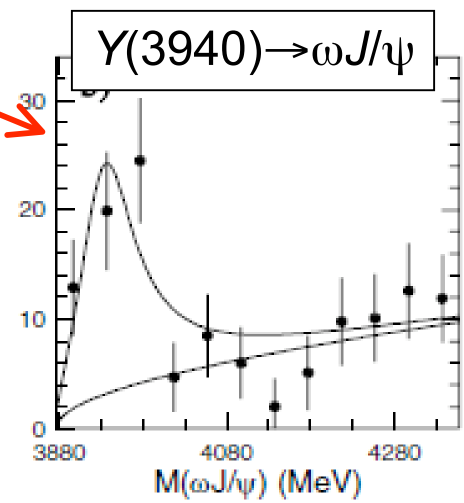
New resonances observed by Belle

- $\eta_c(3653)$
- *X*(3872)
- *X*(3940)
- *Y*(3940)
- *Z*(3930)
- *D**(2308)
- *D*'(2427)
- $\Sigma_c(2800)$



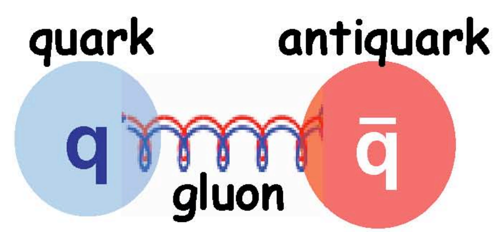
- Mass and width are incompatible with charmonium hypothesis.
- $J^{PC}=1^{++}$ is strongly favored: consistent with *DD** molecule hypothesis.





- A *cc* charmonium meson with this mass would dominantly decay to *DD* and/or *D*D*, and BR($Y\rightarrow\omega J/\psi$) should be very small.

***Y*(3940) = *ccg* hybrid?**



Unanticipated new resonances

- Their impact on particle physics
  - First evidences for “meson molecule” and “hybrid state” (if confirmed)
  - Physics of multi-quark states will be opened.
    - Pentaquark is a multi-quark baryon.

Other "first observations" by *B* factories

- $b \to d$ transitions
  - $B \to (\rho,\omega)\gamma$ and $B \to KK$ decays
- Color suppressed hadronic *B* decays
  - $B \to \pi^0\pi^0$ and $B \to D\pi^0$ decays
- Direct CP violation
  - $B \to K^+\pi^-$ and time dependent analysis of $B \to \pi^+\pi^-$
- EW penguin process, $b \to s l^+ l^-$
  - $B \to K^{(*)} l^+ l^-$ and pseudo-reconstruction of the inclusive process
- Non-spectator *B* decays
  - $B^0 \to D_s^+ K^-$

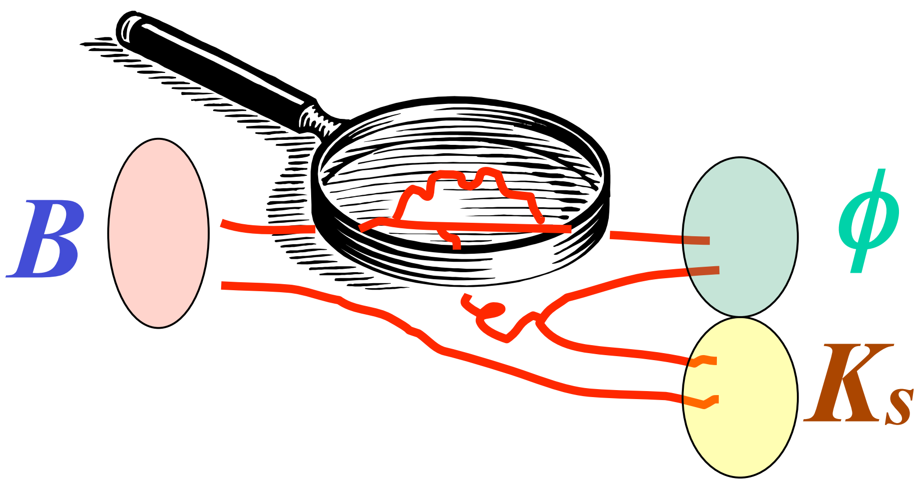
Fundamental questions

- There are very fundamental unanswered questions related to quark flavor.
  - *What is the origin of flavor mixing and CP violation?*
  - *What is the origin of the matter-dominant universe?*
  - *What is the flavor structure in the "beyond SM"?*
    (*If BSM=SUSY, what is the mechanism of the SUSY breaking?*)

B physics' approach to these questions

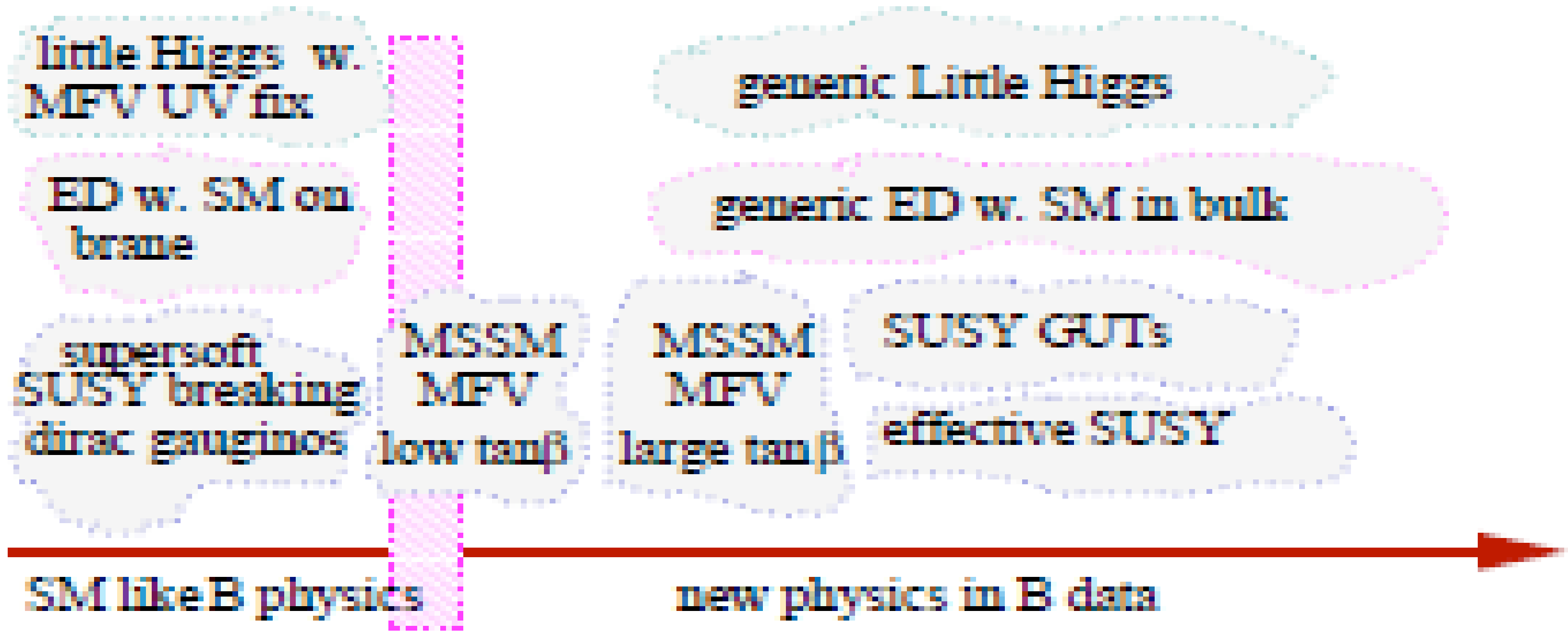
- Questions to be answered by *B* physics:
  - *Are there new CP-violating phases?*
  - *Are there new right-handed currents?*
  - *Are there new flavor-changing interactions with b, c or τ?*

SuperKEKB will answer these questions by scrutinizing loop diagrams.



New physics effect in B physics

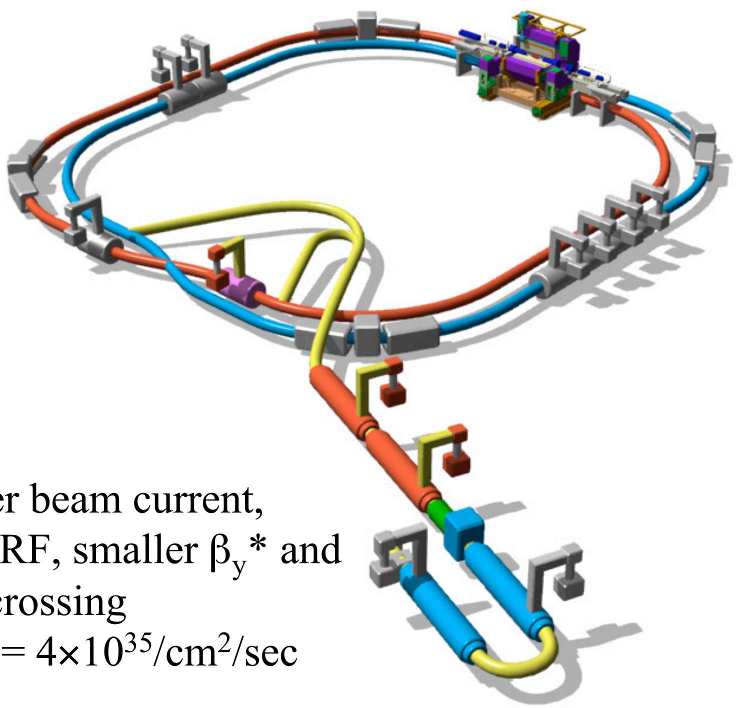
G.Hiller



Likelihood for the effects of new physics to be seen in *B* decays.

Super KEKB

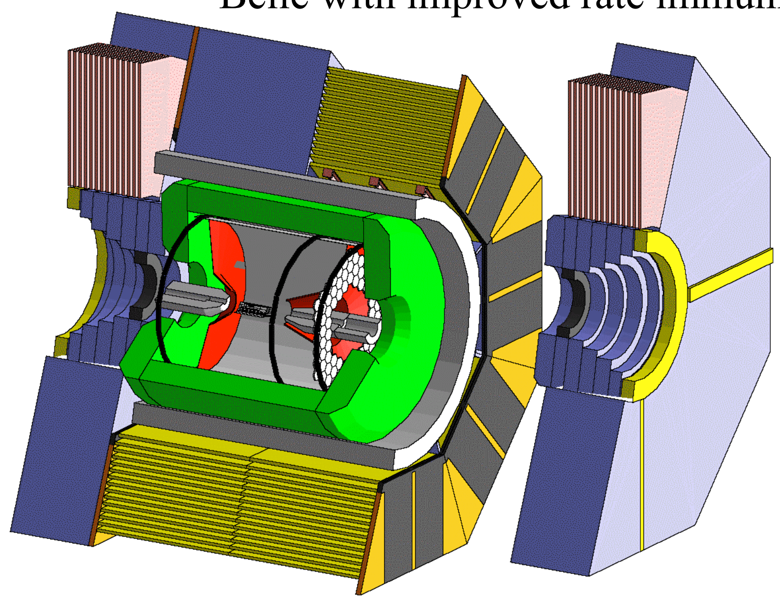
- *Asymmetric energy e^+e^- collider at $E_{CM}=m(\Upsilon(4S))$ to be realized by upgrading the existing KEKB collider.*
- *Super-high luminosity $\cong 4\times10^{35}$/cm^2/sec $\rightarrow$ 5×10^9 BB per yr.*



Higher beam current, more RF, smaller β_y* and crab crossing
$\rightarrow$ L = 4×10^{35}/cm^2/sec

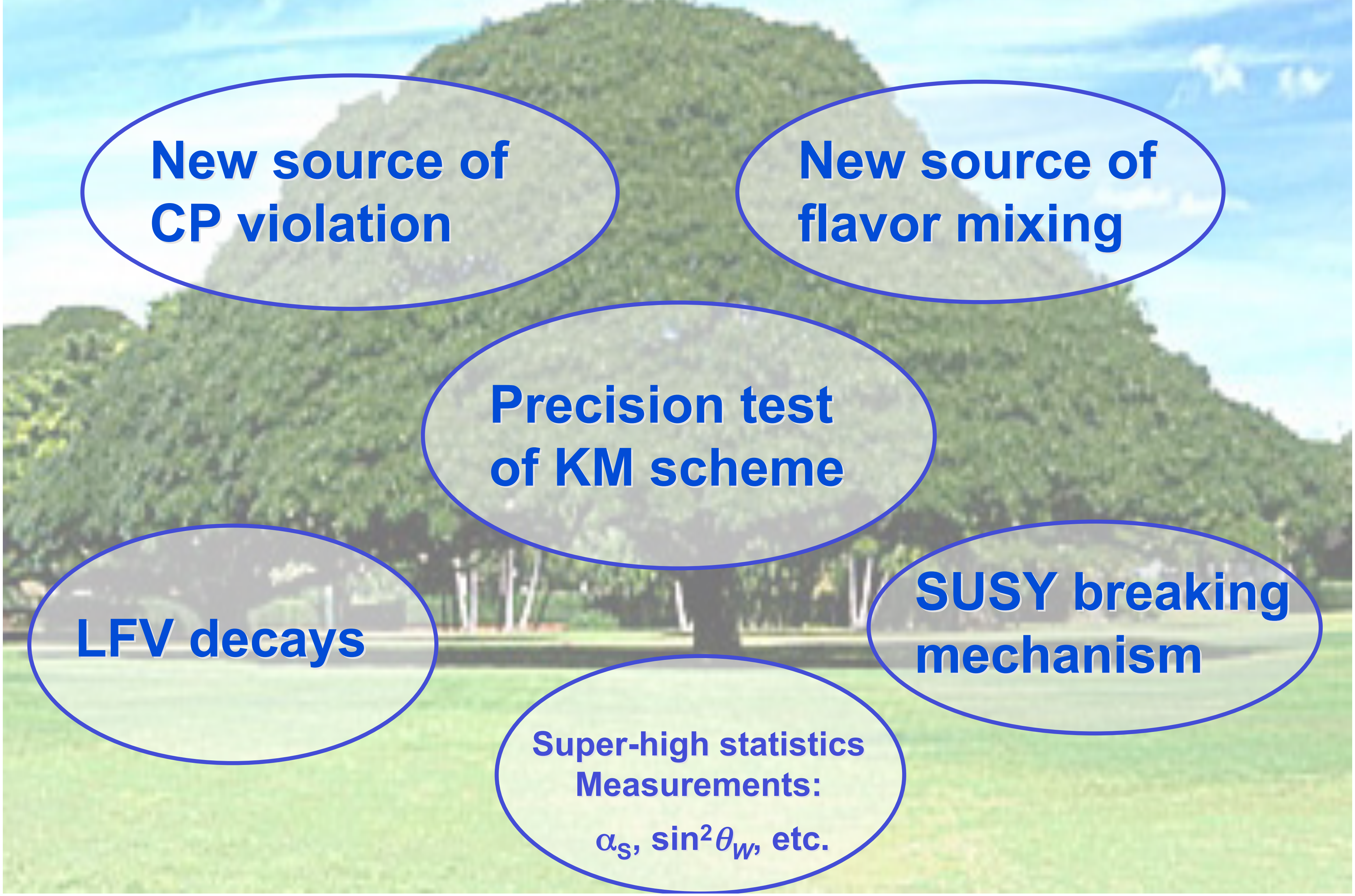
$\rightarrow$ 4×10^9 $\tau^+\tau^-$ per

Belle with improved rate immunity



http://belle.kek.jp/superb/loi

Physics at Super KEKB



Precision test of KM scheme

50 ab^{-1}

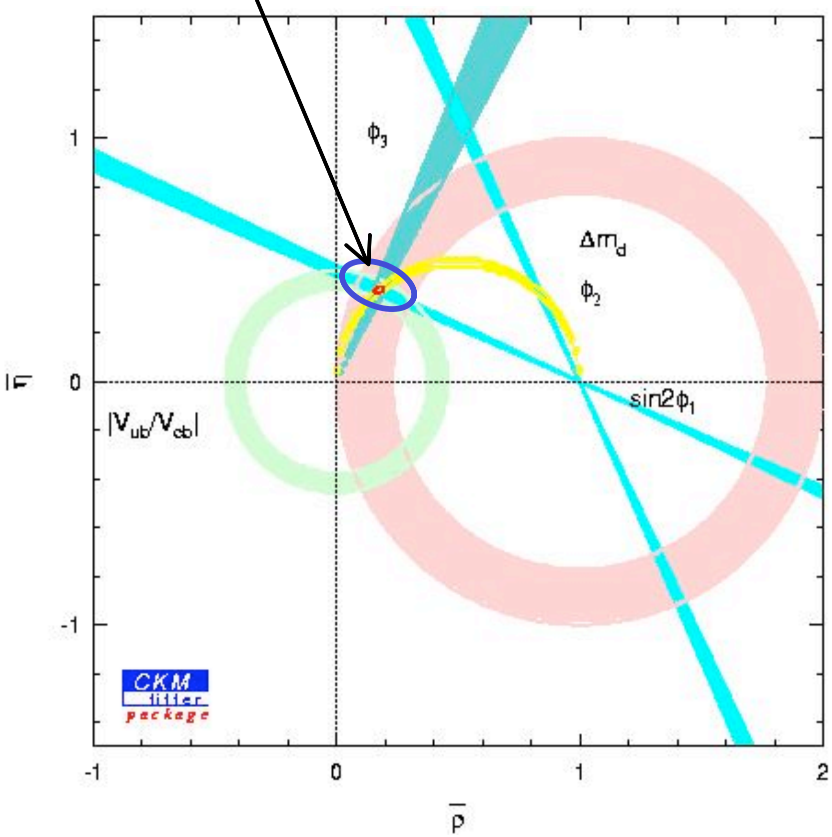
$$\Delta \sin 2\phi_1 = 0.014$$

$$\Delta(f_B\sqrt{B_d}) = 0.005 \pm 0.015$$

$$\Delta |V_{ub}| = 4.4\%$$

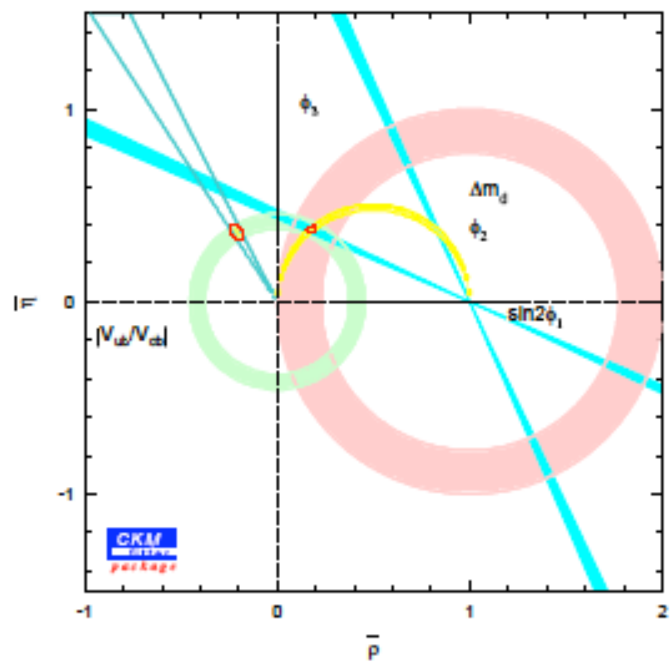
$$\Delta\phi_3 = 1.2^\circ$$

Result with 0.3fb^{-1}

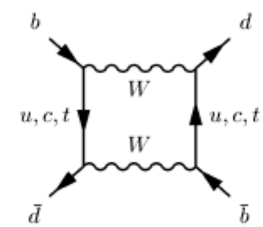


or

If tree-level and *b*→*d* mixing processes give inconsistent results,



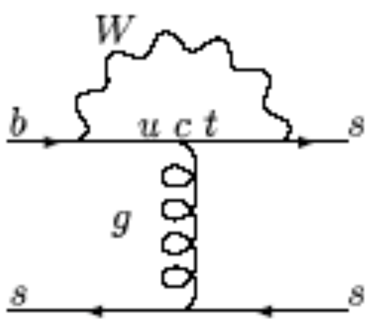
…indicates something new in



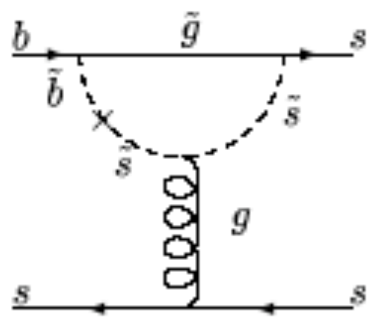
Search for new CP phases

In general, new physics contains new sources of flavor mixing and CP violation.

- In SUSY models, for example, SUSY particles contribute to the $b \to s$ transition, and their CP phases change CPV observed in $B \to \phi K$, $\eta' K$ etc.

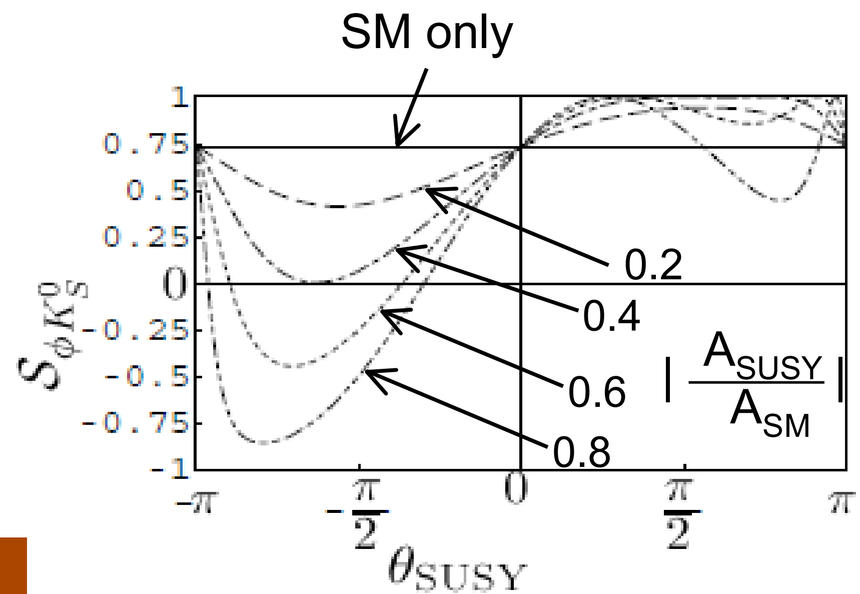


SM



SUSY contribution

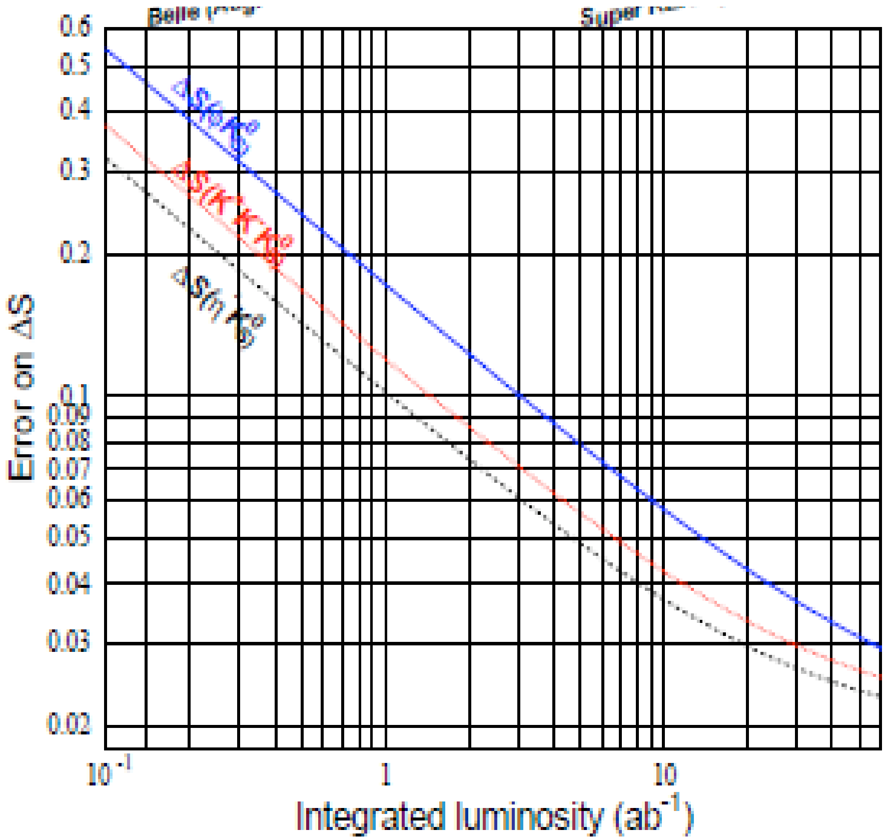
In general, if SUSY is present, the *s*-quark mixing matrix contains complex phases just as in the Kobayashi-Maskawa matrix.



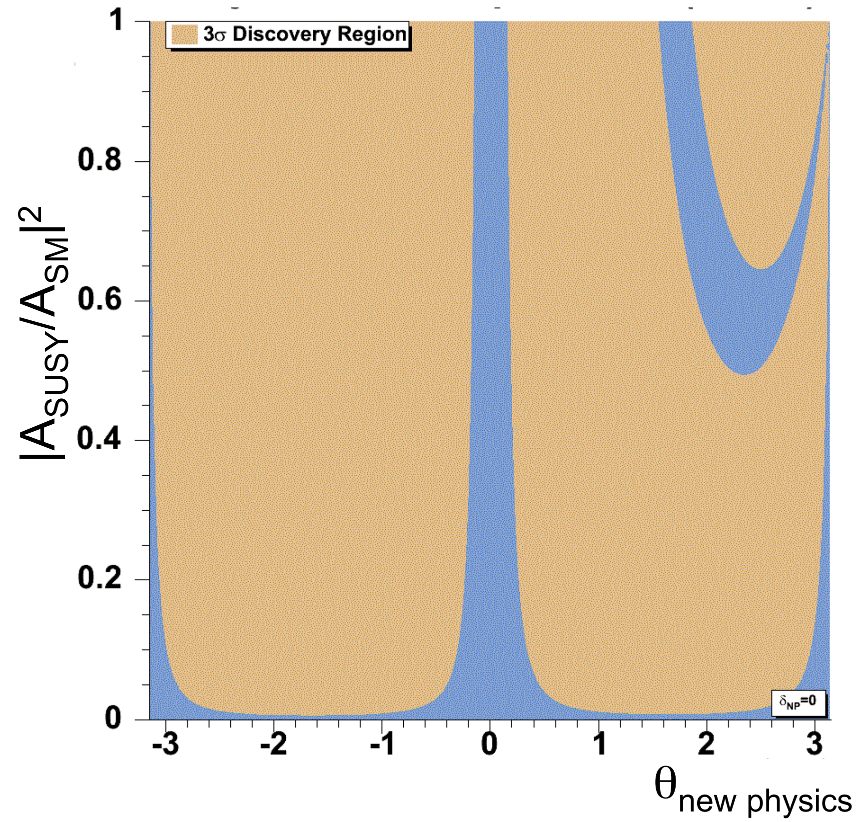
Effect of SUSY phase θ_{SUSY} on CPV in $B \to \phi K$ decay

Sensitivity to new CP phases

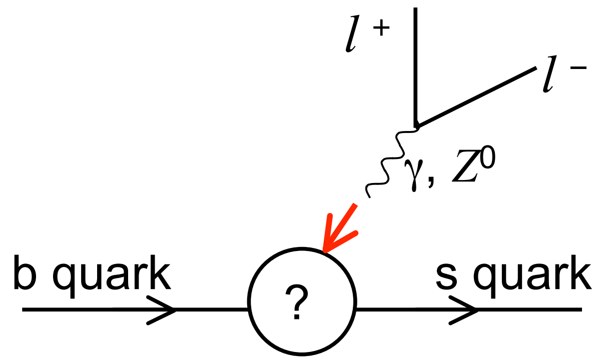
Estimated error in the measurement of time dependent CP violation



Discovery region with 50 ab^{-1}



Search for new flavor mixing



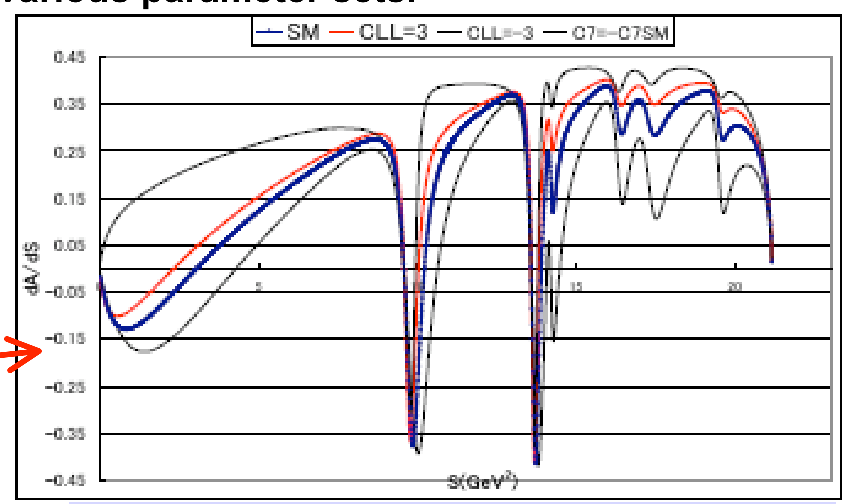
: Probe the flavor changing process with the “EW probe”.

This measurement is especially sensitive to new physics such as SUSY, heavy Higgs and extra dim.

Possible observables:

- Ratio of branching fractions
- Branching fraction
- CP asymmetry
- q^2 distribution
- Isospin asymmetry
- Triple product correlation
- Forward backward asymmetry
- Forward backward CP asymmetry

Theoretical predictions for l^+l^- forward-backward charge asymmetry for SM and SUSY model with various parameter sets.

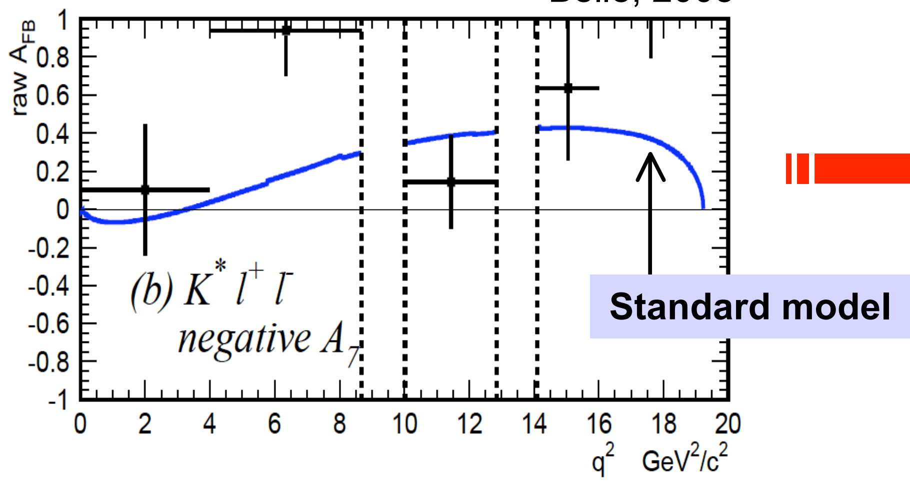


The F/B asymmetry is a consequence of γ-Z^0 interference.

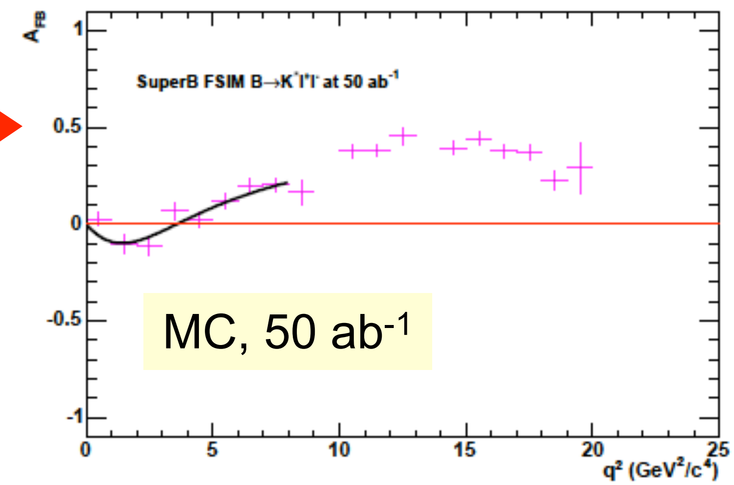
Sensitivity to new flavor mixing

Experimental result with 0.35 ab^{-1}

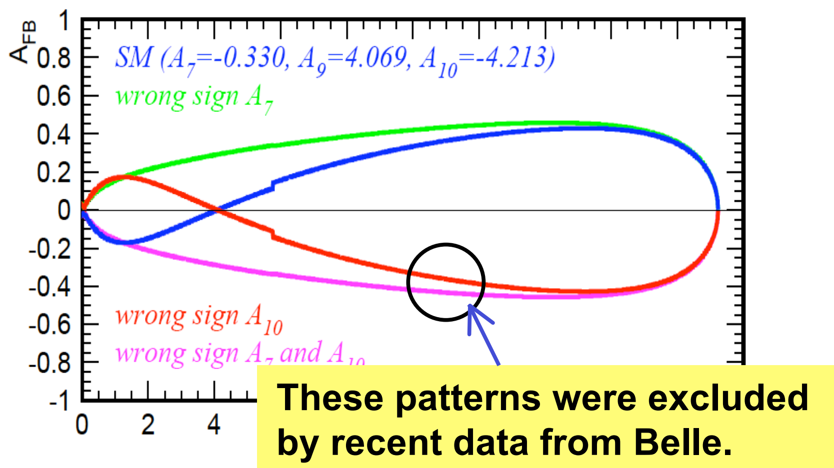
Belle, 2005



Sensitivity at Super KEKB



- Zero-crossing q^2 for A_{FB} will be determined with 5% error with 50ab^{-1}.



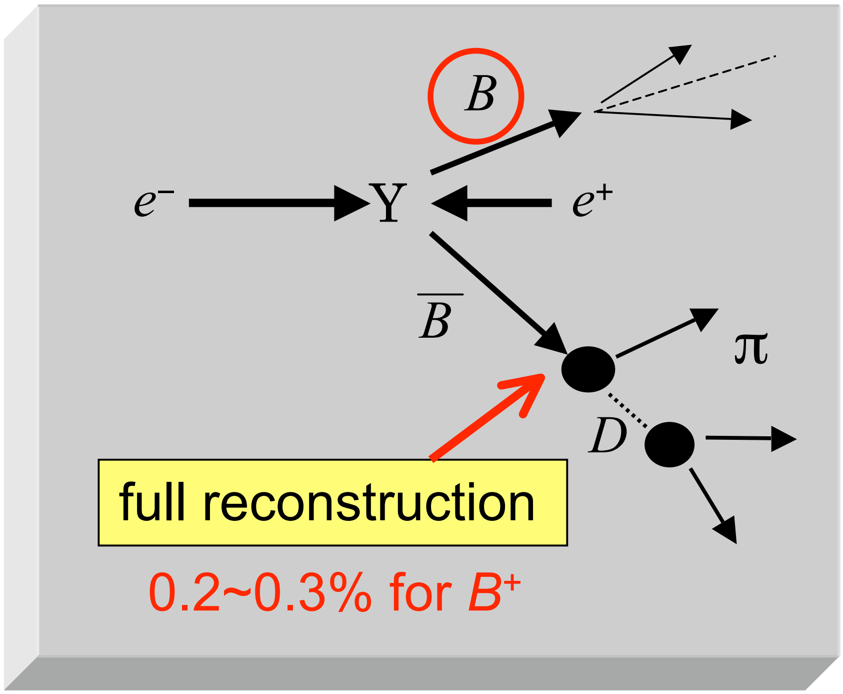
Identification of SUSY breaking scenario

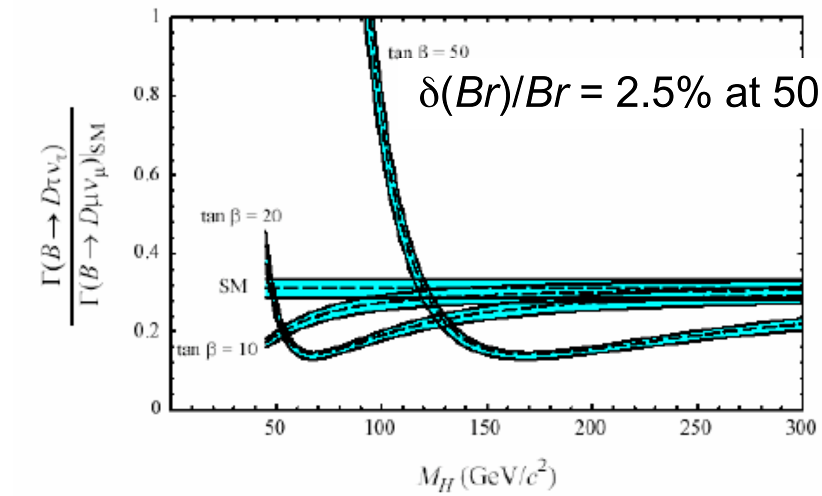
Pattern of deviations from the Standard Model Y.Okada

Observ-ables / SUSY models	Bd-unitarity	ε	Δ m(Bs)	B->ϕKs	B->Msγ indirect CP	b->sγ direct CP
mSUGRA	-	-	-	-	-	+
SU(5)SUSY GUT + νR (degenerate)	-	+	+	-	+	-
SU(5)SUSY GUT + νR (non-degenerate)	-	-	+	++	++	+
U(2) Flavor symmetry	+	+	+	++	++	++

++: Large, +: sizable, -: small

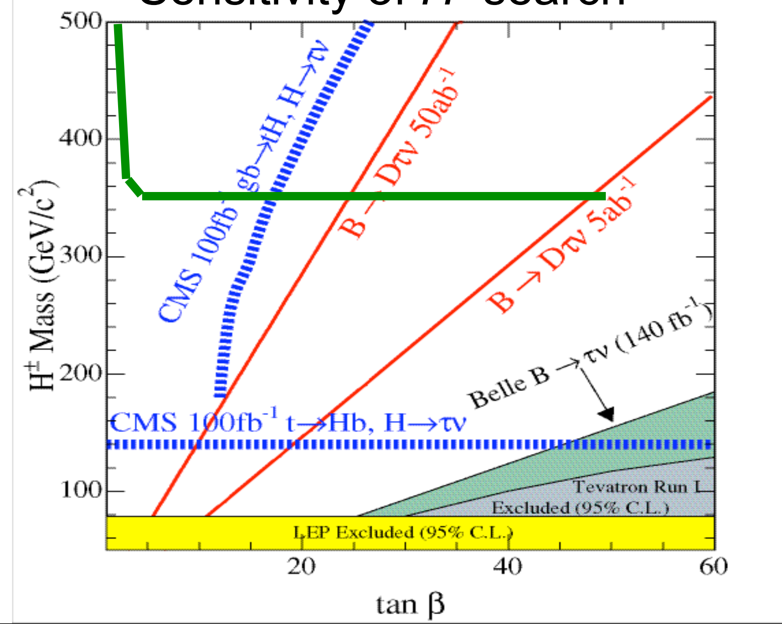
“*B* meson beam” technique





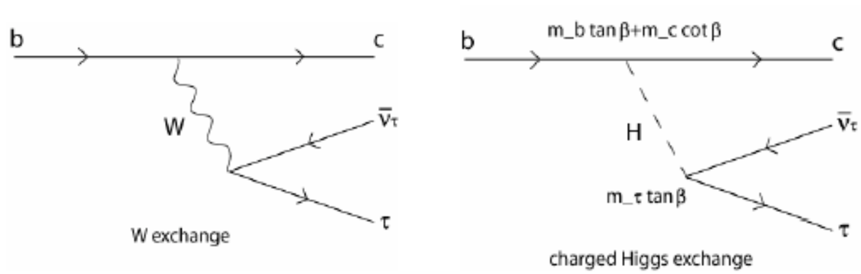
$\delta(Br)/Br$ = 2.5% at 50 ab^{-1}

Sensitivity of $H^{\pm}$ search



Application

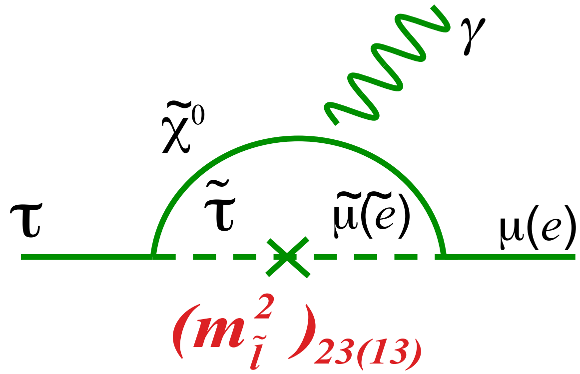
$H^{\pm}$ search in $B \to D^{(*)}\tau\nu$



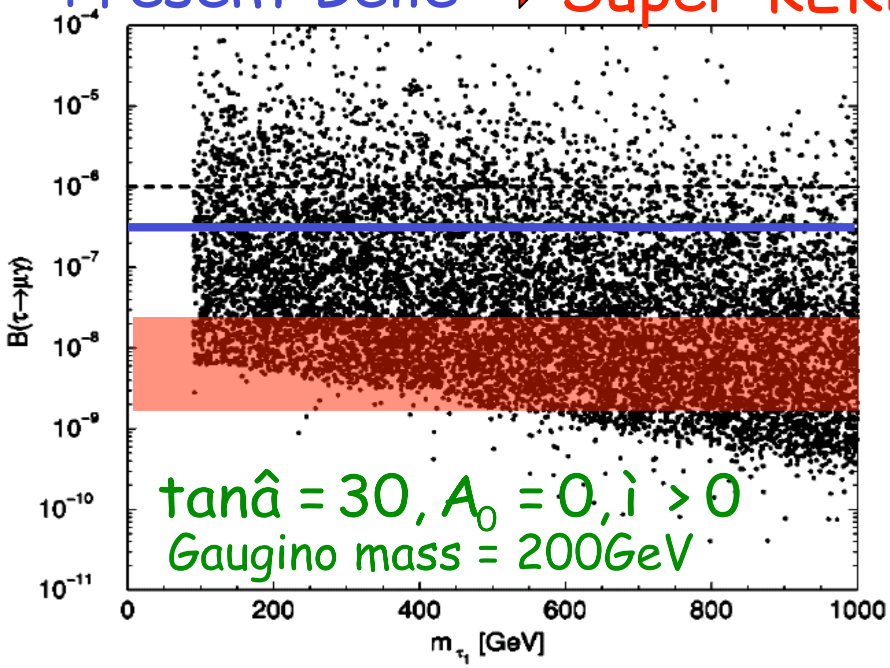
Search for flavor-violating τ decay

- SUSY + Seesaw
  - Flavor violation by ν-Yukawa coupling.
  - Large LFV Br(τ→μγ)=O($10^{-7\sim9}$)

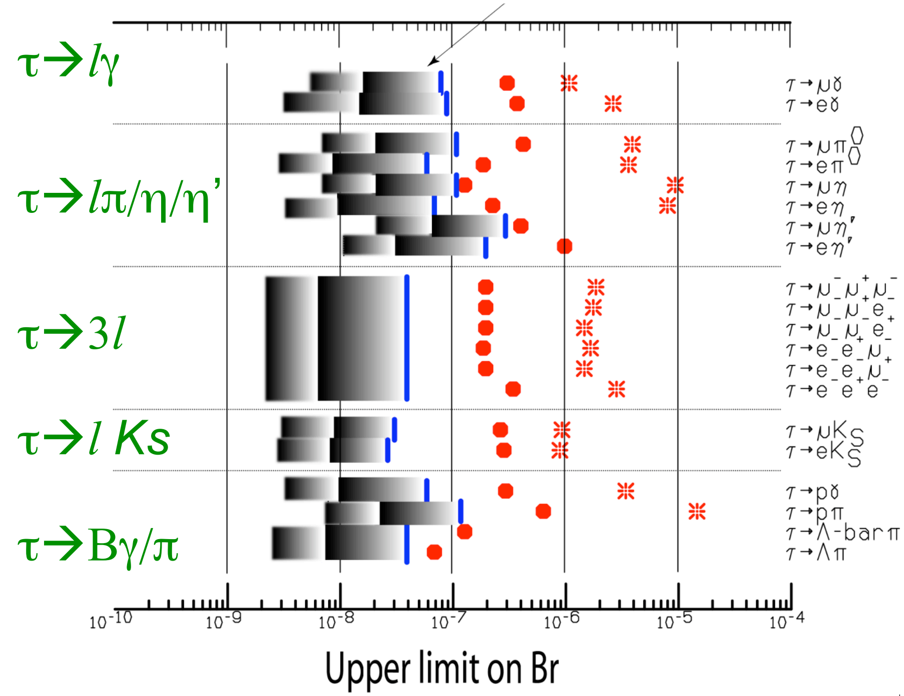
$$BR(\tau\to\mu\gamma) \sim 10^{-6} \times \frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}} \left(\frac{1\ \mathrm{TeV}}{m_{SUSY}}\right)^4 \tan^2\beta$$



Present Belle ➡ Super-KEKB

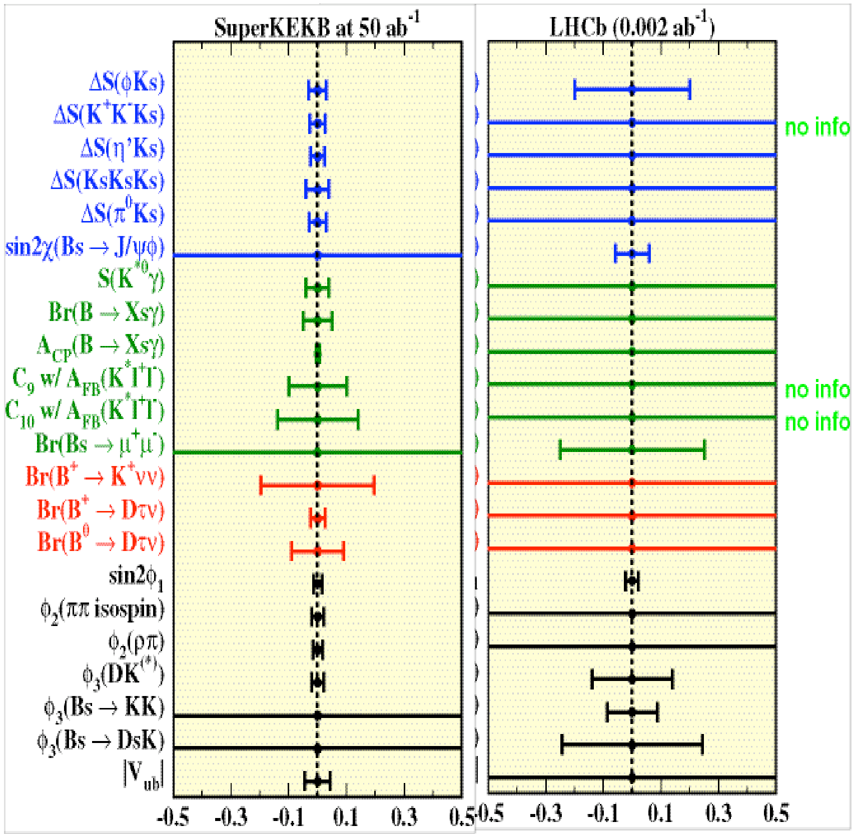


Expected sensitivity at Super KEKB

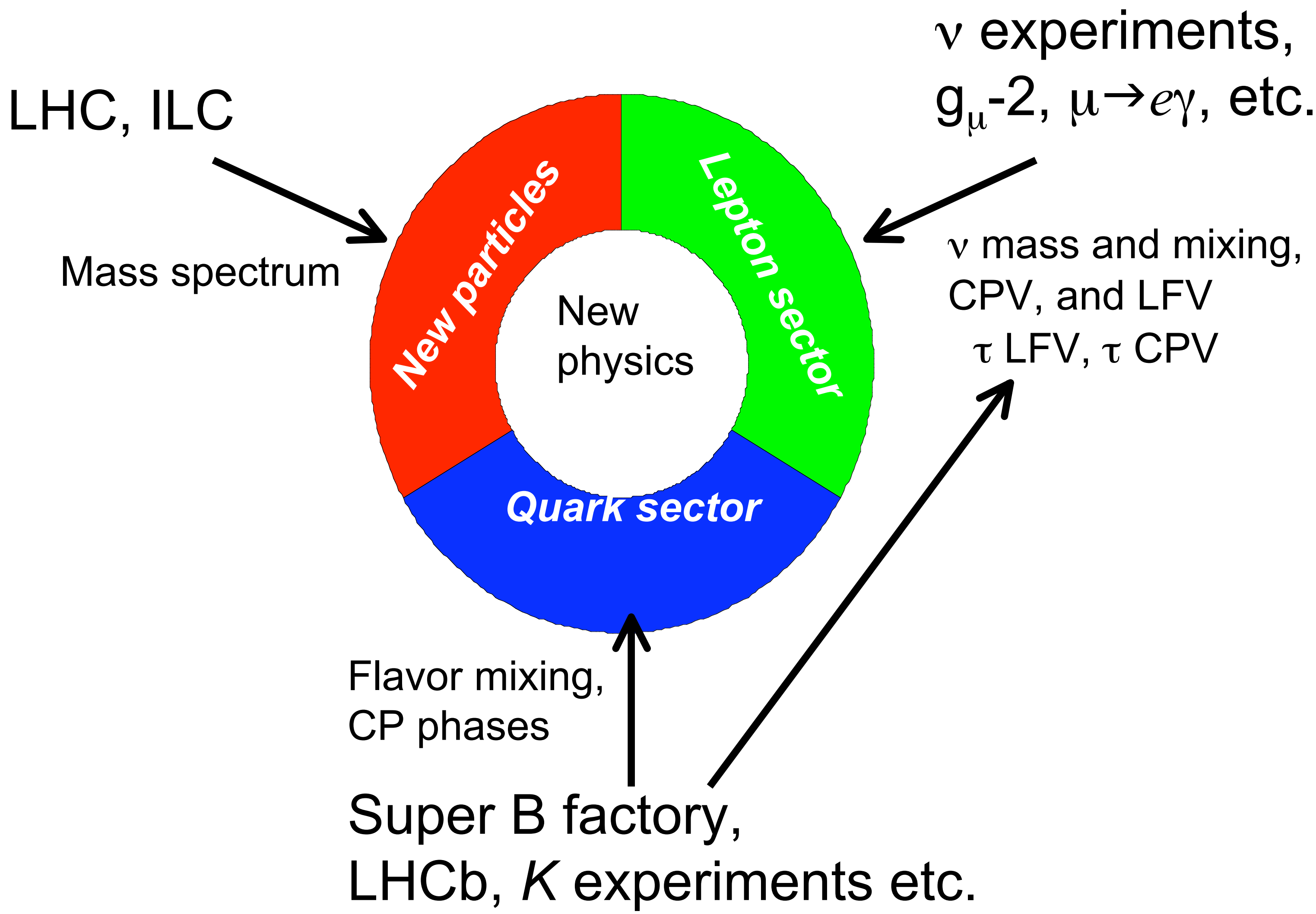


Comparisons with LHCb

- Clean environment → measurements that no other experiment can perform. Examples: CPV in $B \to \phi K^0$, $B \to \eta' K^0$ for new phases, $B \to K_S \pi^0 \gamma$ for right-handed currents.
- "*B*-meson beam" technique → access to new decay modes. Example: discover $B \to K \nu\nu$.
- Measure new types of asymmetries Example: forward-backward asymmetry in $b \to s\mu\mu$, *see*
- Rich, broad physics program including *B*, τ and charm physics Examples: searches for $\tau \to \mu\gamma$ and *D*-*D* mixing with unprecedented sensitivity.



Relation to other experiments

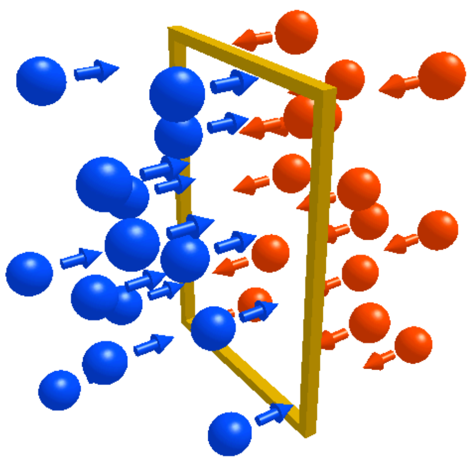


Note

- The parameters and designs of the machine and detector I show today are all “models”.

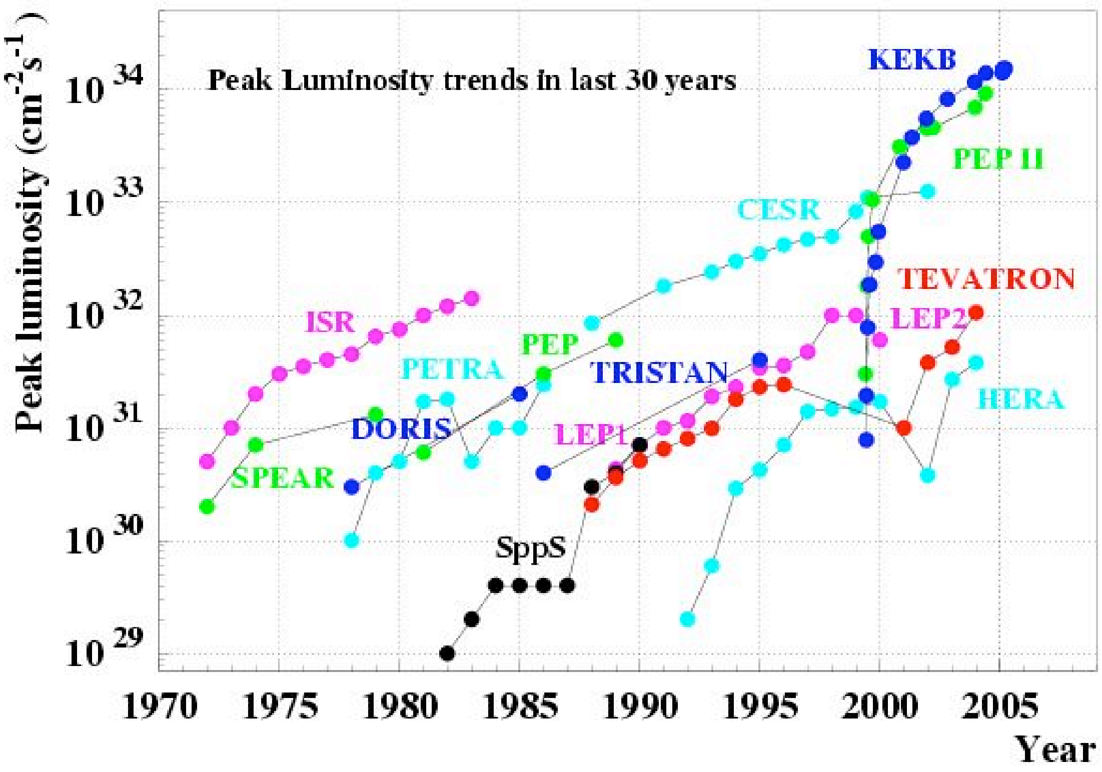
KEKB / SuperKEKB

The Luminosity Frontier

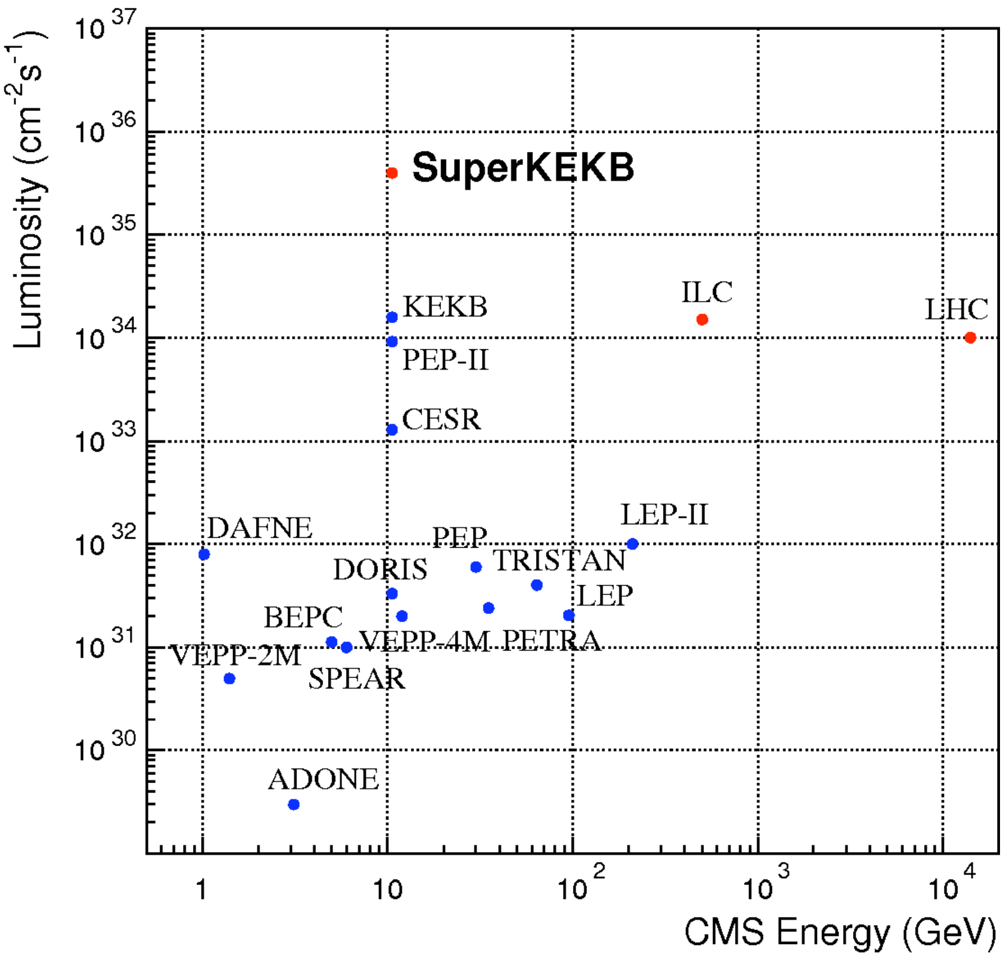


(number of events/unit time)

= (cross section) X (luminosity)



SuperKEKB, the next step



Super KEKB parameters

Stored current:

1.34/1.8 A (KEKB)

→ 4.1/9.4 A (SuperKEKB)

Beam-beam parameter:

0.057 (KEKB)

→ 0.19 (SuperKEKB)

Lorentz factor

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm\xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

Classical electron radius

Beam size ratio

Geometrical reduction factors due to crossing angle and hour-glass effect

Luminosity:

0.15 $\times 10^{35}$ cm^{-2}s^{-1} (KEKB)

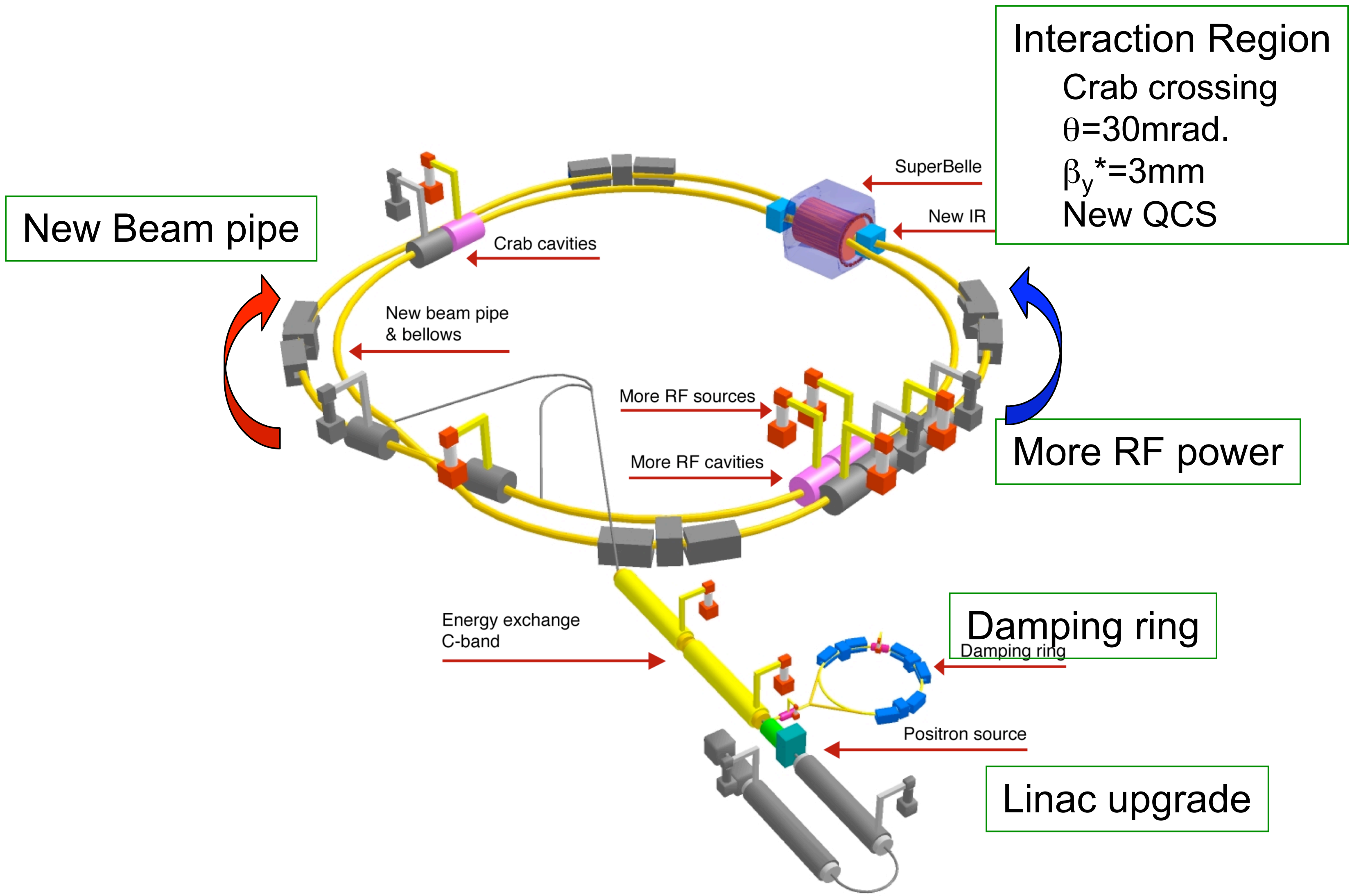
4×10^{35} cm^{-2}s^{-1} (SuperKEKB)

Vertical β at the IP:

6.2/6.5 mm (KEKB)

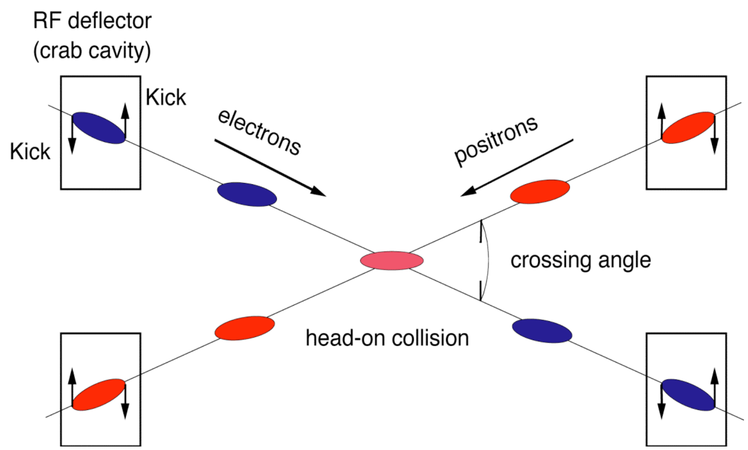
→ 3.0/3.0 mm (SuperKEKB)

Components to be upgraded

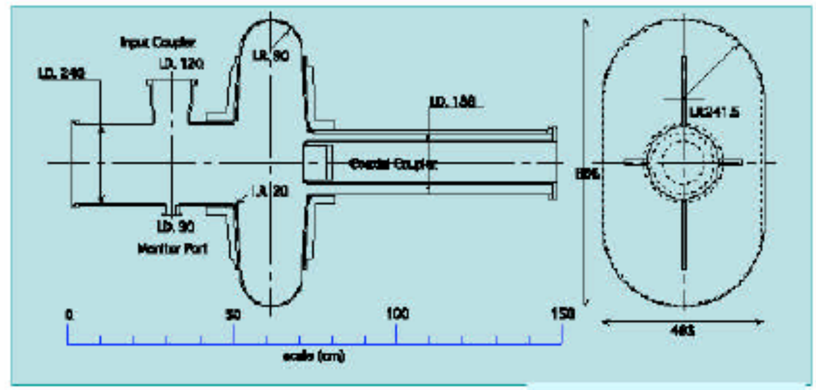


Crab cavity and ante-chamber

- Head-on collision w/ Crab cavity

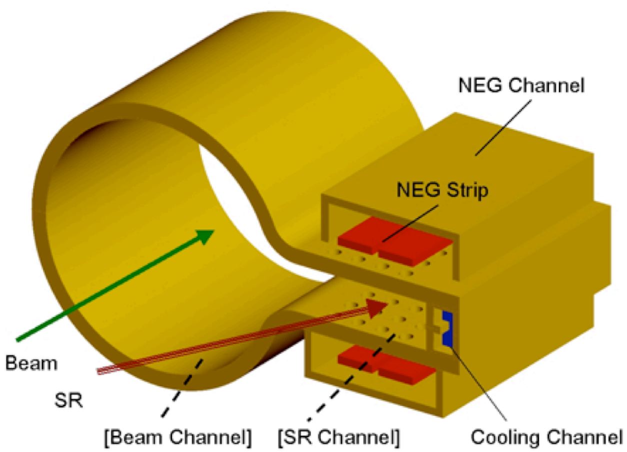


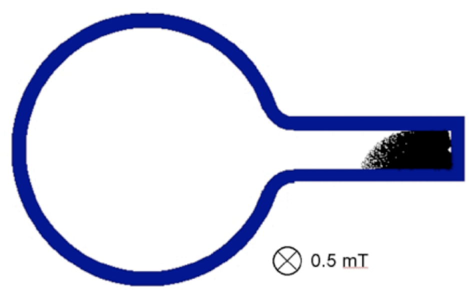
●Superconducting crab cavities are under development, will be installed in KEKB in early 2006.



K. Hosoyama, et al

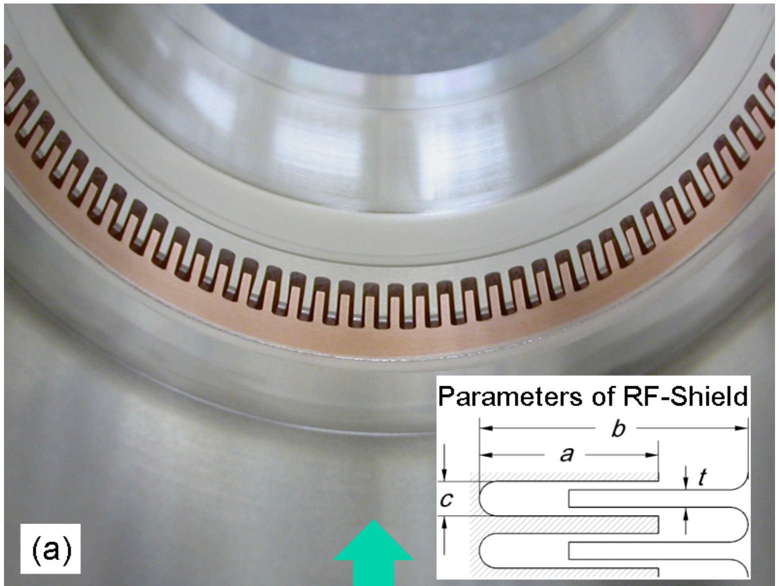
- Ante-chamber /solenoid for reduction of electron clouds

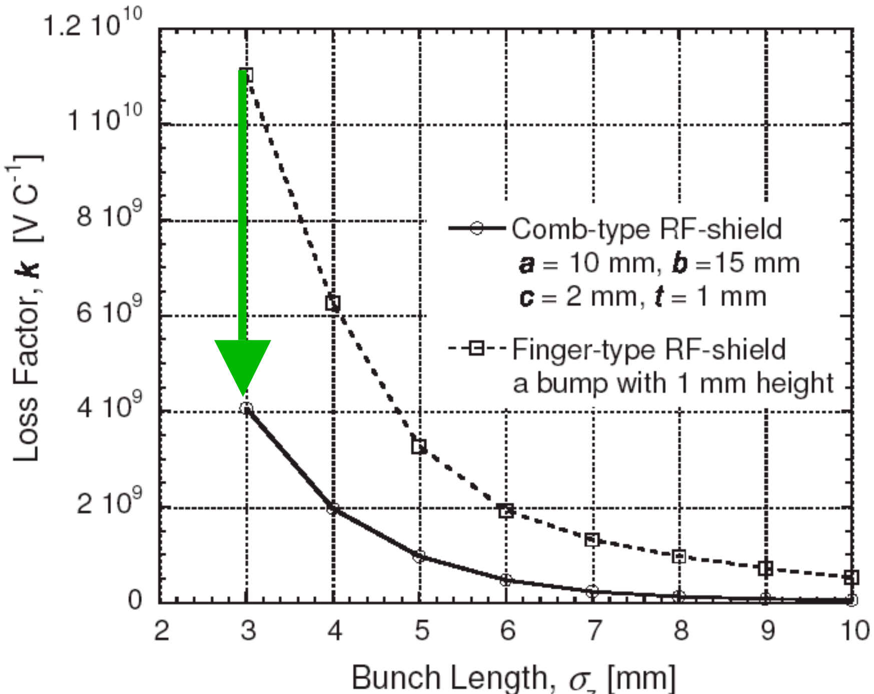




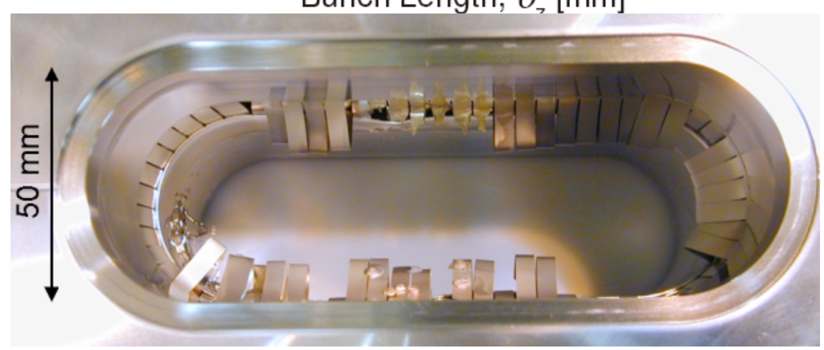
Ante-chamber
with solenoid field

Bellows chamber with comb type RF-shield



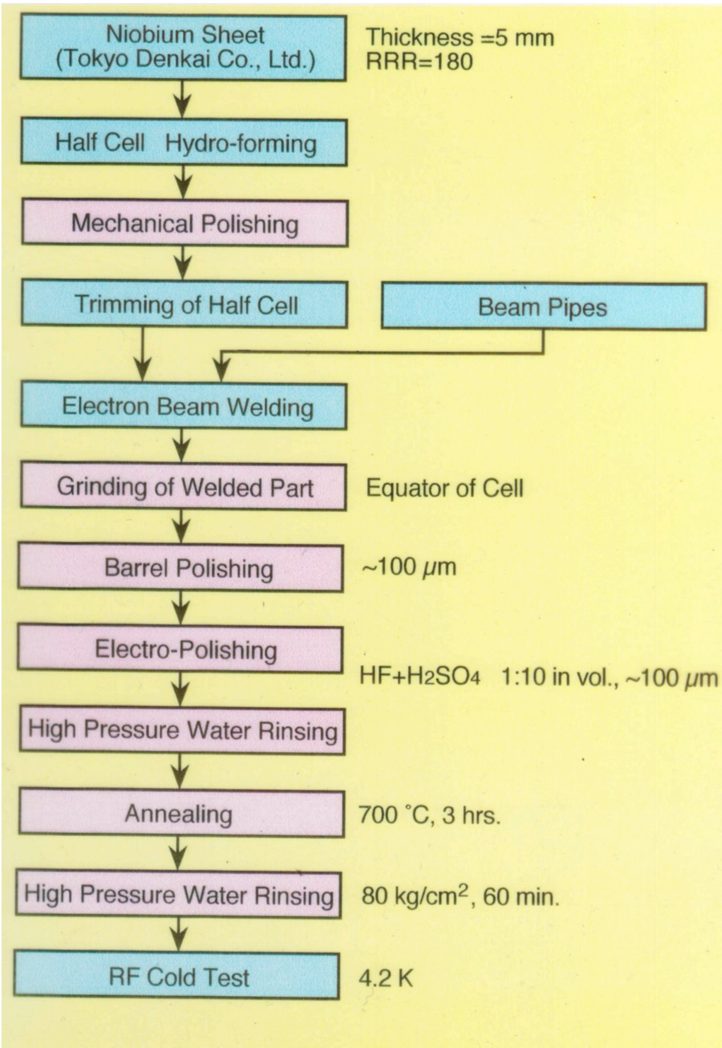


- High thermal strength
- Low impedance
- No sliding contact on the surface facing the beam

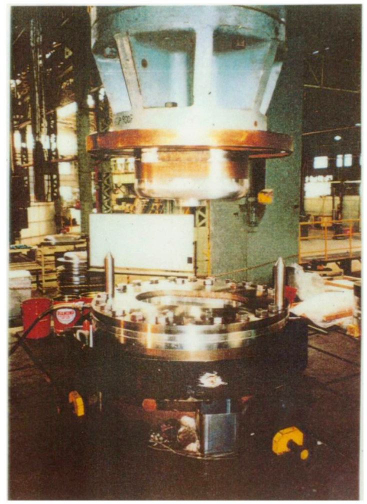


Comb-type bellows were installed in the LER (2004).

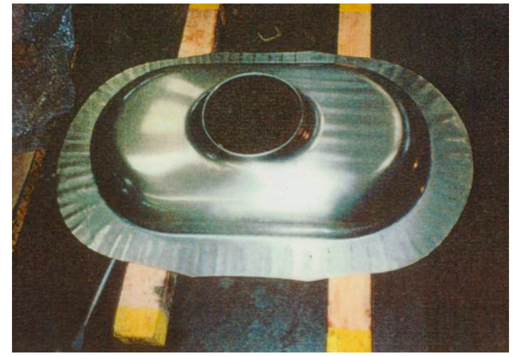
Fabrication & Processing 1



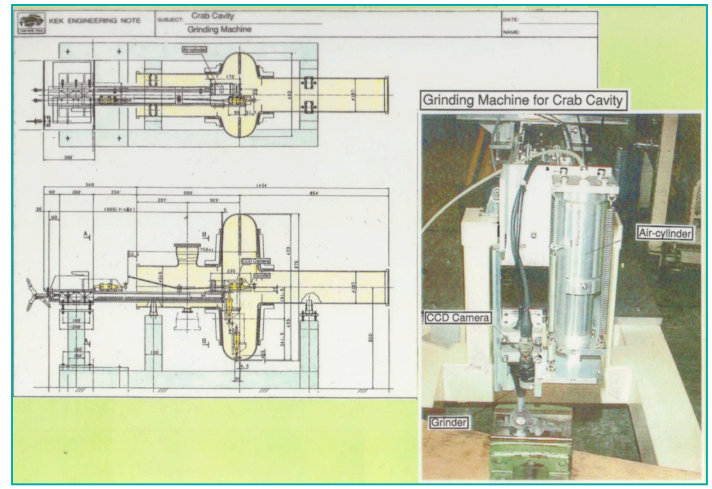
Fabrication & Processing of Crab Cavity



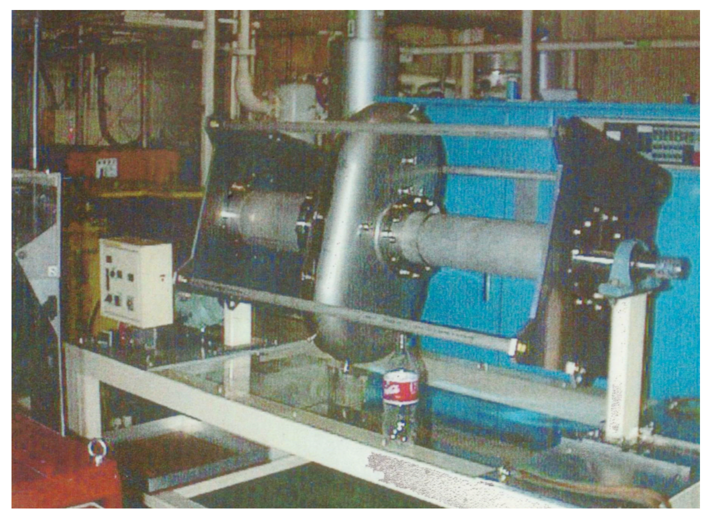
Hydro-forming



Nb Half Cell

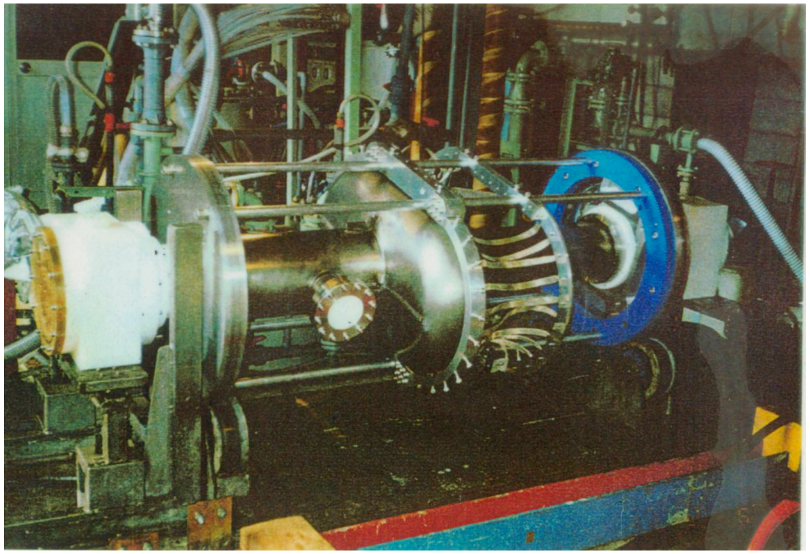


Grinding of Welding Part

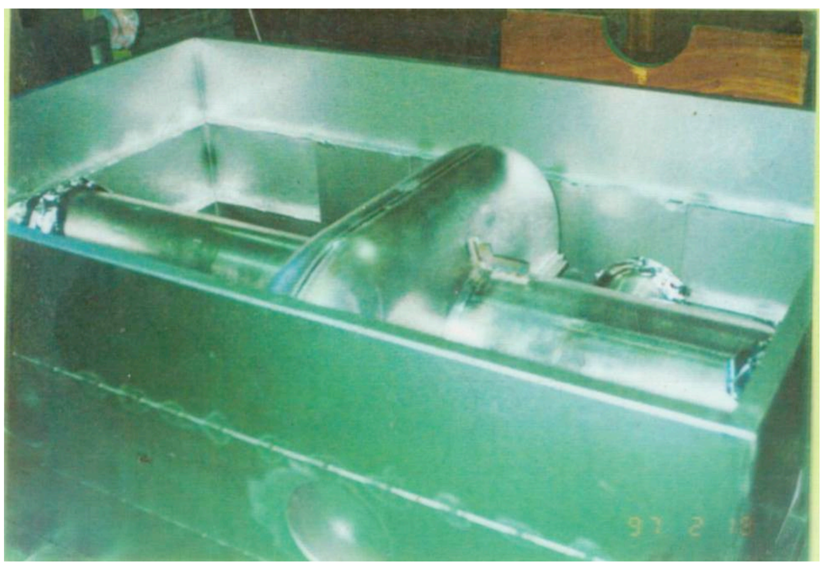


Barrel Polishing

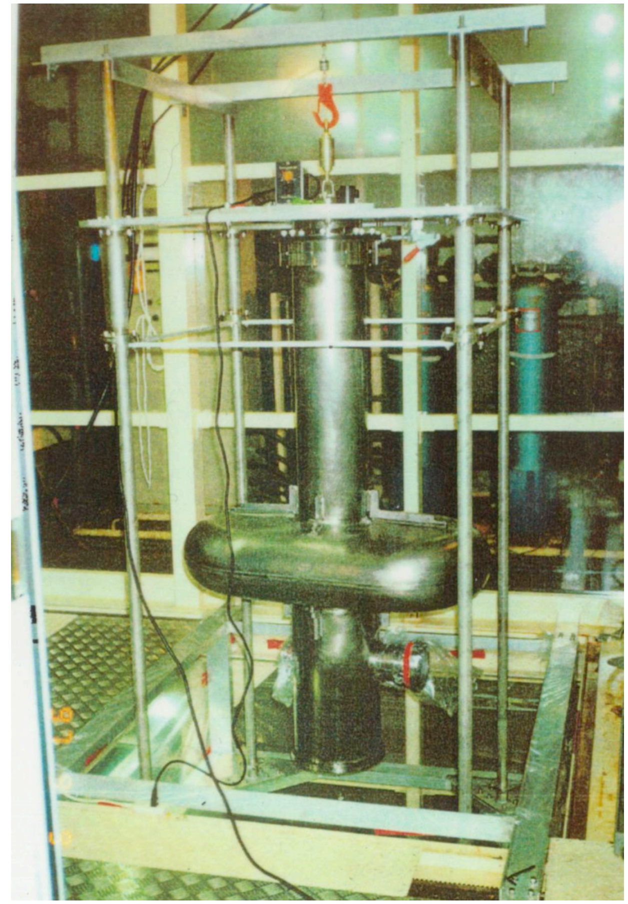
Fabrication & Processing 2



Electro-Polishing

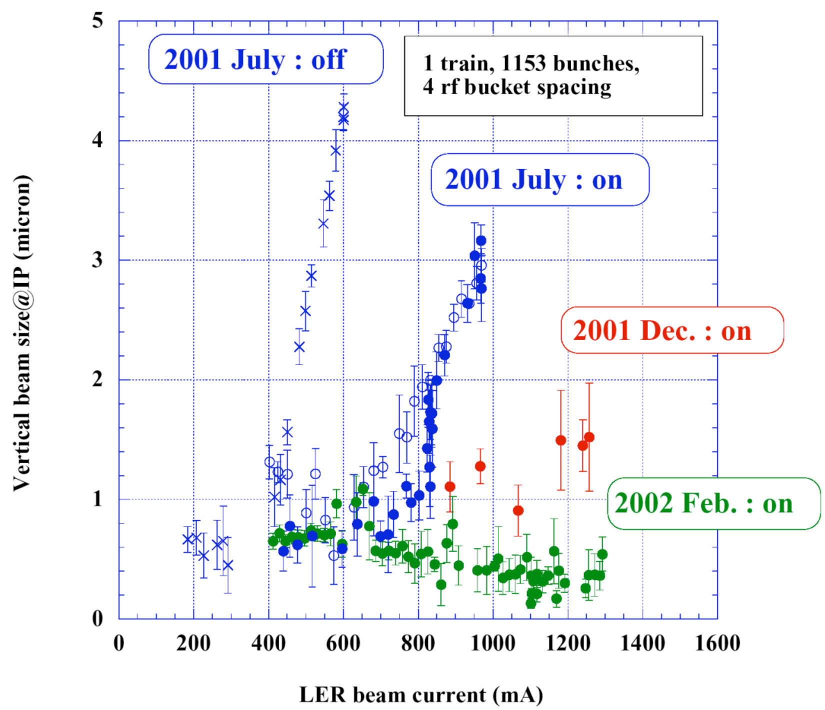


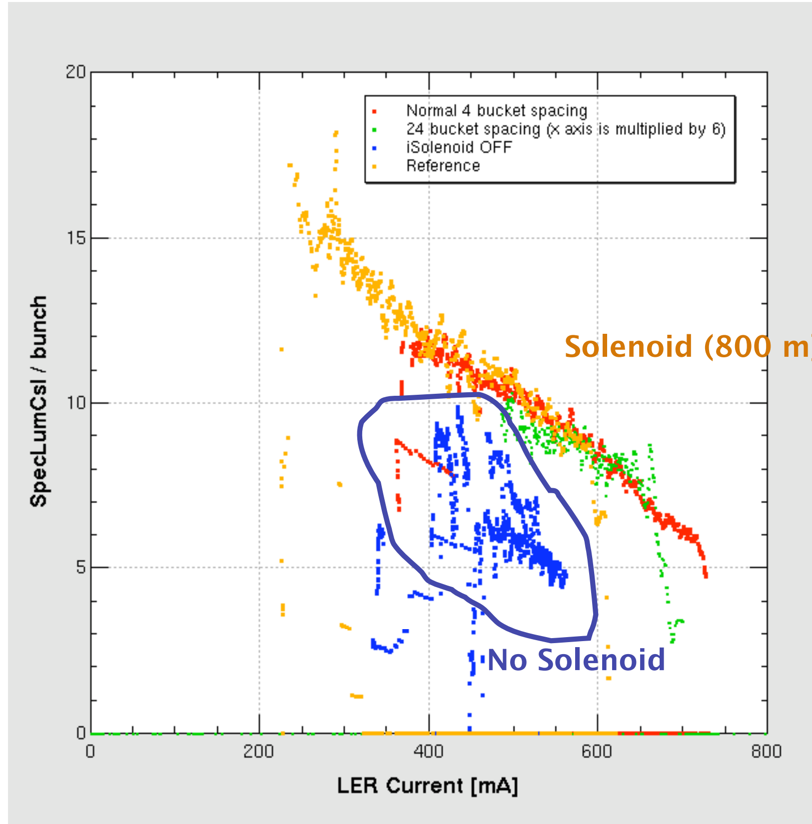
Annealing at 700^{0}C for 3 hours



High Pressure Water Rinsing
by 80 bar Ultra-Pure water

Electron cloud





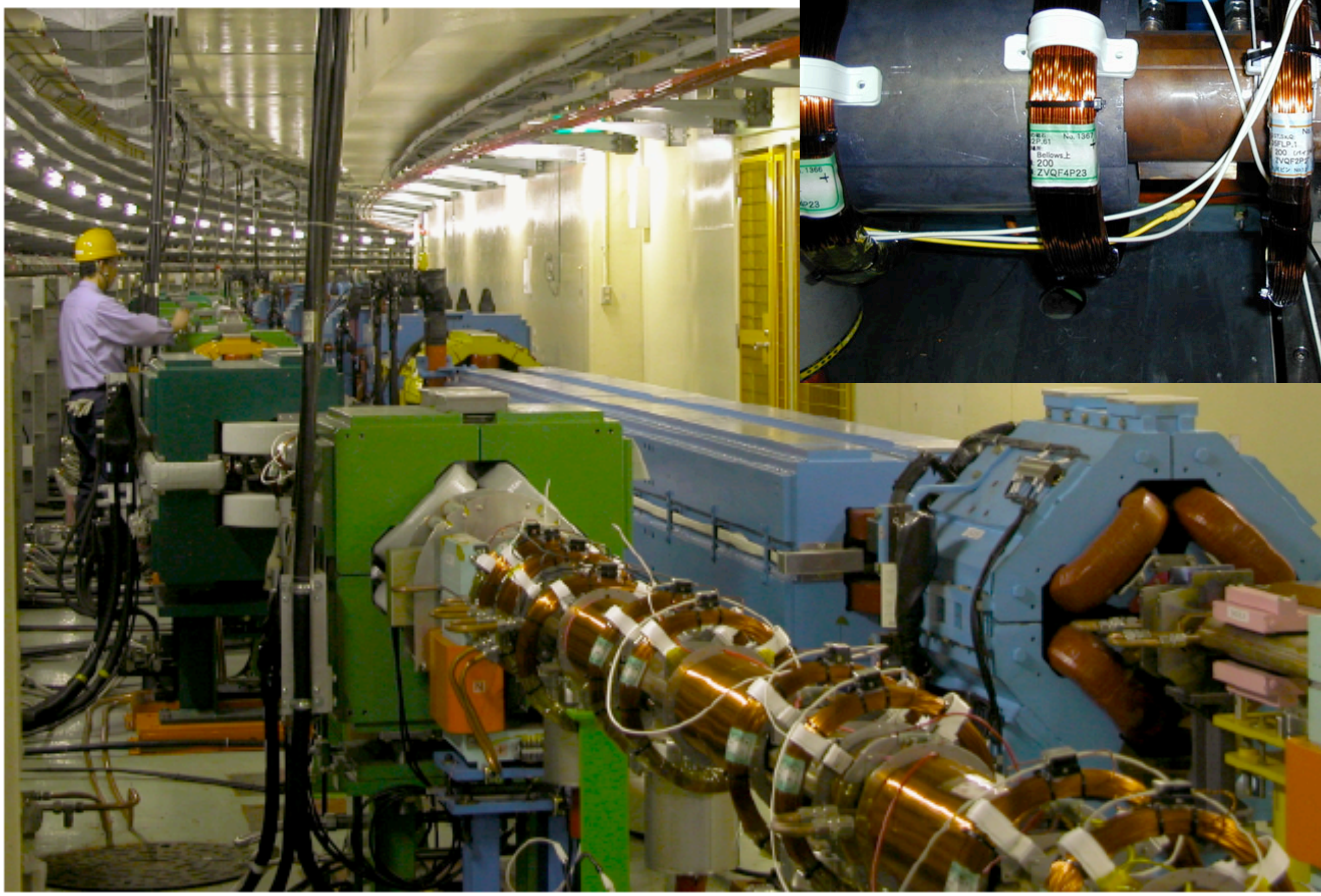
Blow-up of the vertical beam size in LER has been suppressed by more solenoid windings.

The coverred length of solenoids reached 2,300 m, raised the threshold to 1.8 A.

Specific luminosity vs. LER current.

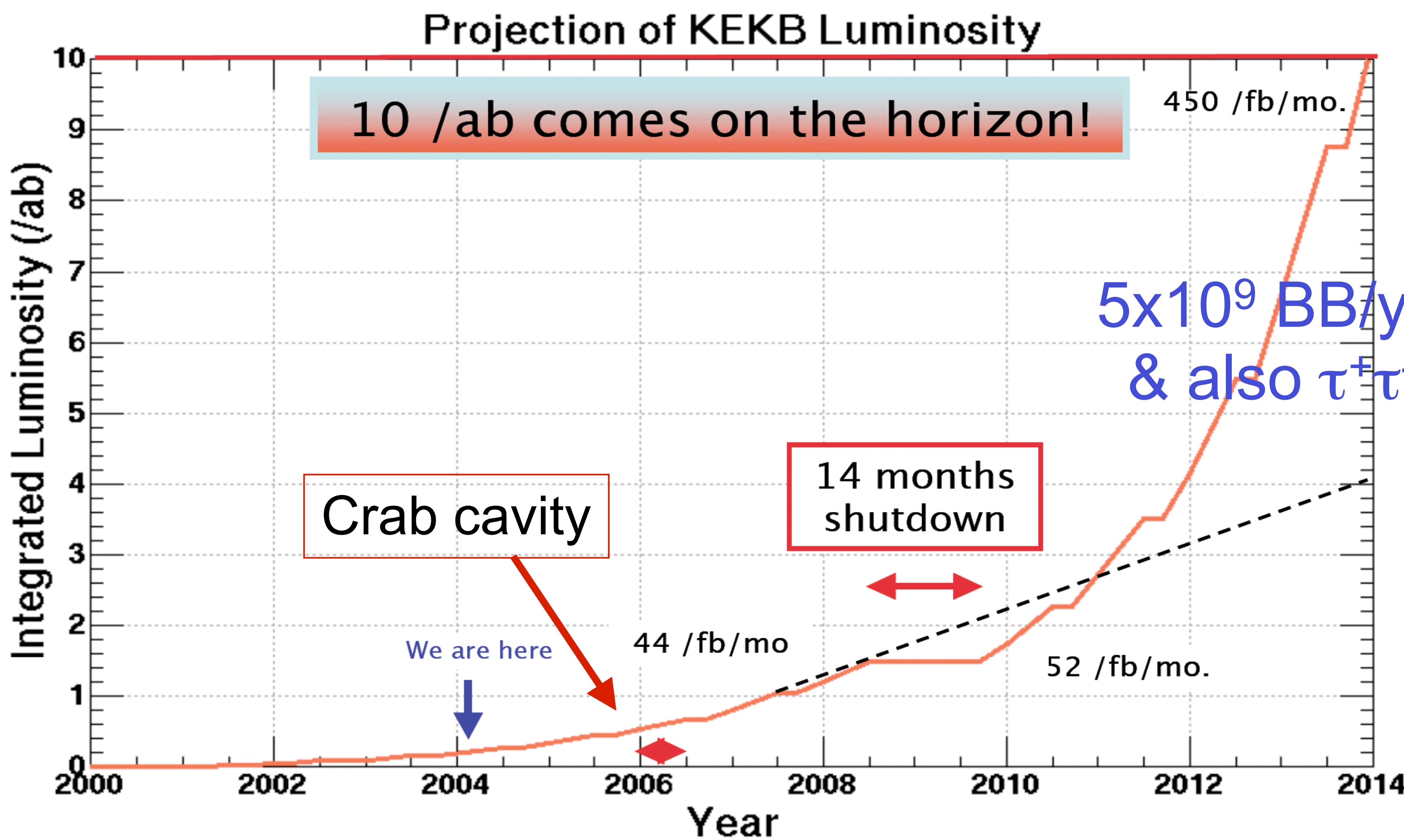
Solenoids are just so effective.

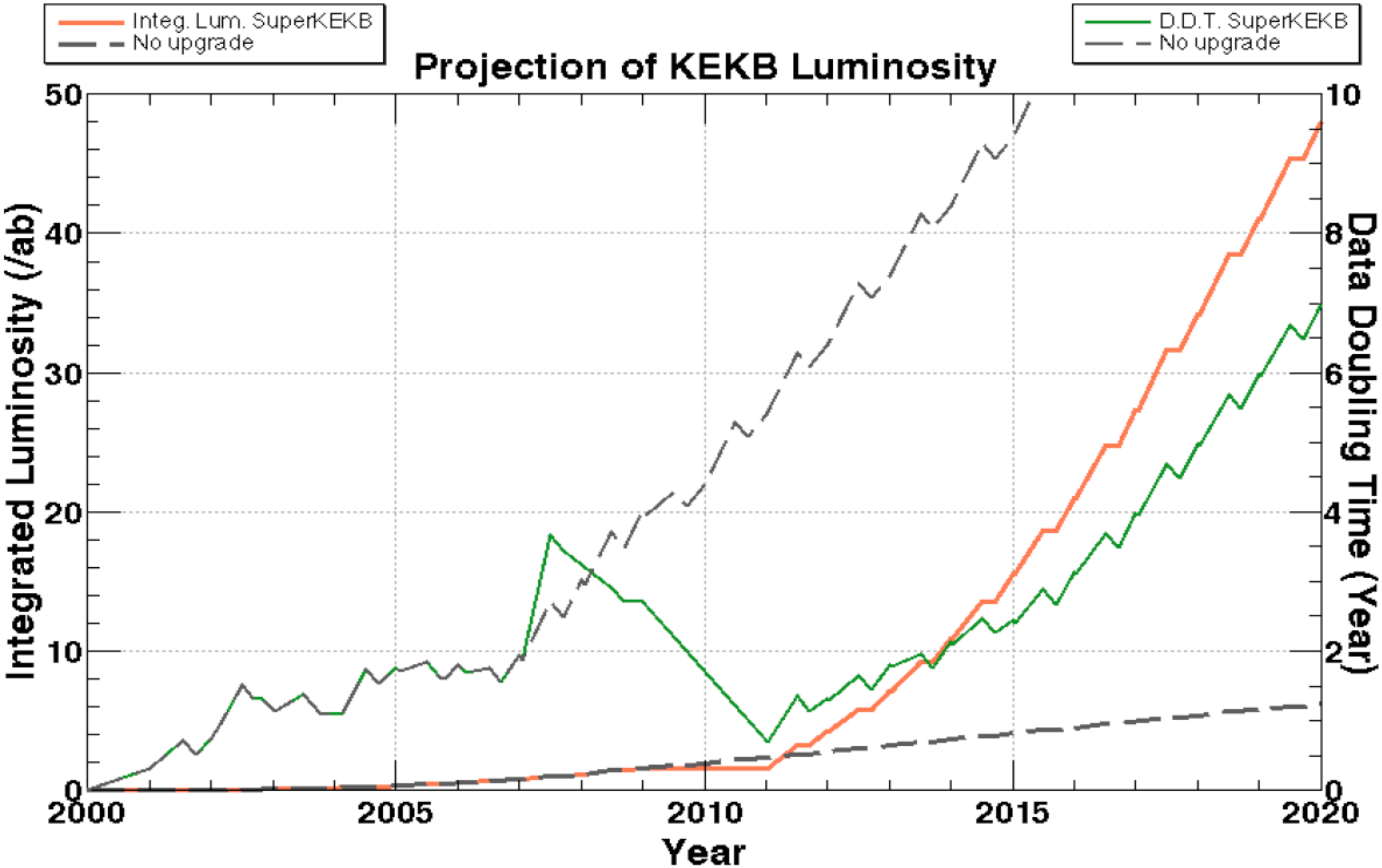
Winding more solenoids in the LER



Super KEKB: Proposed schedule

L_{peak} ($cm^{-2}s^{-1}$)	1.5×10^{34}	5×10^{34}	4×10^{35}
L_{int}	470 fb^{-1}	1 ab^{-1}	10 ab^{-1}



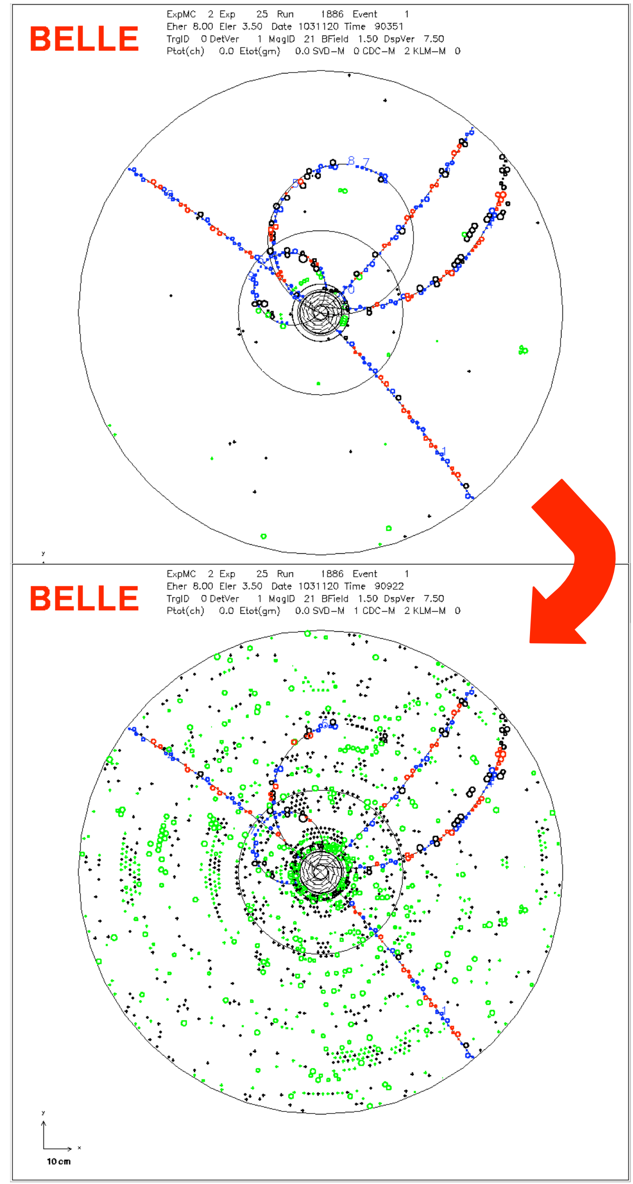


Integ. Lum. SuperKEKB
No upgrade
D.D.T. SuperKEKB
No upgrade
Projection of KEKB Luminosity
Integrated Luminosity (/ab)
Data Doubling Time (Year)
Year
0
10
20
30
40
50
2
4
6
8
10
2000
2005
2010
2015
2020

Requirements to the detector

Issues

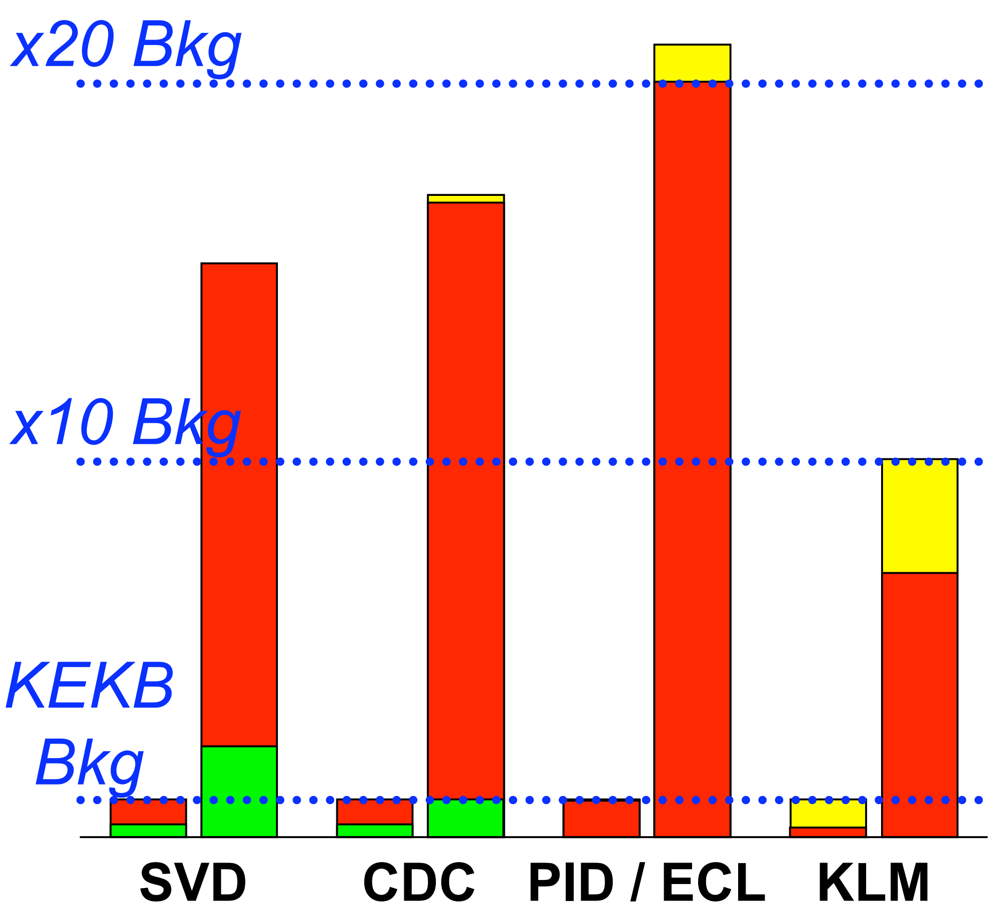
- **Higher background ($\times$20)**
  - radiation damage and occupancy
  - fake hits and pile-up noise in the EM
- **Higher event rate ($\times$10)**
  - higher rate trigger, DAQ and computing
- **Require special features**
  - low p μ identification $\leftarrow$ $s\mu\mu$ recon. eff.
  - hermeticity $\leftarrow$ ν “reconstruction”



Possible solution:

- Replace inner layers of the vertex detector with a silicon striplet detector.
- Replace inner part of the central tracker with a silicon strip detector.
- Better particle identification device
- Replace endcap calorimeter by pure CsI.
- Faster readout electronics and computing system.

Bkg & TRG rate in future

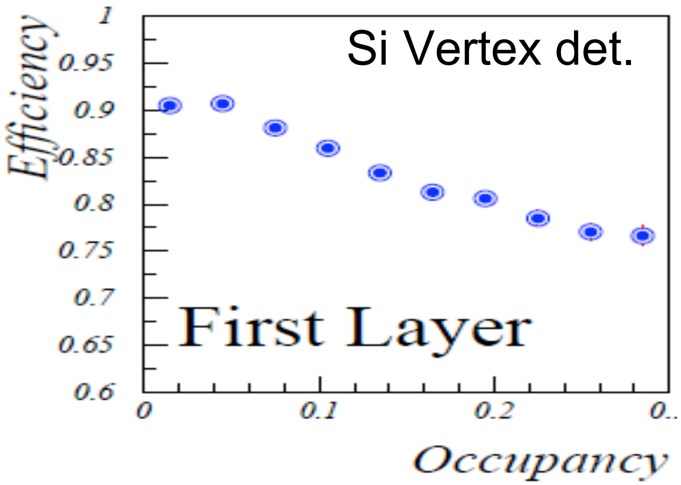


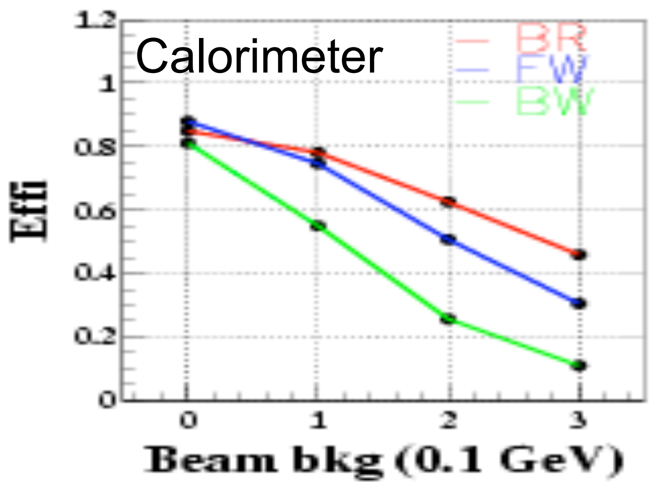
Shynchrotoron radiation
Beam-gas scattering (inc. intra-beam scattering)
Radiative Bhabha

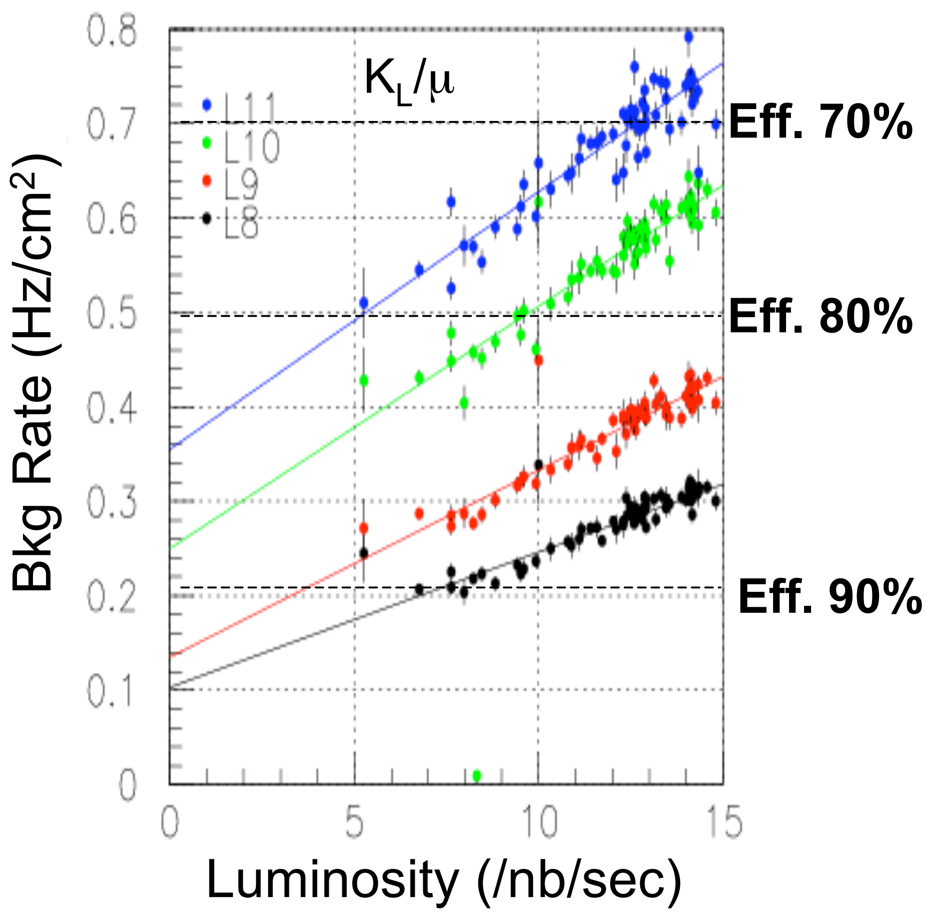
	KEKB	SuperB
Luminosity ($10^{34}cm^{-2}sec^{-1}$)	~1	50
HER curr. (A)	1.2	4.1
LER curr. (A)	1.6	9.4
vacuum (10^{-7}Pa)	~1.5	5
Bkg increase	-	
TRG rate (kHz)	0.4	
phys. origin	0.2	
Bkg origin	0.2	

Poison of high background

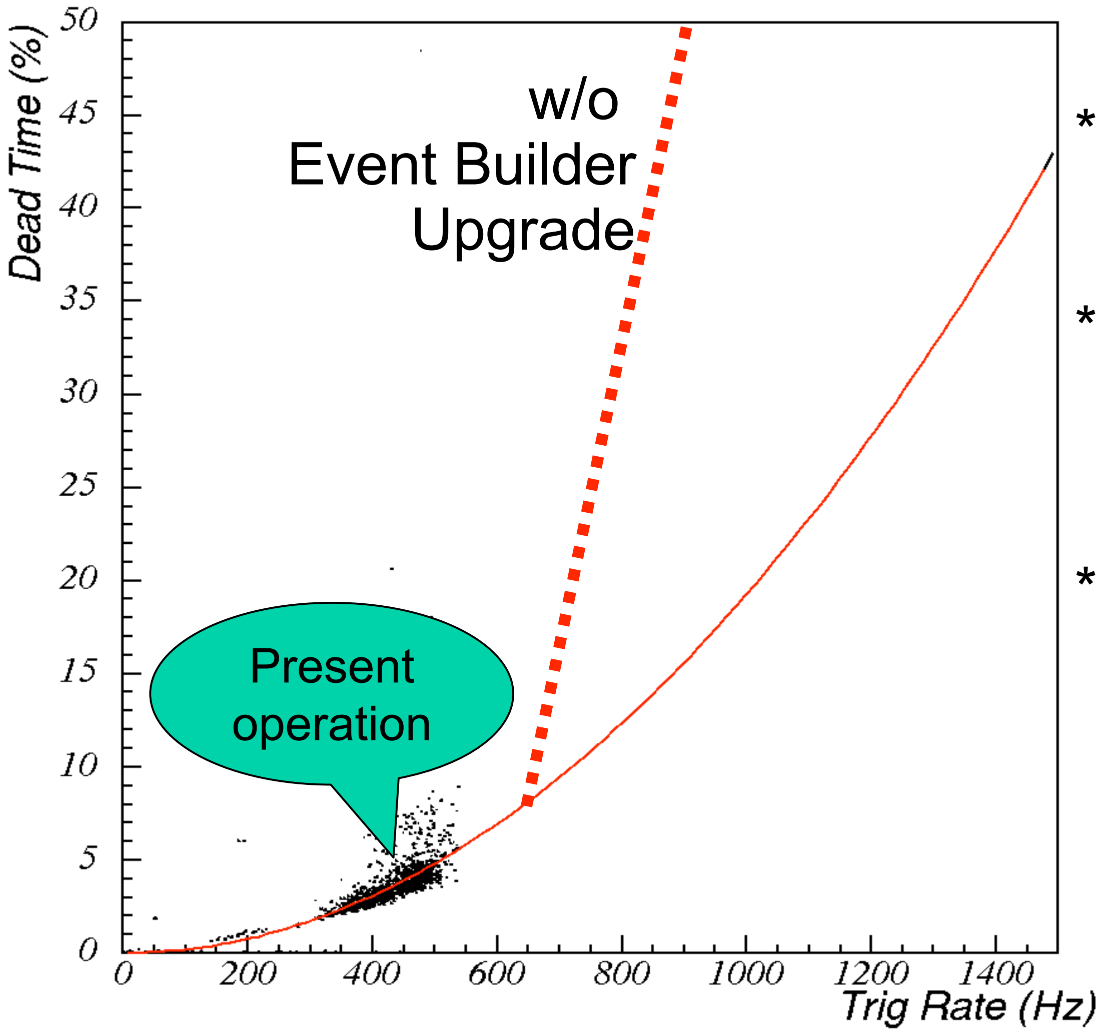
High-Bkg degrades Eff. badly







Another loss: deadtime



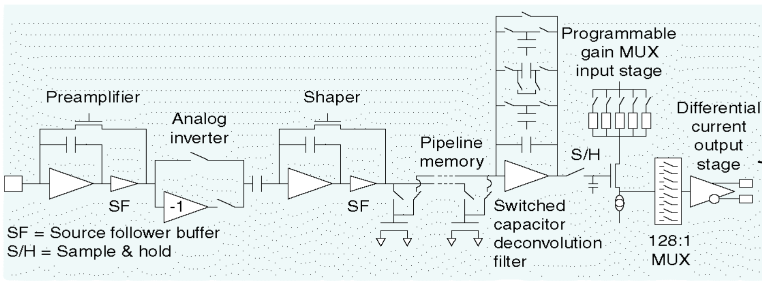
* Dead time evolution is not linear to trigger rate.

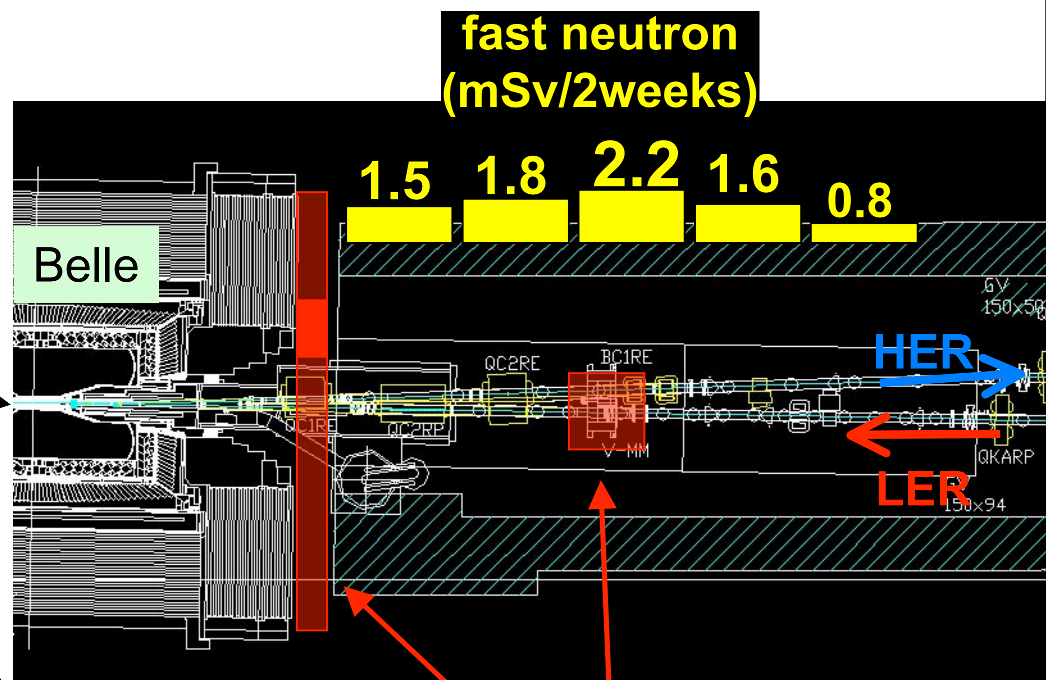
* Prediction is obtained by a fit to 0 ~ 550 Hz region with a 2nd order polynomia

* Prediction has a large ambiguity.

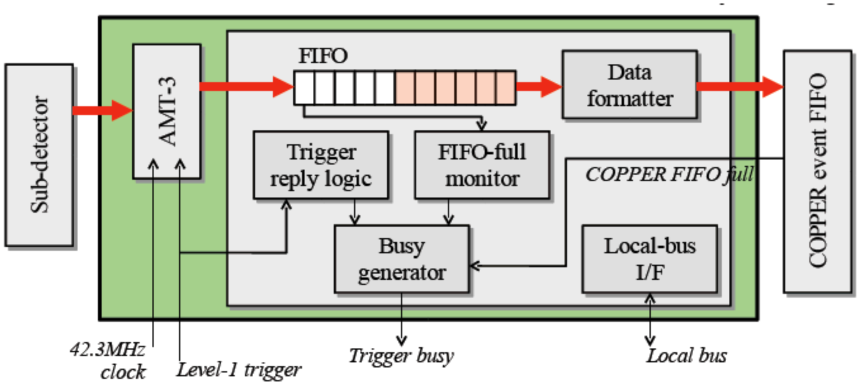
Ongoing upgrade

Faster signal processing with CMS chip in SVD (Silcon vertex det.)





New pipelined data Acquisition system (COPPER)



Extensive PE shield against neutron

Further upgrade for SuperKEKB

Super-Belle Strategy

- Vertexing with new SVD
  - Beam pipe radius = 1cm.
  - 2 lyr. striplet/pixel + 4 lyr. DSSD
- Tracking with new CDC
  - Smaller cell size (for inner part) + Faster gas
- Endcap detector replacement
  - Pure CsI for EM calorimetry
  - Strip/tile scintillator or RPC in avalanche mode with new gas mixture.
- PID improvement
  - Ring imaging counters (TOP + Aerogel-RICH)
  - Other options; FDIRC, TOF w/ finer seg.
- DAQ/TRIG/Comp.
  - Full pipeline readout (FINESSE + COPPER)
  - 3-stage event building (new RFARM)
  - Large scale computing with GRID architecture

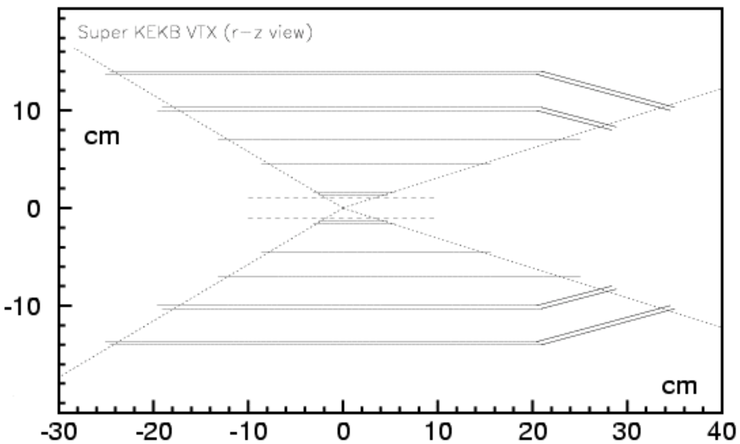
Same acceptance as Present Belle even with new IP design.

r = 15cm (low p tracking by SVD)

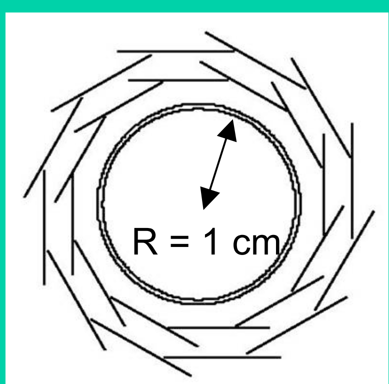
Front-end electronics
- Shoter shaping time
- Wave form sampling (CsI, CDC)
- High timing resolution (TOP/TOF)

Si vertex det. & Tracker (CDC)

SVD



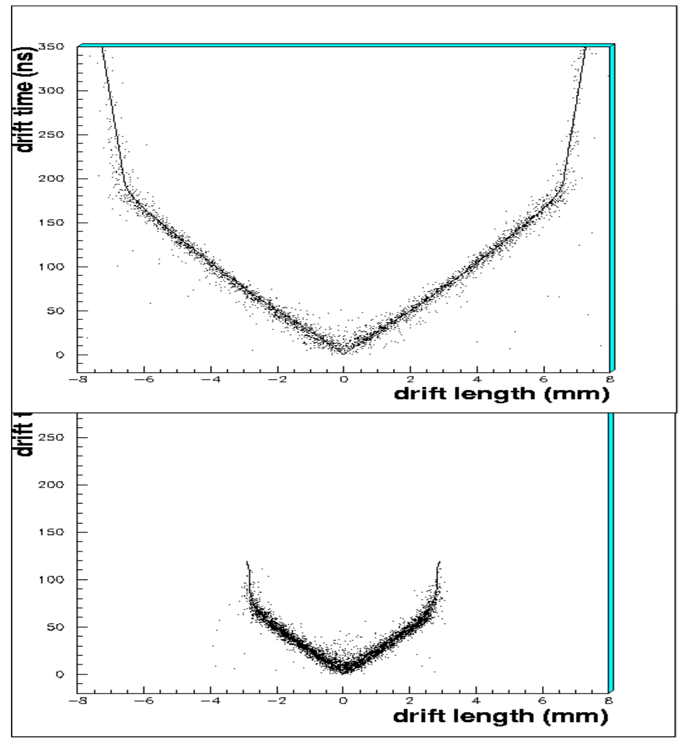
- 6 or more Layers
- Large area Si tracker



2-layer sensors at inner layer for robust vertexing

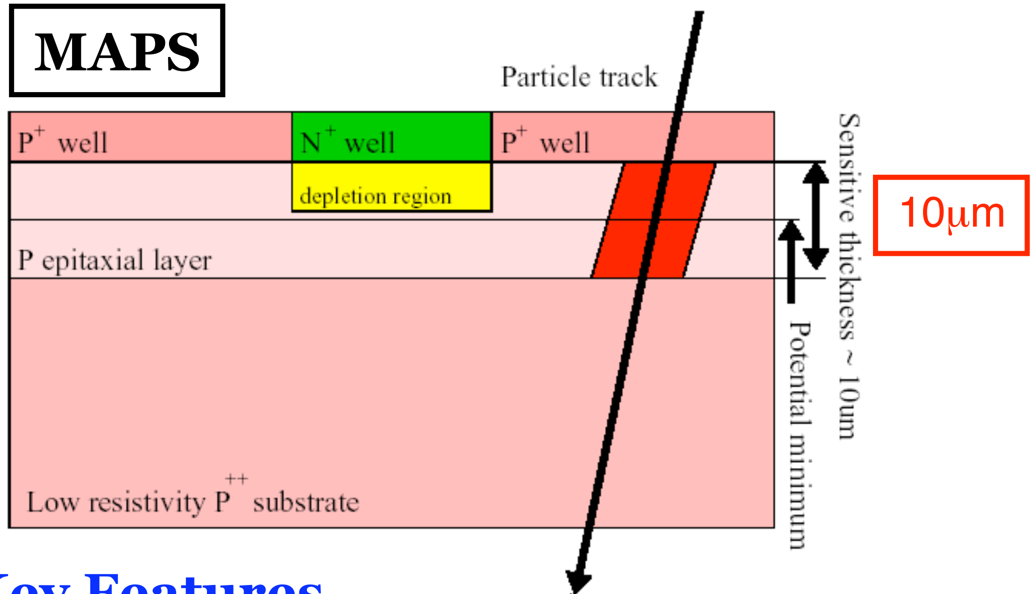
- Self tracking of low momentum tracks.
- Dead time less readout at the luminosity of 5×10^{35}/ cm^2/sec.
- Rejection of beam background that is 30 times severer than that in KEKB.

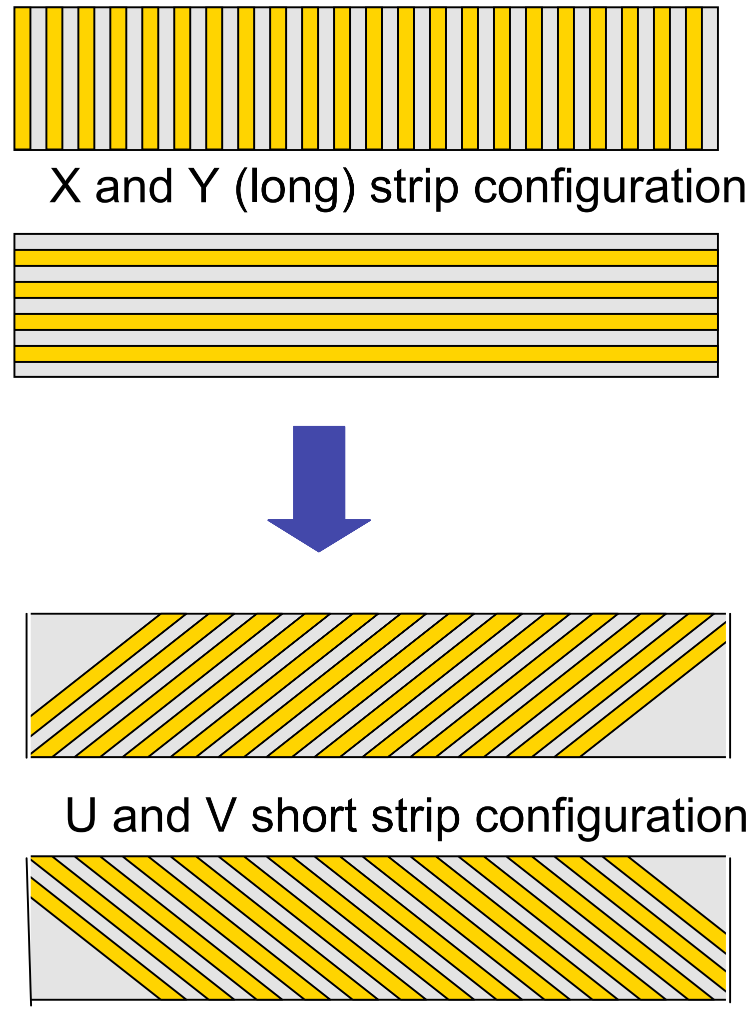
CDC



- Smaller cell size
  - Lower hit rate for each wire.
  - Shorter maximum drift time.
- Faster drift velocity
  - Shorter maximum drift time

Monolithic Active Pixel Sensor(MAPS) and Silicon striplet



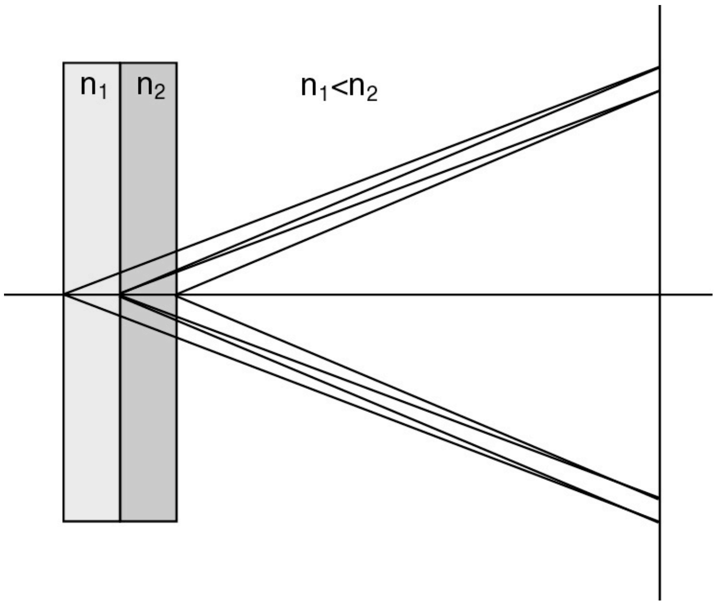


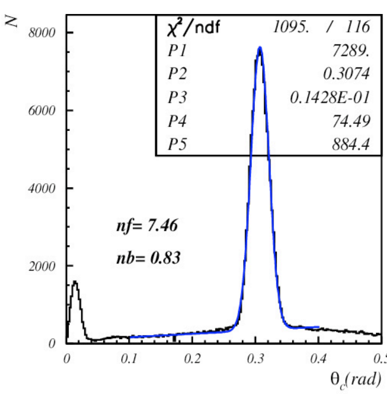
Key Features

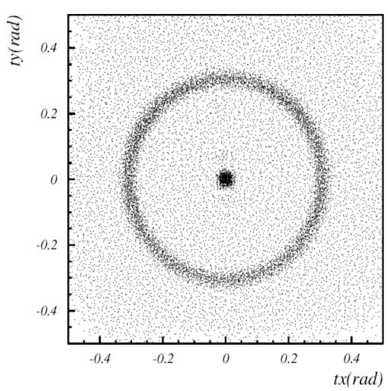
- Thermal charge collection (no HV)
- Thin - reduced multiple-scattering, γ conversion, background γ target
- NO bump bonding – fine pitch possible (8000x geometrical reduction)
- Standard CMOS process - “System on Chip” possible

Particle ID & Calorimeter

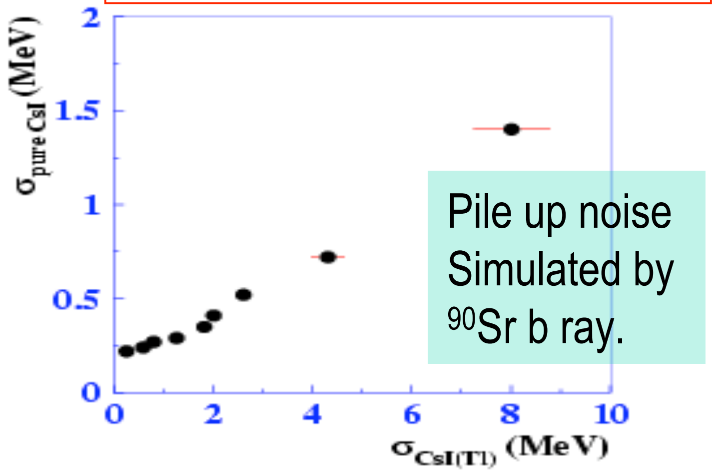
Aerogel Ring image Cherenkov (RICH)
with focusing configuration

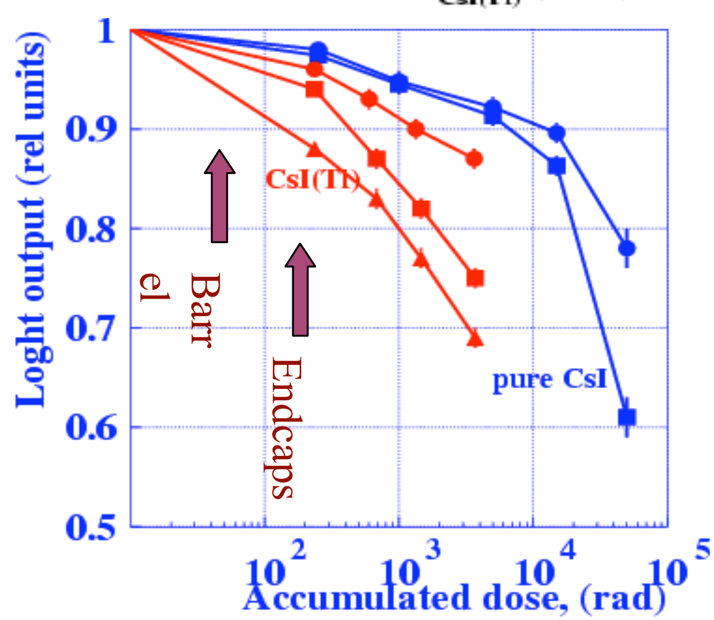






Pure CsI for Calorimeter under high background



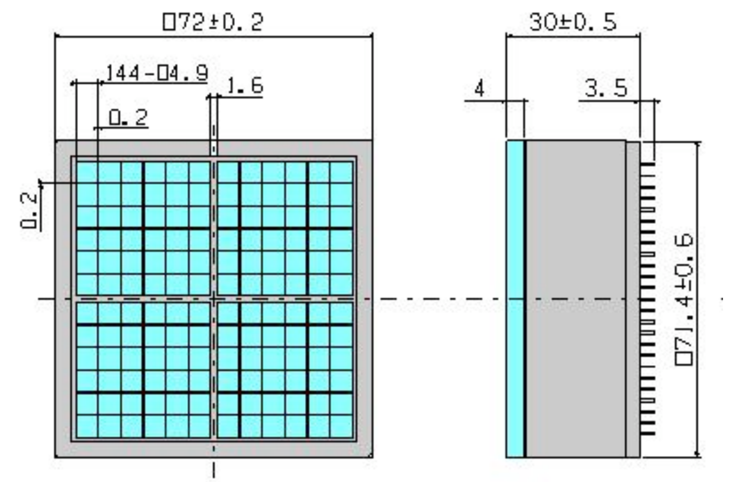


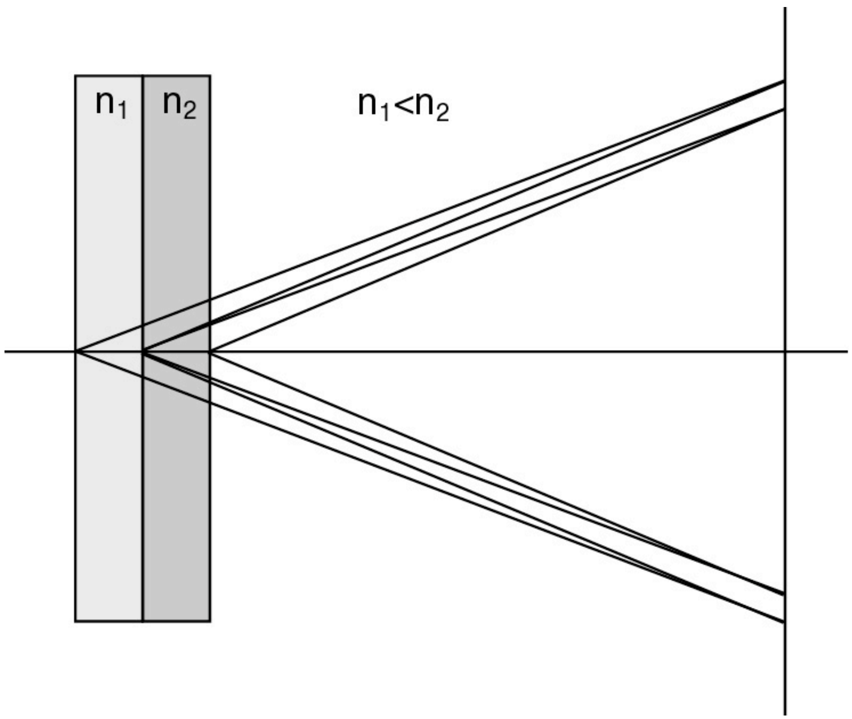
Aerogel RICH

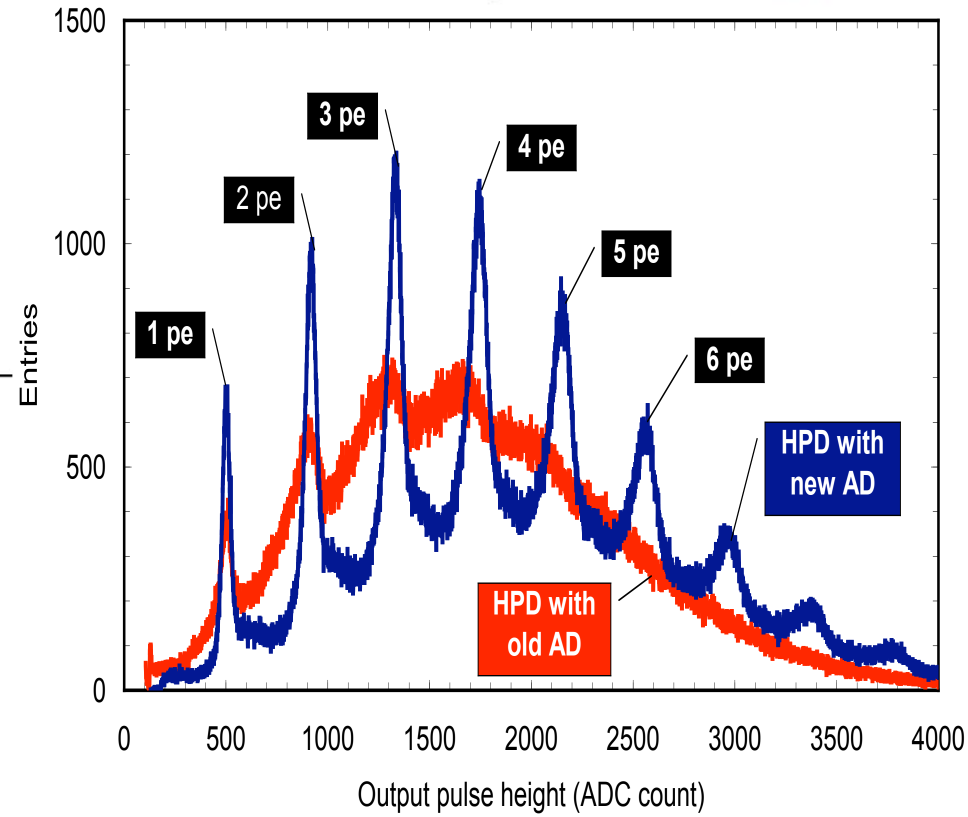
with multiple refractive indices
and high resolution HPD

- measure overlaping rings

"focusing" configuration

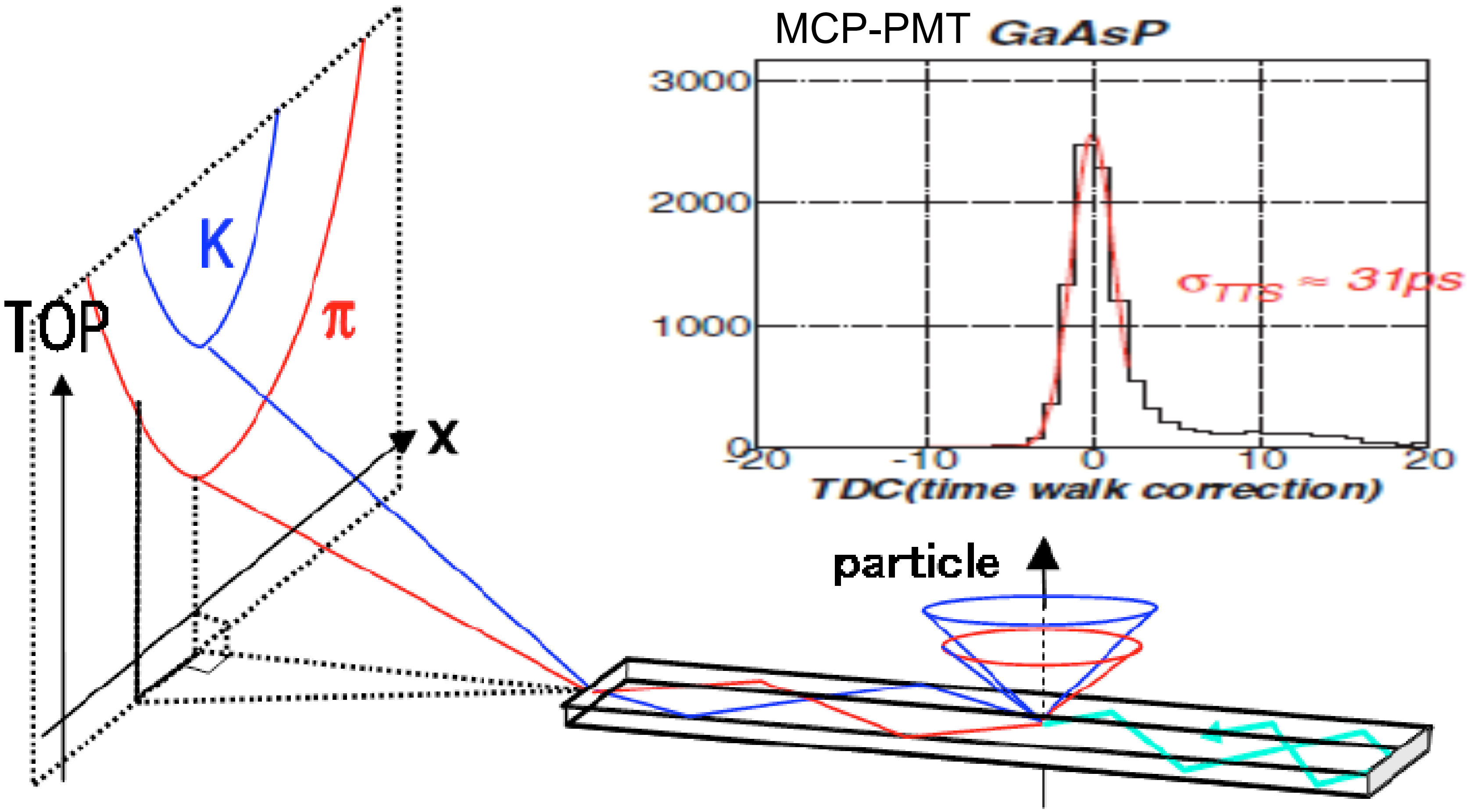






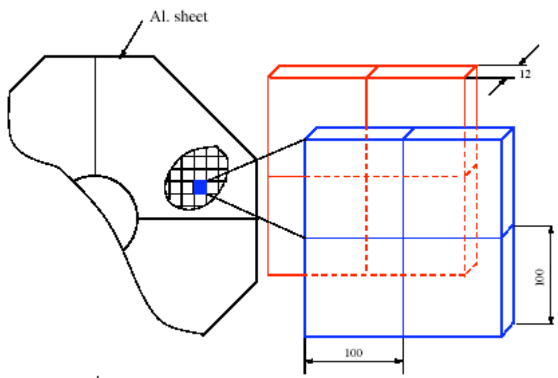
TOP Counter

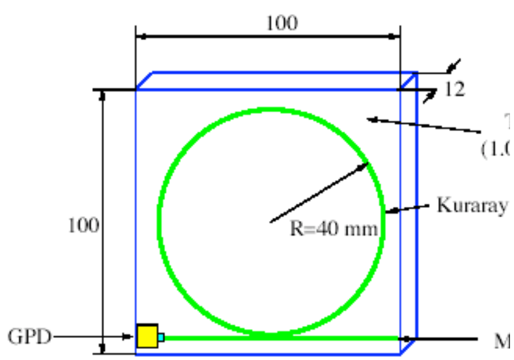
- Ring Imaging Cherenkov counter
  with precise measurement of the Time Of Propagation (TOP)



K_L/μ det. and Data Acq. (DAQ)

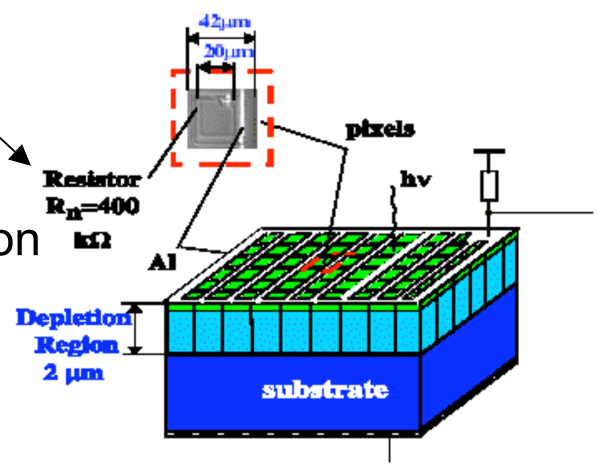
K_L/μ det. for high count capability



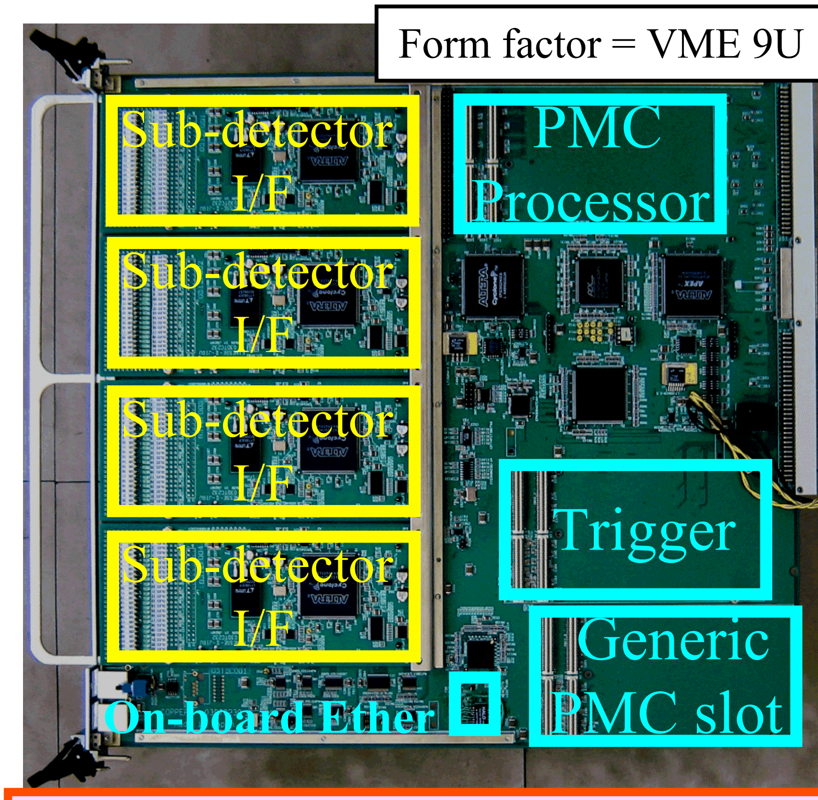


Scintillator Tile and WLS fiber

New generation Photon Detector



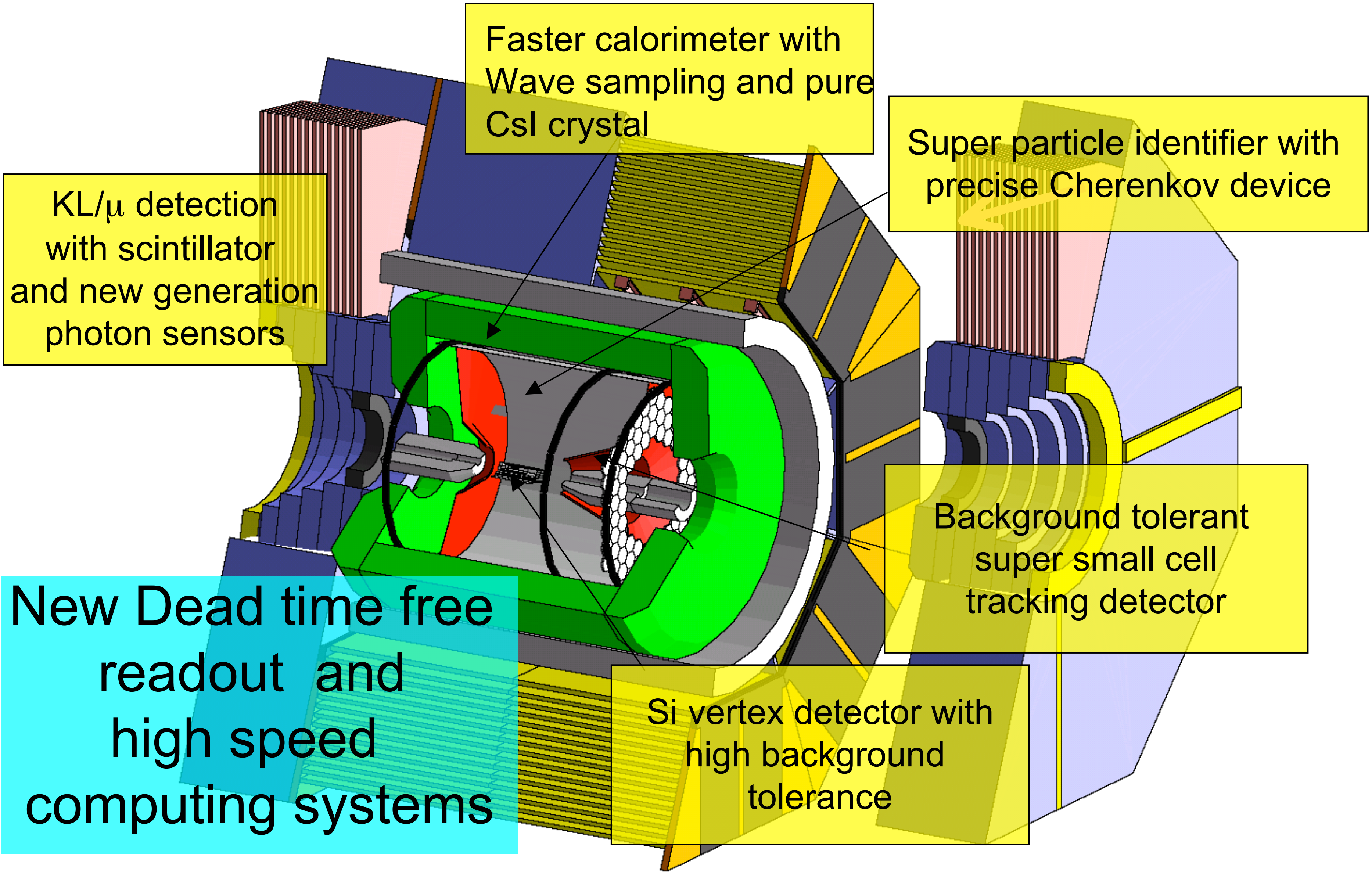
Common Readout Platform: COPPER



Data transfer on COPPER measured >65 MB/s.

>30 kHz L1 rate @ 1.6 kB/ev.
Data size corresponds to typical SuberKEKB DC/COPPER.

Super Belle


Faster calorimeter with Wave sampling and pure CsI crystal
Super particle identifier with precise Cherenkov device
KL/μ detection with scintillator and new generation photon sensors
Background tolerant super small cell tracking detector
New Dead time free readout and high speed computing systems
Si vertex detector with high background tolerance

Summary

- KEKB/Belle has been running very successfully, and brought important scientific achievements together with BaBar.
  - Observation of CPV in the *B* meson system
  - Quantitative confirmation of the KM theory
  - Hints for new physics
  - Unanticipated resonances
  - …and other new observations
- Super KEKB upgrade has been proposed
  - Why? – Search for new sources of flavor mixing and CP violation
  - How? – Increase N_B, decrease β_y^*, and crab crossing: $\mathcal{L}=4\times10^{35}/\mathrm{cm}^2/\mathrm{s}$
  - What? – New beam pipe, crab cavity, new injector with damping ring. Belle will also be upgraded assuming DC is usable.
  - Who? – KEKB/Belle (and PEP-II/BaBar) will be core of the project.
  - Where? – Upgrade existing KEKB.
  - When? – JFY2009 and 2010
  - How much? – up to US$450M, depending on what to be upgraded.