Superb prospects: Belle & KEKB upgrades

SuperKEKB Quest for BSM

Aspen Physics Workshop

February 12, 2009

Belle and beyond: physics, collider, detector

Kay Kinoshita
University of Cincinnati
Belle Collaboration

Belle (1999-2009)

Primary goal: establish unitarity & complex phase of CKM matrix

Kobayashi & Maskawa (1973)

- proposed 3rd generation of particles
- Explained CP violation in K, predicted for B

B-Factories (-2009)

- CP asymmetry manifested in diverse processes in B decay

-> many measurements, (over)constrain CKM, found consistent with unitarity

2008
Nobel Prize

Belle (1999-2009)

- … + other Upsilon physics has been RICH

Headliners
- new charmonia, charmonium-like states, ISR, D_{sJ}, many B decays
- D^0 mixing
- probes of New Physics

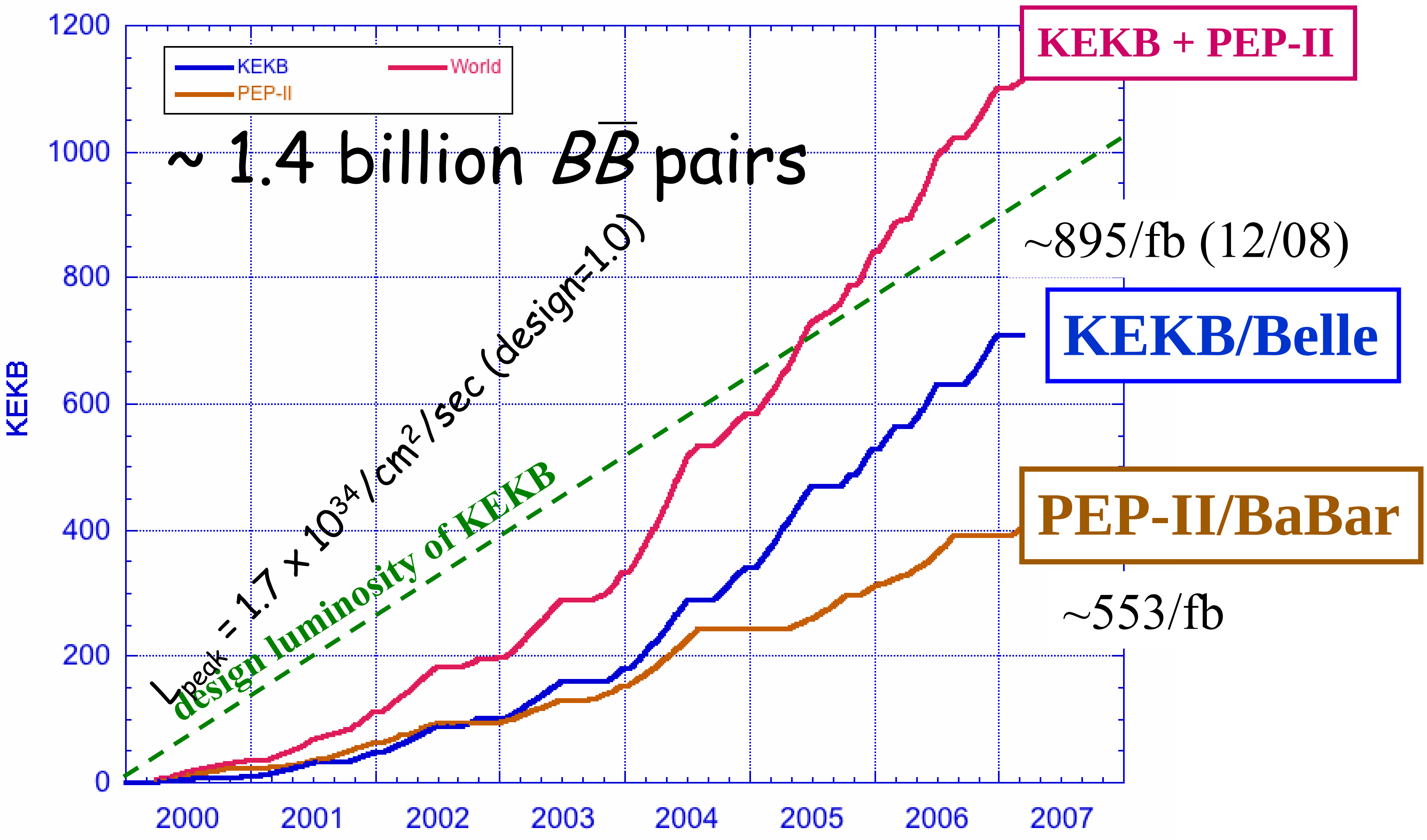
+ many more measurements on
B, charm, tau, 2-photon, $\Upsilon(4S)$, $\Upsilon(10860)$, B_s, $\Upsilon(3S)$, $\Upsilon(1S)$, ...

Addressing
CP, CKM, QCD, HQ spectroscopy, LFV, NP, Dark Matter, ...

283 journal articles published/submitted

http://belle.kek.jp/bdocs/b_journal.html

B world sample



Why continue flavor physics?

From 1.4 ab^{-1} at Belle+Babar

many CKM measurements limited by statistics: $\rho^0\rho^0(\varphi_2)$, Dalitz analyses (φ_3), $b \to d\gamma$

Best limits/measurement on many SM-suppressed/forbidden B, D processes

1.4 ab^{-1}

Best limits on LFV in tau: $\tau \to \mu\gamma$

precise CKM: hints of internal inconsistency?

Limits on Higgs via $B \to \tau\nu$, $B \to D^{(*)}\tau\nu$

$\varphi_1, \varphi_2, \varphi_3 \Leftrightarrow \beta, \alpha, \gamma$

Why continue flavor physics?

SM extensions likely to have new sources of CPV & flavor couplings
With x10^2 luminosity, open significant window

precise CKM:
$\rho^0\rho^0(\varphi_2)$, Dalitz analyses (φ_3),
b->dγ
+ much more
b->s penguin(φ_1)

SM-suppressed/forbidden
B, D processes:
b->sγ, b->dγ, B-> sl^+l^-
Right-handed currents in B->{s}γ
CP asymmetry in D mixing

100 ab^{-1}

SM-forbidden
lepton processes
LFV decays in tau

internal
inconsistencies,
non-SM rates/CP
violation

Lepton universality
B-> τν, B->$D^{(*)}$ τν

new sources of CP violation,
flavor mixing

pro's for e^+e^-: γ, K_L detection; hermeticity -> neutrinos

Standard Model: "standard" $\sin 2\varphi_1$

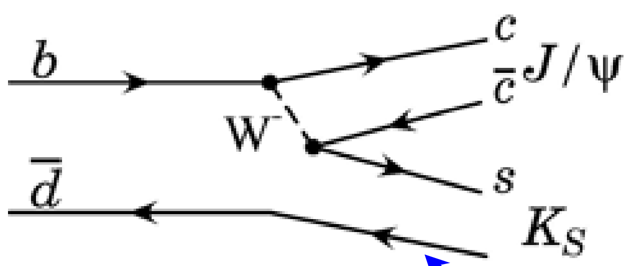
for $B \to J/\psi\ K_s$

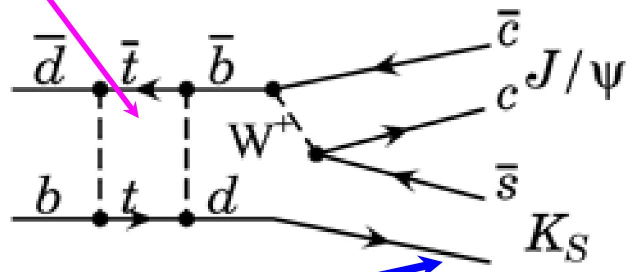
tree (real V_{ij}) $\propto V_{cb}^* V_{cs}$

<u>mixing</u>+tree $\propto V_{tb}^{*2} V_{td}^{2} V_{cb} V_{cs}^{*}$

well-measured rate

phase = $\arg(V_{tb}^{*2} V_{td}^{2}) = 2\varphi_1$





identical hadronic processes -> same |Amplitude|

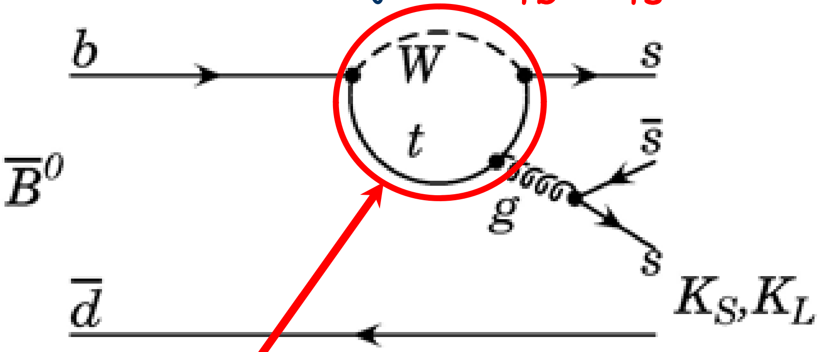
$V_{cb}^* V_{cs}$ real => zero phase difference

=> relative phase = $2\varphi_1$, CP asymmetry ~ $\sin 2\varphi_1$

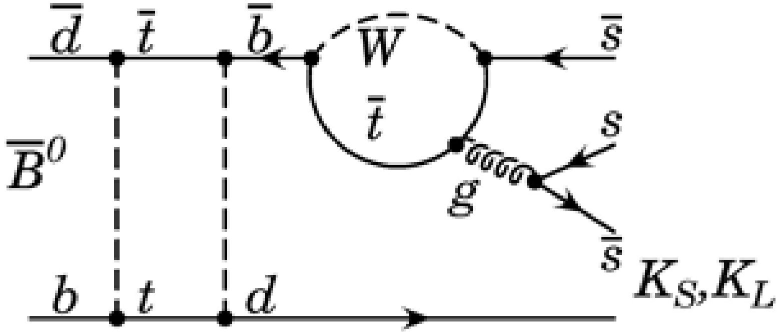
Standard Model: "other" $\sin 2\varphi_1$

for b -> $s\bar{s}s$: identical reasoning

tree (real V_{ij}) $\propto V_{tb}^{*}V_{ts}$



mixing+tree $\propto V_{tb}^{*2}V_{td}^{2}V_{tb}V_{ts}^{*}$



$V_{tb}^{*}V_{ts}$ real => zero phase difference

=> relative phase = $2\varphi_1$, CP asymmetry ~ $\sin 2\varphi_1$

A new process w complex phase φ_{new}

---> CP asymmetry ~ $\sin(2\varphi_1 \pm 2f\varphi_{new})$

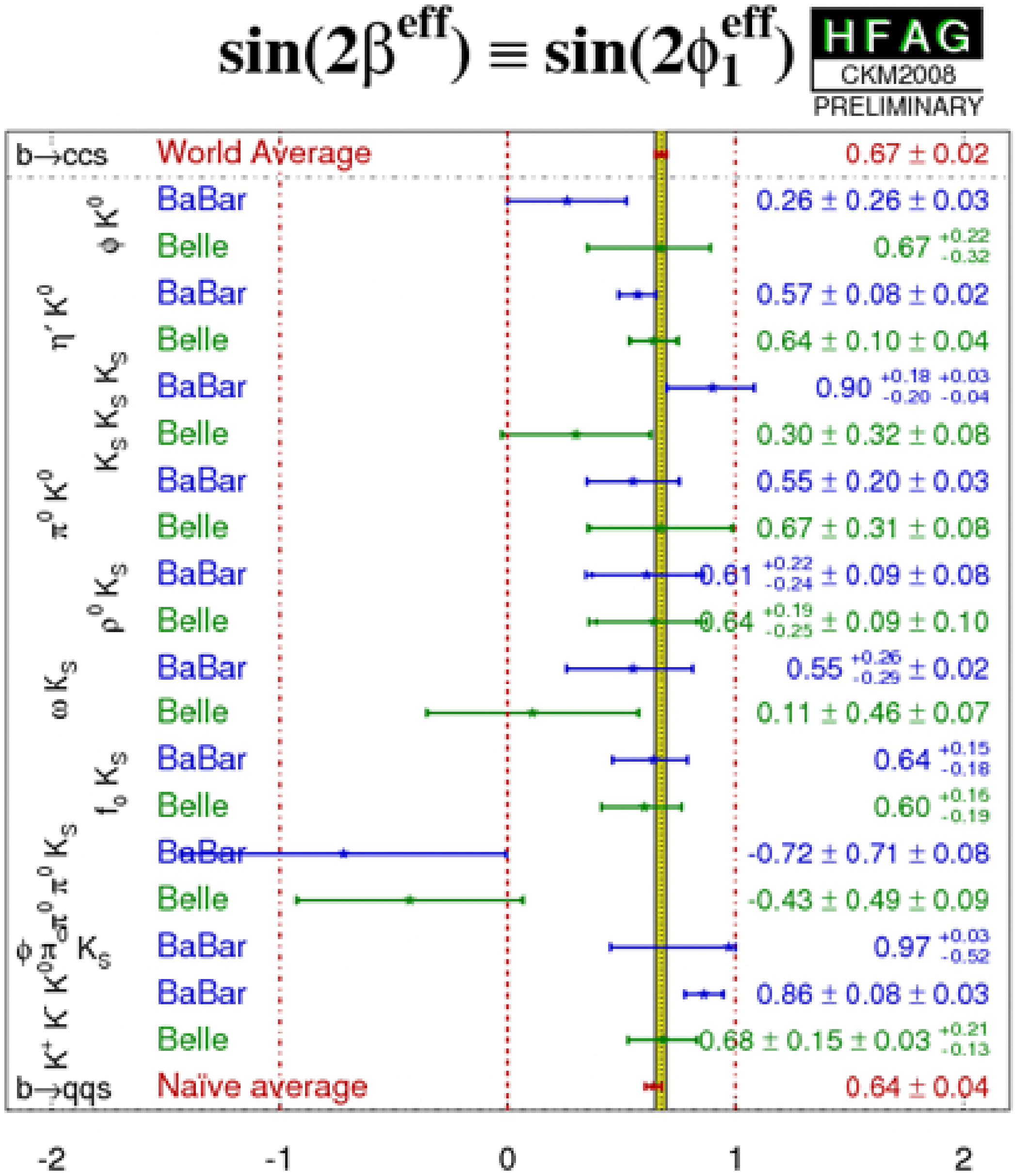
$f<1$

Average "sin2φ_1" from *b->s* penguins

Naïve World Average
$\sin 2\varphi_1(b \to sq\bar{q}) = 0.64 \pm 0.04$

Compare to $c\bar{c}s$:
$\sin 2\varphi_1(b \to c\bar{c}s) = 0.672 \pm 0.024$

CL = 0.47 (0.7σ)

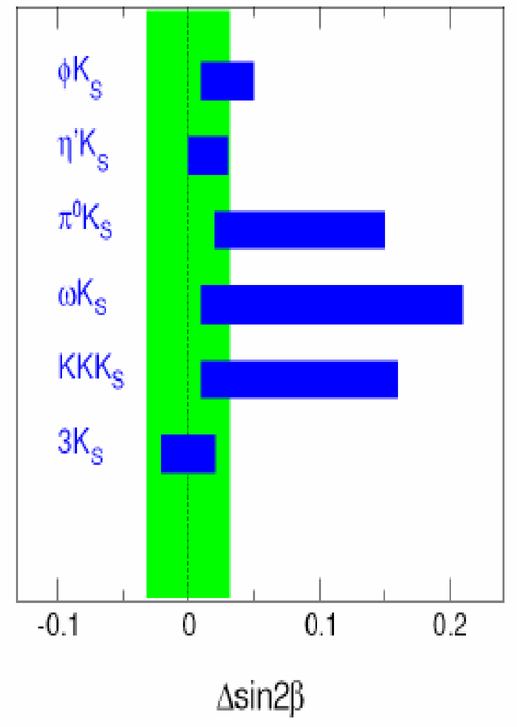


Sensitivity to new physics requires
- statistics
- reduced systematics
- theory corrections

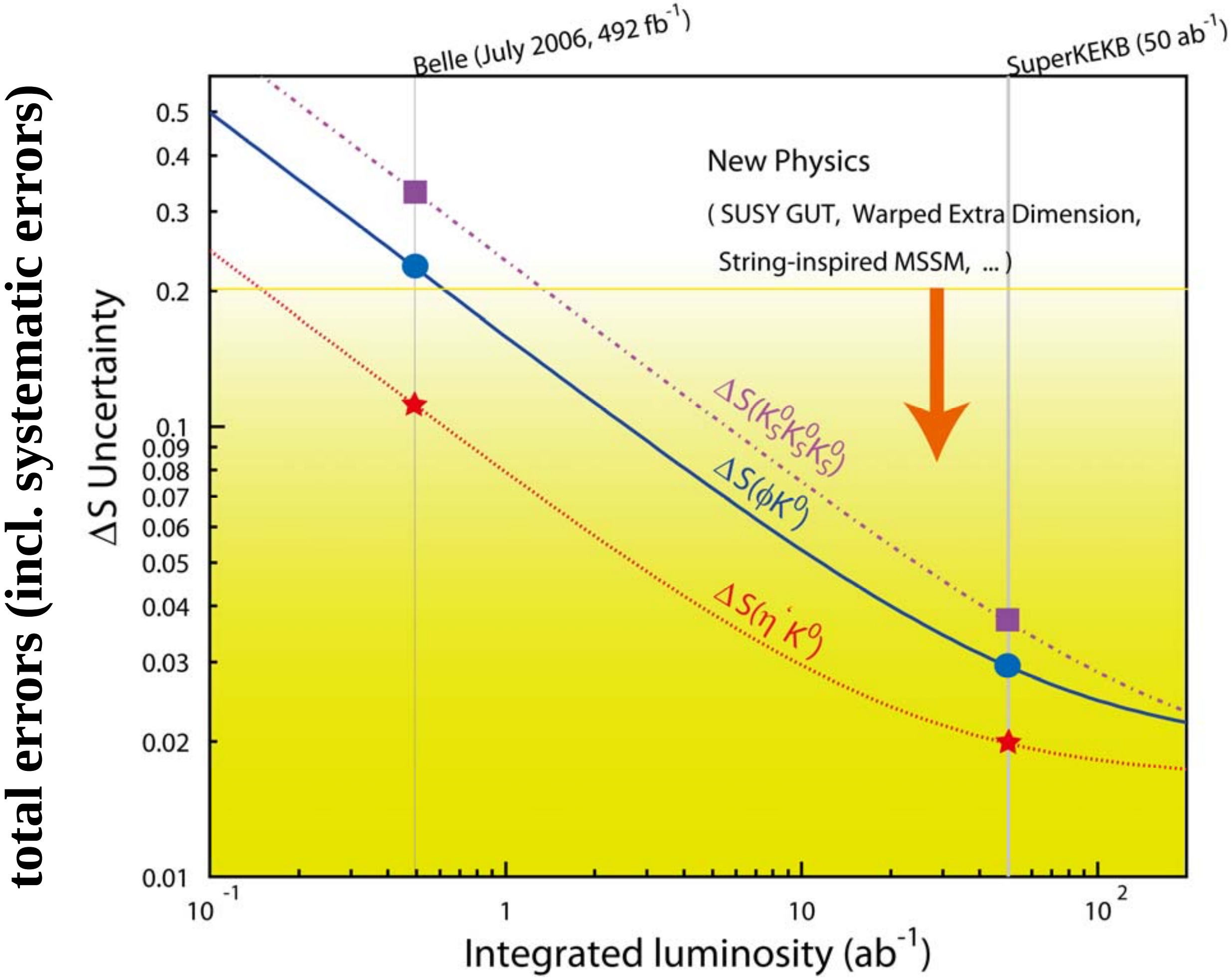
CP asymmetry in b → s: sensitivity vs luminosity

SM prediction

some of recent QCDF estimates
$\sin2\beta^{f}_{eff} - \sin2\beta$



B → φK⁰, η'K⁰, KsKsKs projection for SuperKEKB

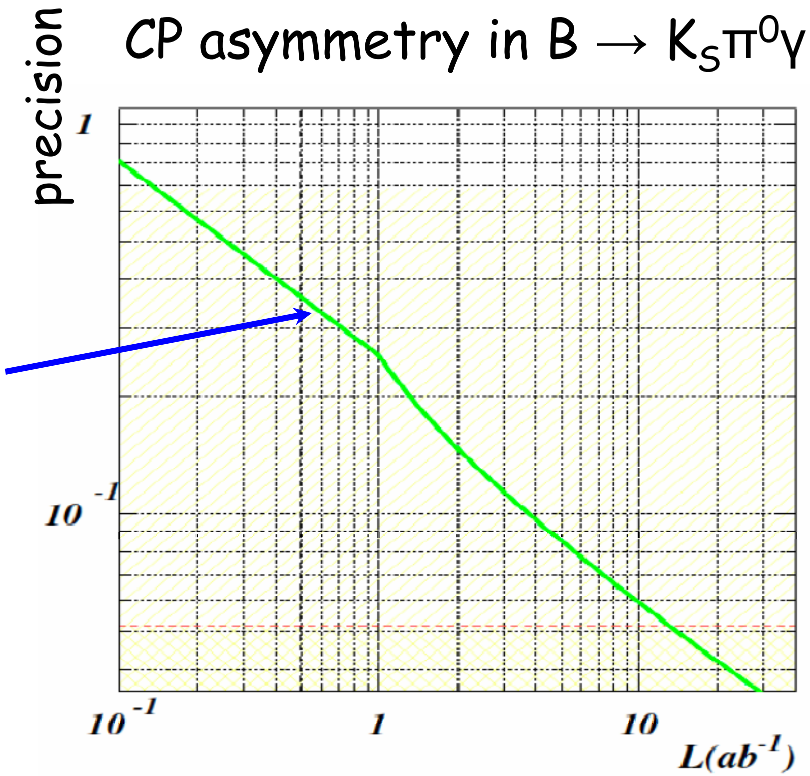


Right-handed currents

in SM $B^0 \rightarrow X_s^{CP}\gamma$ is ~flavor-specific (γ polarization)

-> low CP-asymmetry (few %)

larger asymmetry <- right-handed current

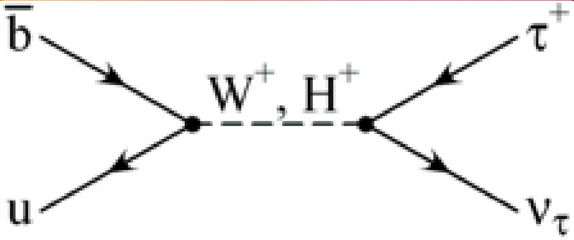


PRD 74, 111104(R) (2006)

$B^+ \to \tau^+ \nu_\tau$: constraints on charged Higgs

$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}(B \to \tau\nu)_{\rm SM} \times r_H$$

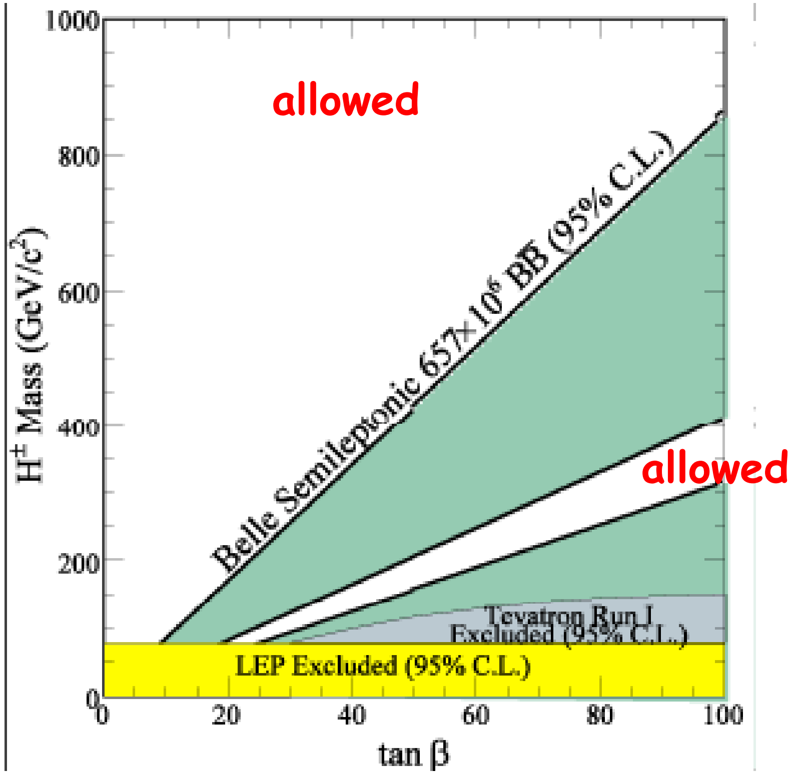
$$r_H = (1 - \frac{m_B^2}{m_H^2} \tan^2\beta)^2$$



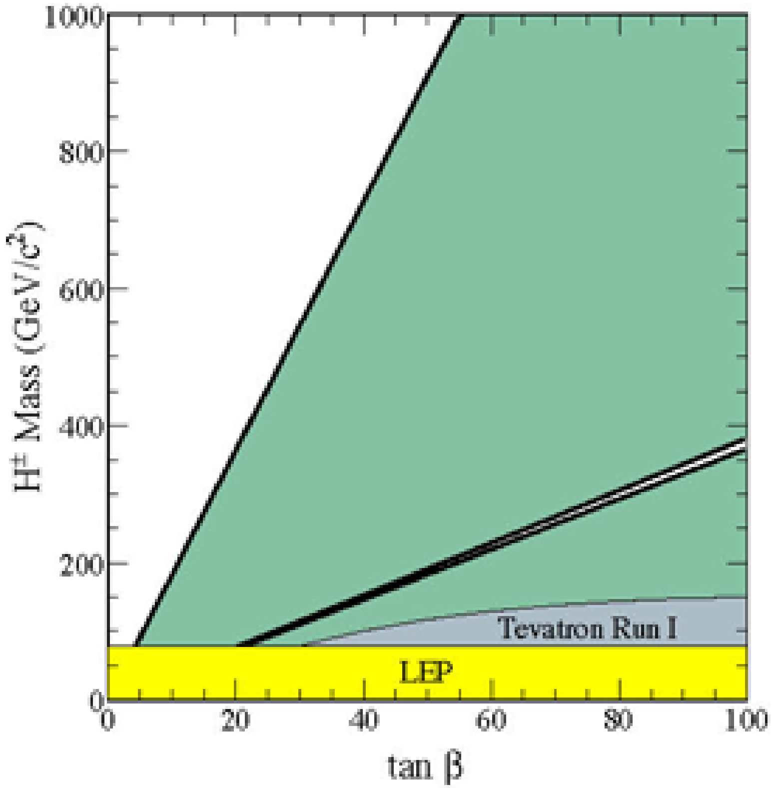
{WS Hou, PRD 48, 2342 (1993)}

(Belle) 0.65 ab^{-1}

$\mathcal{B}(B \to \tau\nu) = (1.7 \pm 0.4 \pm 0.4) \times 10^{-4}$



(extrapolation) 50 ab^{-1}



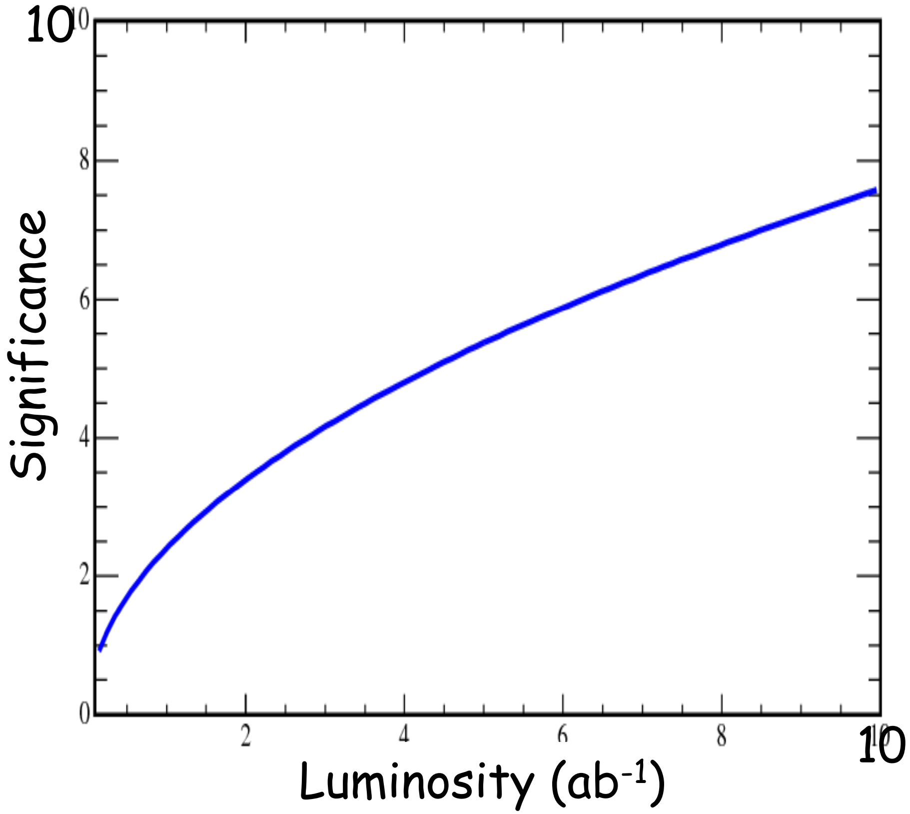
Lepton universality: B→μν

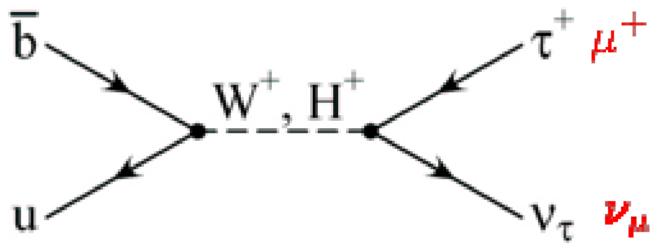
SM:

$B(B\to\tau\nu) = 1.6\times10^{-4}$

$B(B\to\mu\nu) = 7.1\times10^{-7}$ expect observation within few ab^{-1}

$B(B\to e\nu) = 1.7\times10^{-11}$



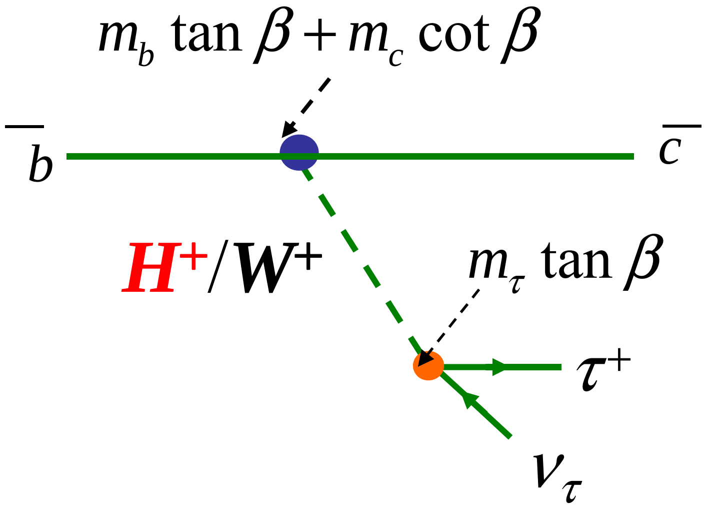


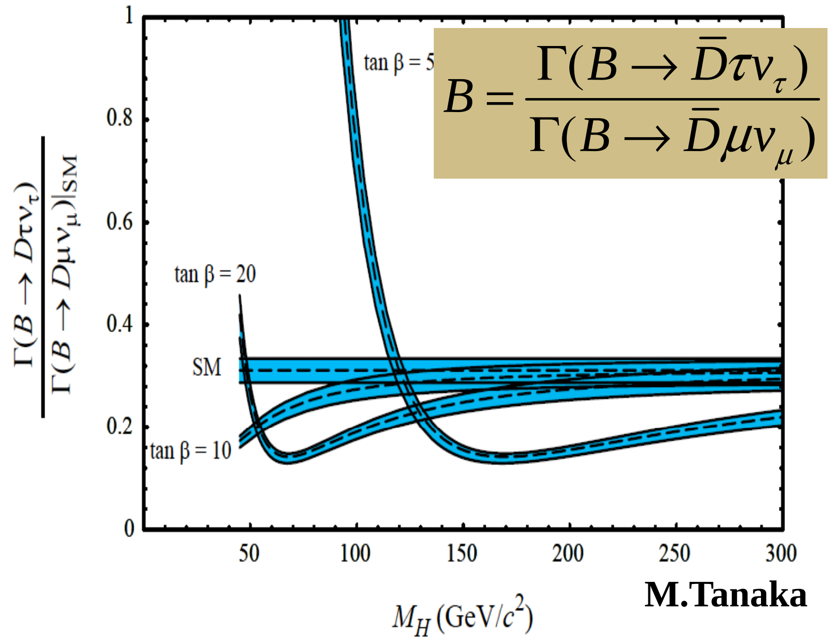
$\frac{B\to\tau\nu}{B\to\mu\nu}$

deviations from SM sensitive to NP

B → D(*) τ ν

- Lepton universality via semileptonic decays





M.Tanaka

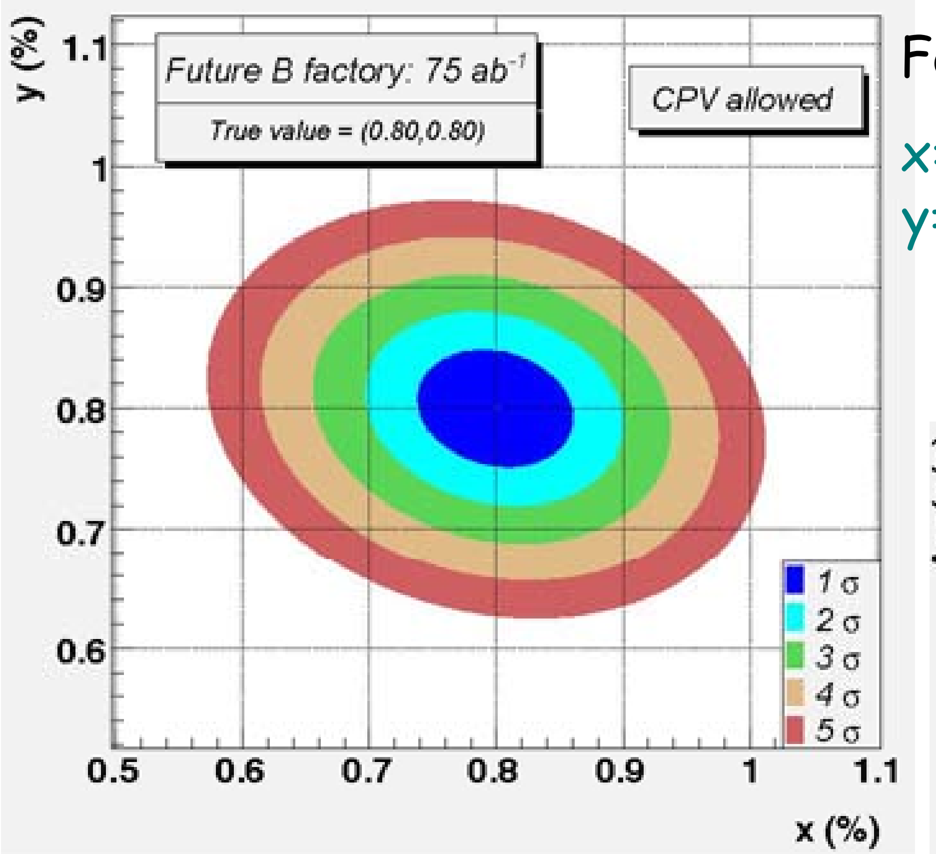
B(B^0->$D^{*-}\tau\nu$) = (2.0±0.4±0.4)%
[PRL 99, 191807 (2007)]

- Ratio (τ/μ) is sensitive to charged Higgs (similar to B→τ ν)

B→τ X decays probe NP in different ways:

- B→τ ν: H-b-u vertex
- B→Dτν: H-b-c vertex

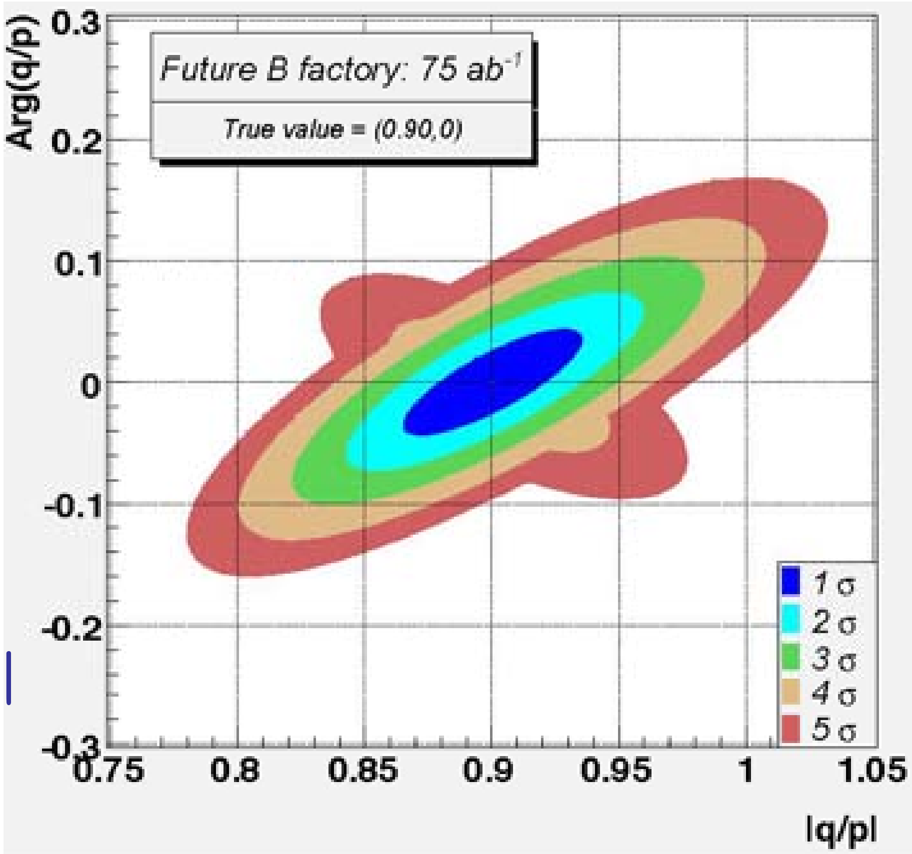
D mixing/CP violation



For 75 ab^{-1}

x=0.8 >4σ significance on x

y=0.8 >5σ significance on y



|q/p|=0.9

~4σ significance on 1-|q/p|

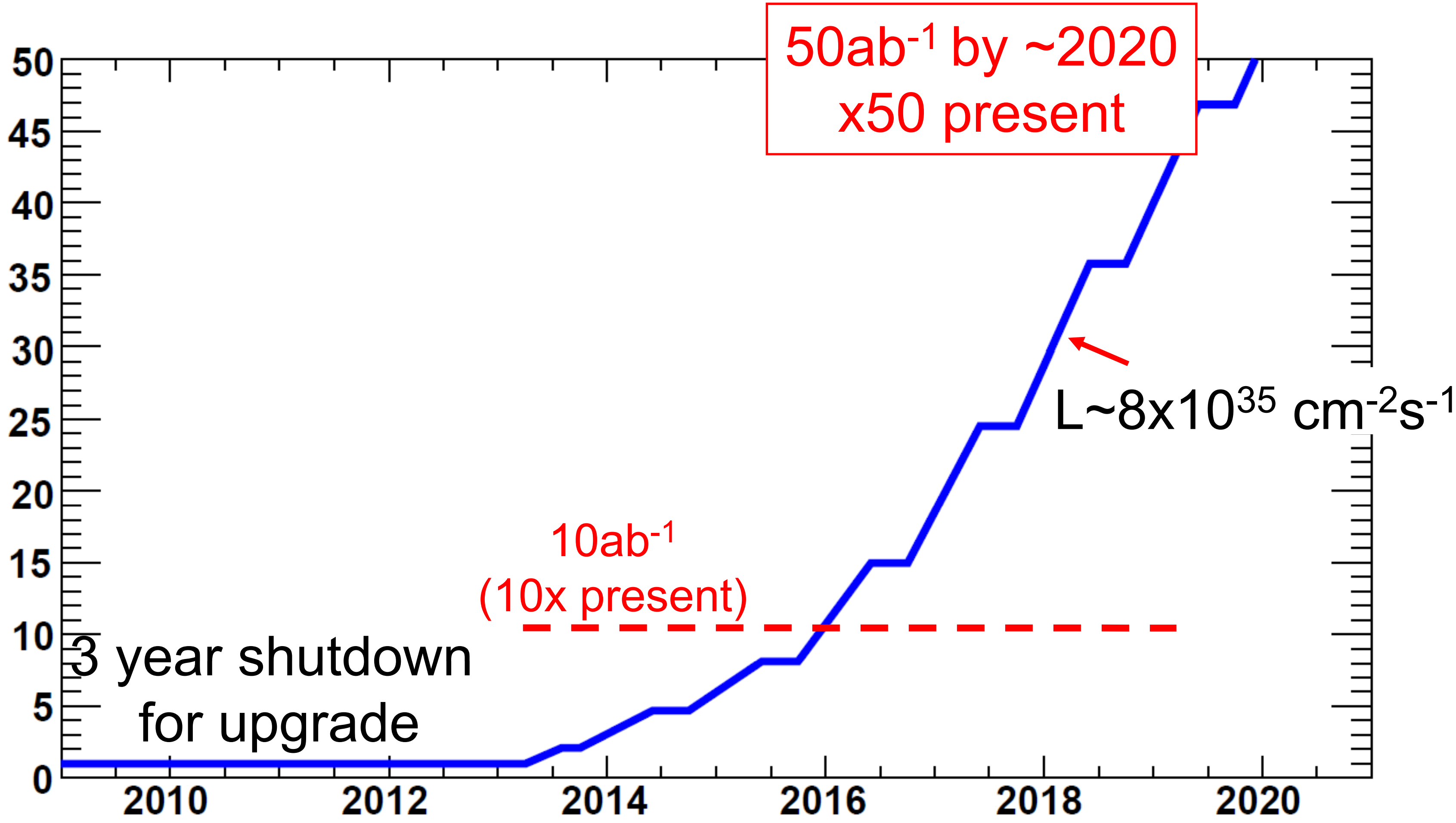
=> what we need is

Billions and Billions

of B's

KEKB and Belle
upgrade plans

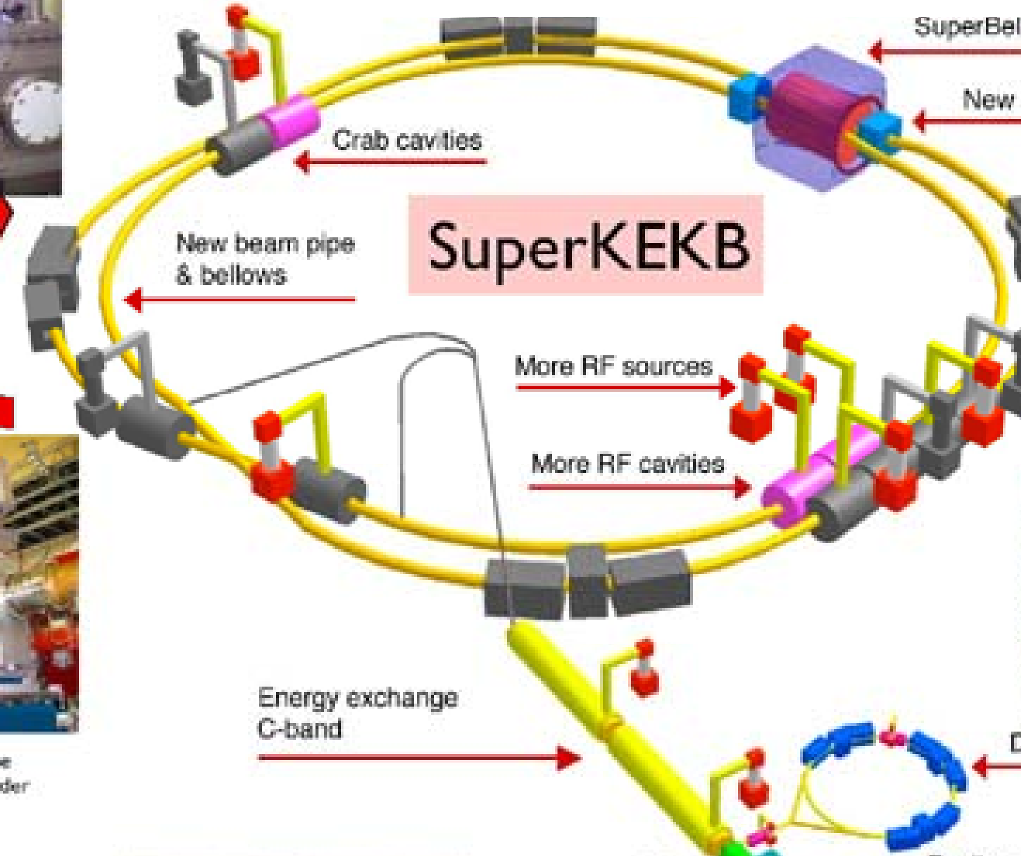
Super KEKB Luminosity projection



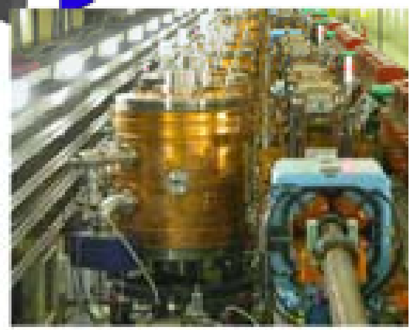
KEKB Upgrade plan

- *upgrade existing KEKB collider*
- *Final goal: $L=8\times10^{35}/cm^2/sec$ and $\int L\,dt = 50\ ab^{-1}$*

Crab cavities will be installed and tested with beam in 2006.

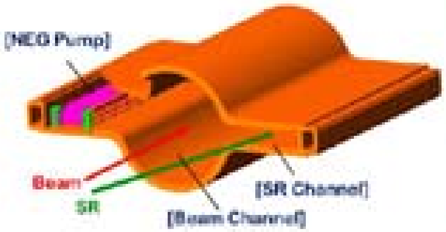


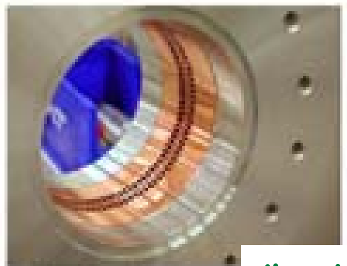
The superconducting cavities will be upgraded to absorb more higher-order mode power up to 50 kW.



The state-of-art ARES copper cavities will be upgraded with higher energy storage ratio to support higher current.

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





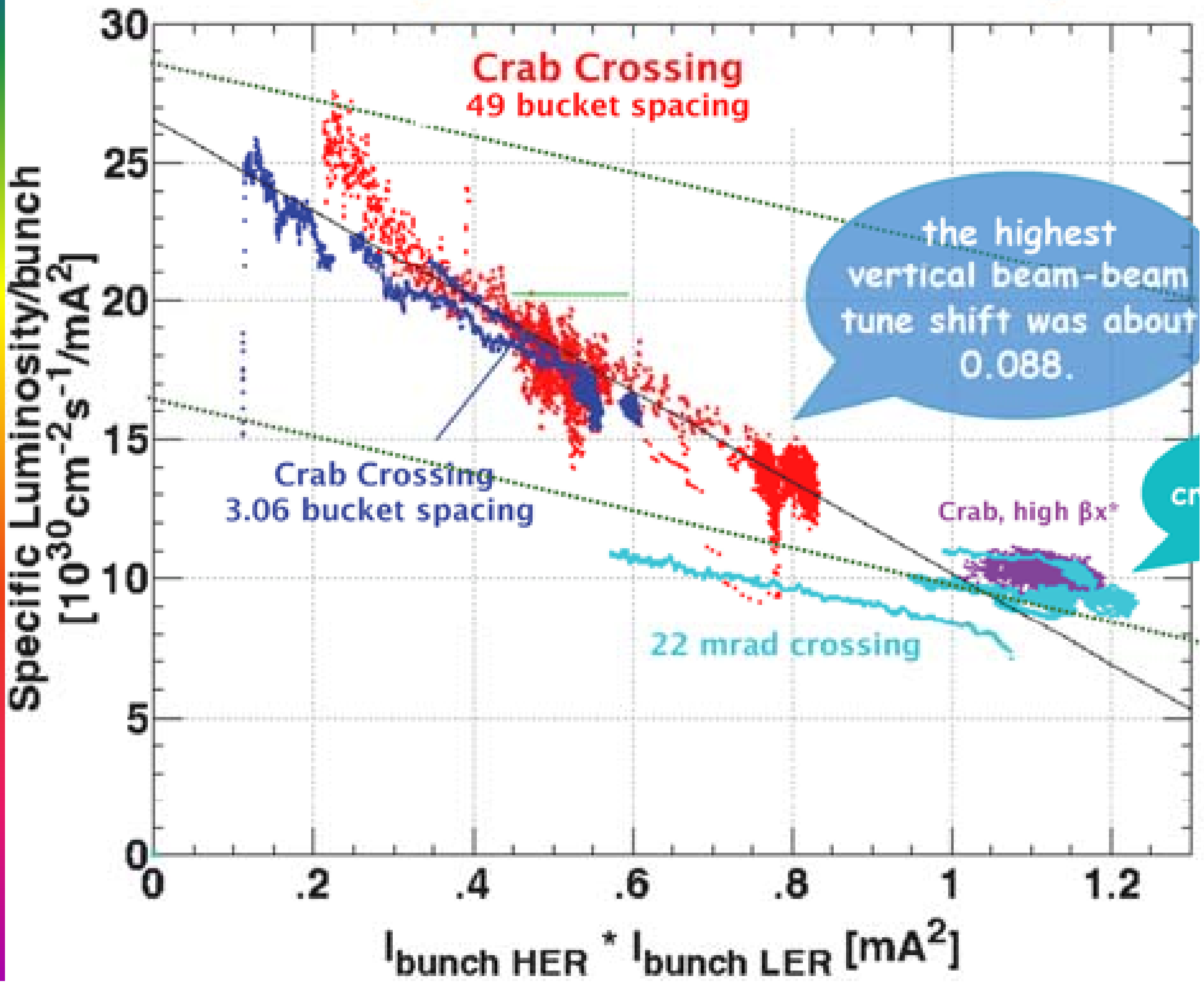
The beam pipes and all vacuum components will be replaced with higher-current-proof design.

"adiabatic" - test/install in existing machine

Crab cavities

First operations 1/2007

- demonstrated effective head-on collisions
- specific luminosity matches simulations for low (but not high) currents
- low beam lifetime



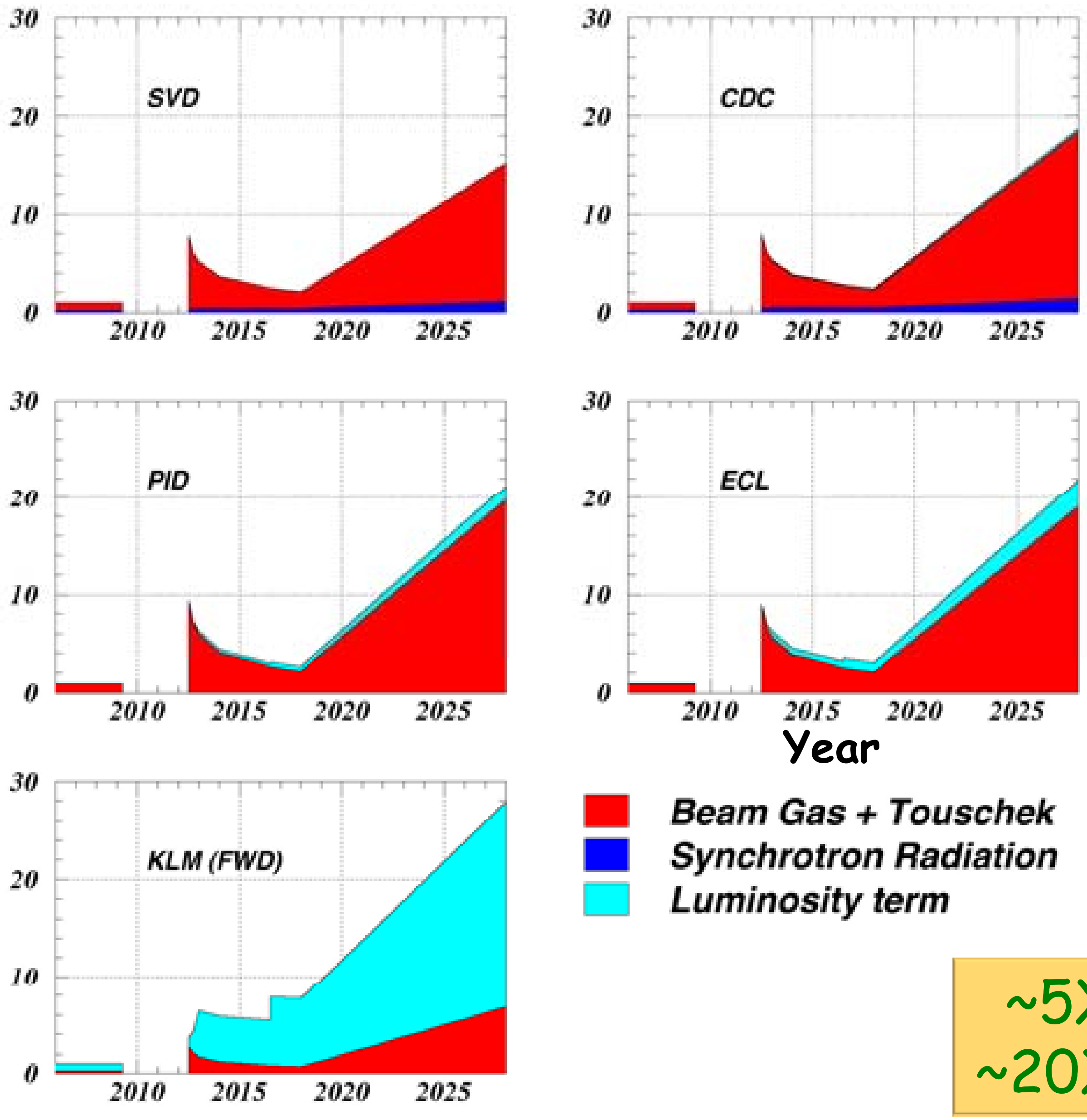
Studies in 2007-8

- aperture at crab cavities limits beam lifetime
- beam-beam simulations indicate: large machine errors yield lower luminosity – upgrade tuning method?

as of 12/08

$\mathcal{L}_{max} = 1.64 \times 10^{34}\ cm^{-2}s^{-1}$

Detector: Background projections



Belle detector normalized to current rates

Issues
Radiation damage
Occupancy
Fake hits, pile-up
Event rate

~5X first few years
~20X at full luminosity

(the detector temporarily known as) sBelle

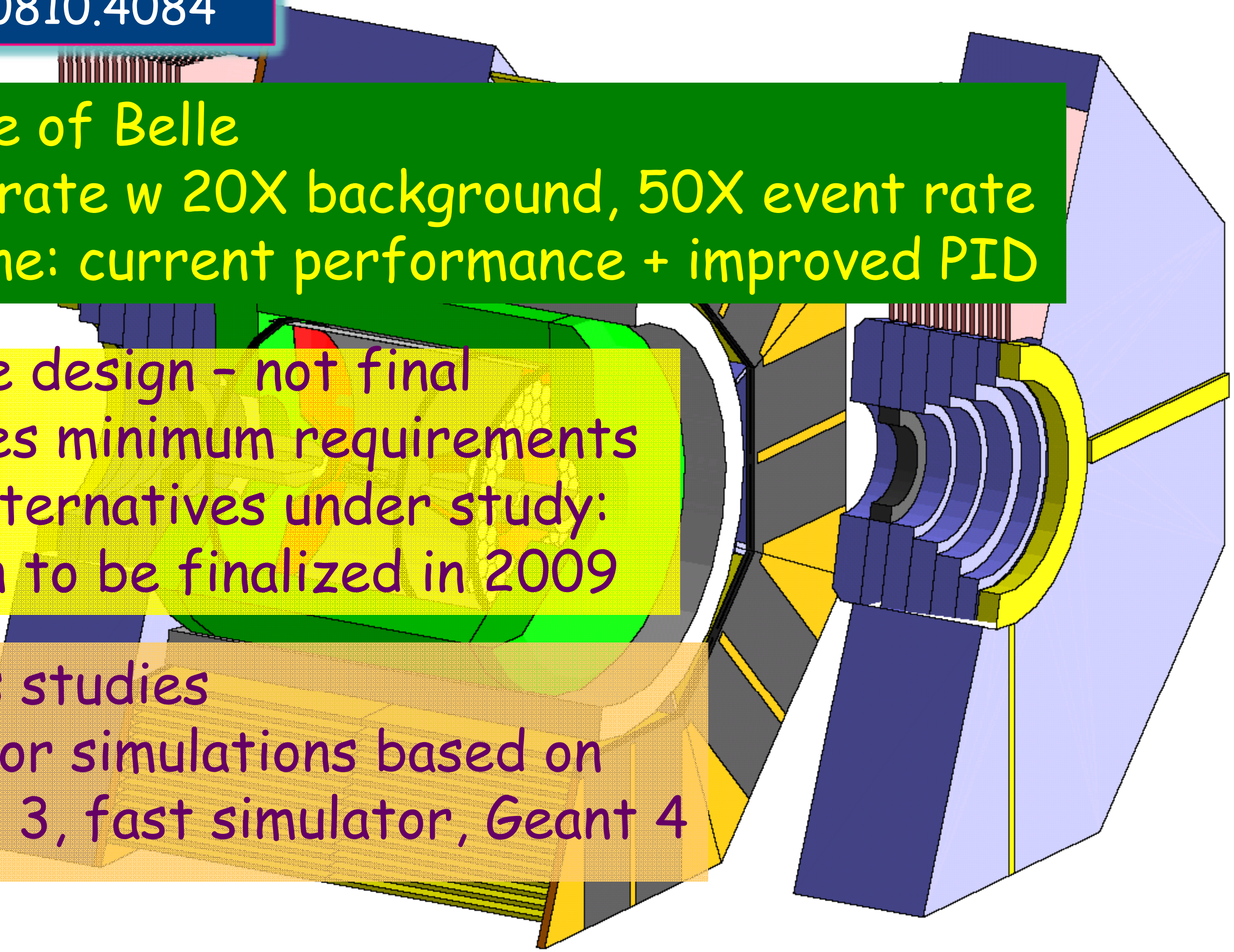
Super KEKB Quest for BSM

Design Study Report
arXiv: 0810.4084

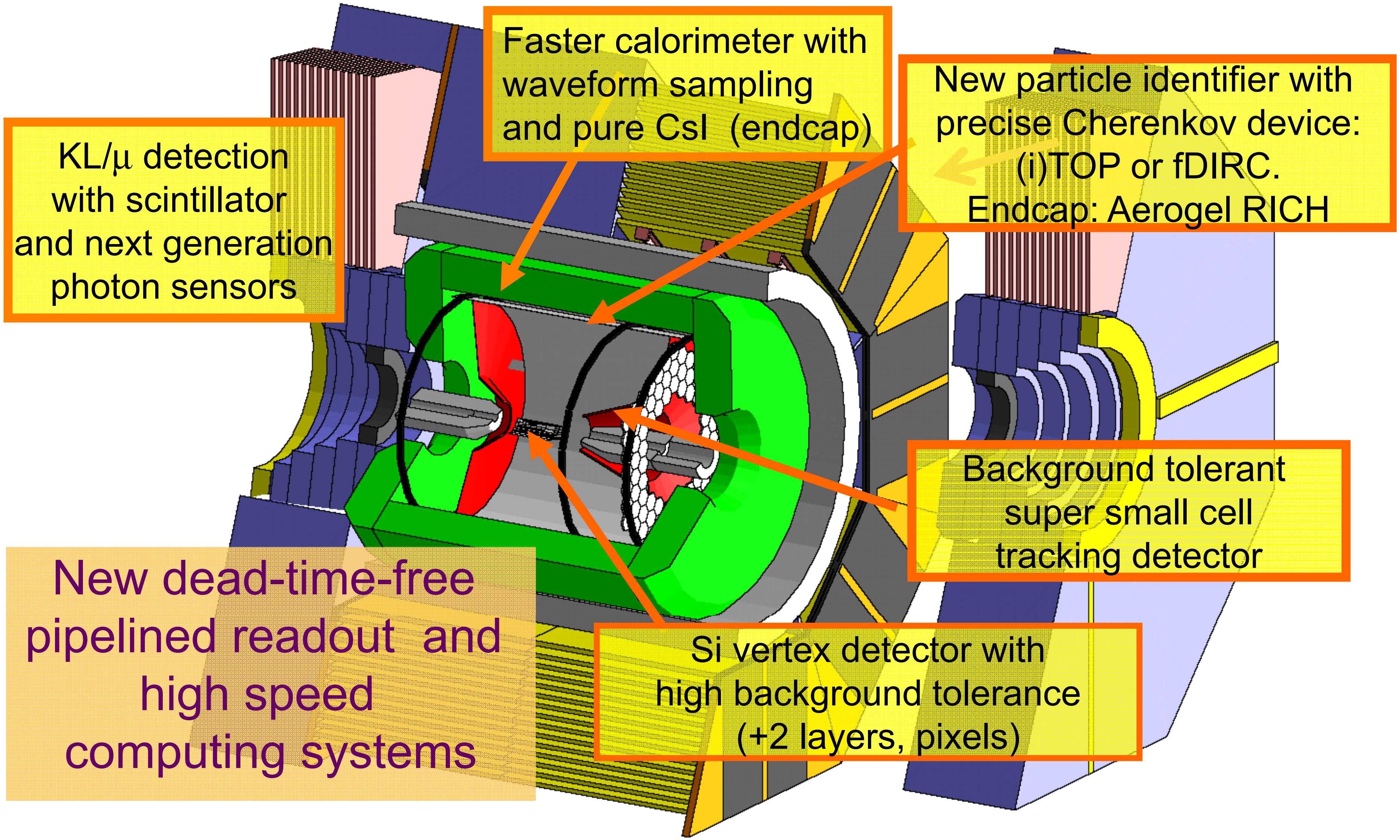
Upgrade of Belle
- to operate w 20X background, 50X event rate
- baseline: current performance + improved PID

Baseline design – not final
Satisfies minimum requirements
Many alternatives under study:
- Design to be finalized in 2009

Physics studies
Detector simulations based on
- Geant 3, fast simulator, Geant 4



(the detector temporarily known as) sBelle: baseline



New dead-time-free pipelined readout and high speed computing systems

Baseline design

Silicon inner tracker

- improve vertexing -> thin innermost 2 layers, reduce inner radius
- improve K_S acceptance -> increase outer radius
- background/occupancy -> striplets, pixels, pipelined readout

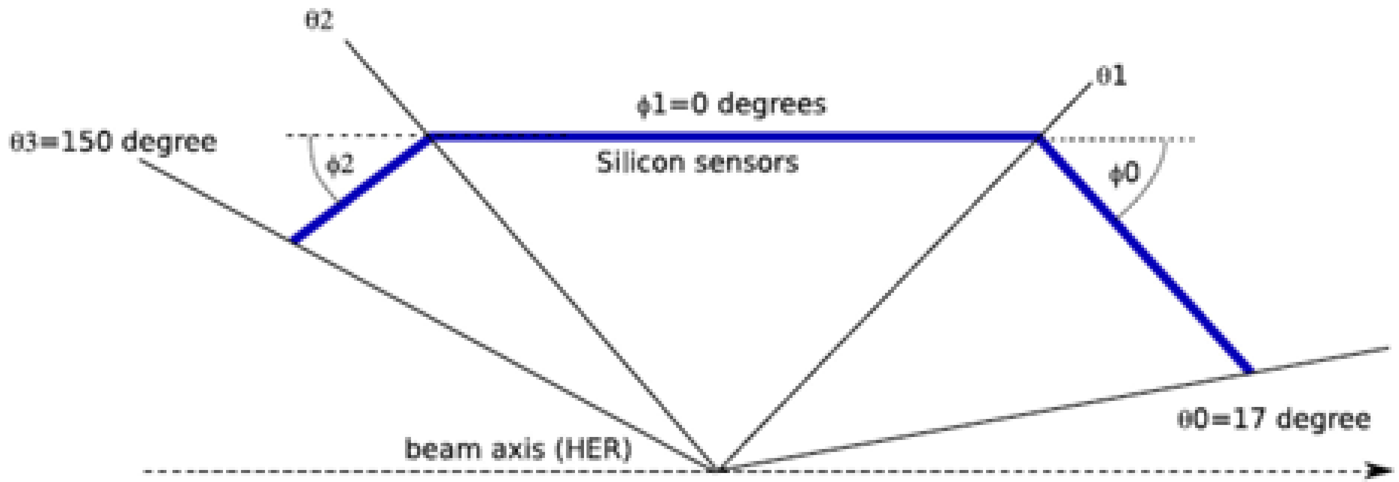
+ standalone tracking, dE/dx

	Belle	sBelle
Detector type	4-DSSD	2-DEPFET pixel + 2-DSSD + 2-DSSD (short strips/angled) chip-on-sensor lyr 5&6
Inner radius	15 mm	10 mm
Outer radius	70 mm	120 mm
DSSD readout	Hold 3μs/readout 27μs	pipelined
Readout time	800 ns	50 ns

Baseline design

Silicon inner tracker

Layers 5 and 6
- shorten strips
- angle to reduce total area



	θ_1	θ_2	ϕ_0	ϕ_2	V_1	V_2	$S(cm^2)$
LoI	34	---	–15		28	33	5018

Baseline design

Drift chamber

- improve momentum resolution -> increase outer radius
- improve dE/dx -> longer radial path
- background/occupancy -> smaller cells

	Belle	sBelle (t>0)
Inner radius	77 mm	160 mm
Outer radius	880 mm	1140 mm
Inner layer cell size	12 mm	8 mm
# sense wires	8400	15140

Baseline design

Particle ID

- improve K/π for b->s vs b->d, etc.
- add endcap PID
- reduce material in front of calorimeter

	Belle	sBelle (t>0)
Barrel	Aerogel TOF dE/dx in CDC	Cerenkov time-of-propagation (TOP)
Endcap	(dE/dx)	Aerogel RICH

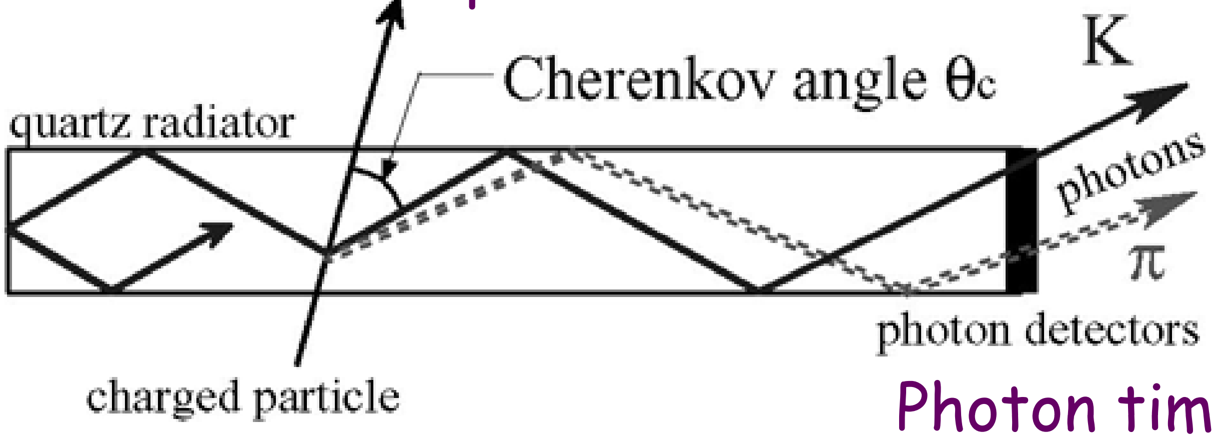
Baseline design

Particle ID

Barrel

TOP counter

π/K time-of-flight;
at 3 GeV, 1m path,
$\Delta t \sim 50$ ps



Photon time-of-propagation
due to θ_c difference;
at 3 GeV, 1m path, $\Delta t \sim 75$ ps

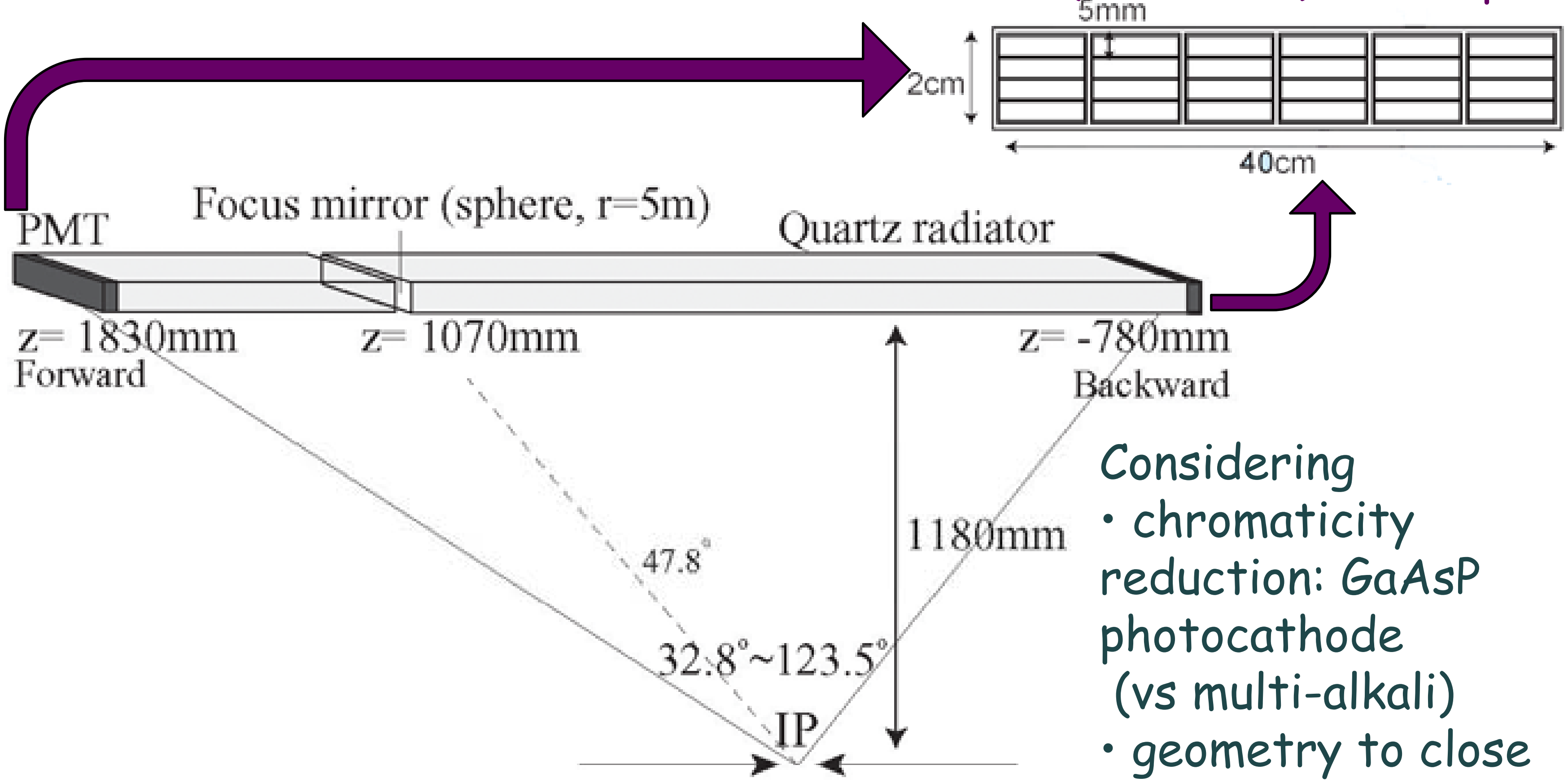
Baseline design

Particle ID

Barrel

TOP counter

Photon detection
Multi-anode
Microchannel plate PMT
(MCP-PMT) Δt<40 ps



Considering
- chromaticity reduction: GaAsP photocathode (vs multi-alkali)
- geometry to close gaps
- 1-piece radiator

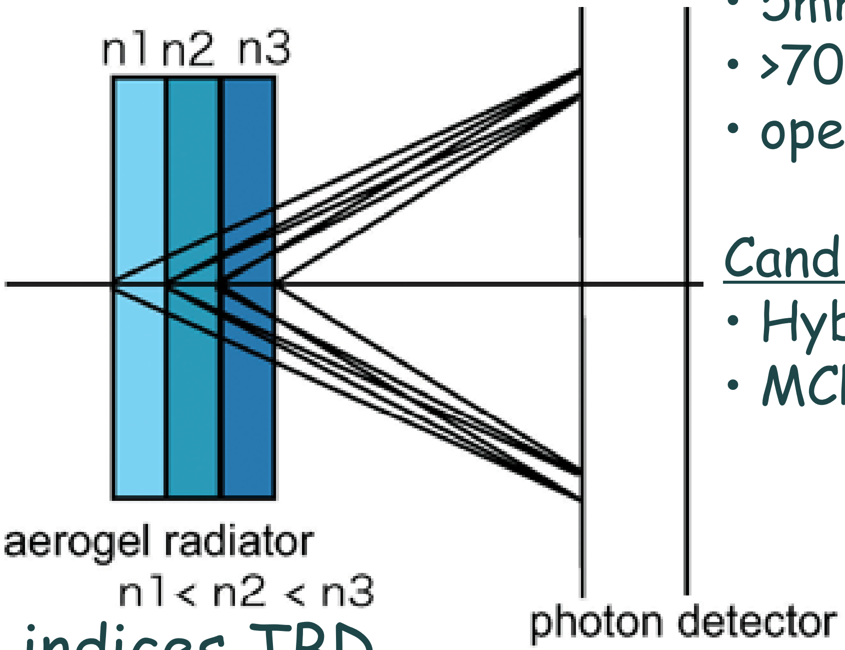
Baseline design

Particle ID

Endcap

Proximity focusing Aerogel RICH

Multi-index to minimize ring width
n = 1.045-1.055



indices TBD

Photon detector requirements

- high QE, >20%
- high gain
- 5mm x 5 mm segmentation
- >70% coverage
- operate in B=1.5 T

Candidates

- Hybrid APD
- MCP-PMT (includes TOF)

Baseline design

Electromagnetic calorimeter

- reduce background without loss of resolution

	Belle	sBelle (t>0)
Barrel	CsI (Tl)	CsI(Tl) +waveform sampling/fitting
Endcap Rise time Photodetector	CsI(Tl) 1000 ns Si photodiode	Pure CsI 30 ns PMT +waveform sampling/fitting

Baseline design

Electromagnetic calorimeter

endcap

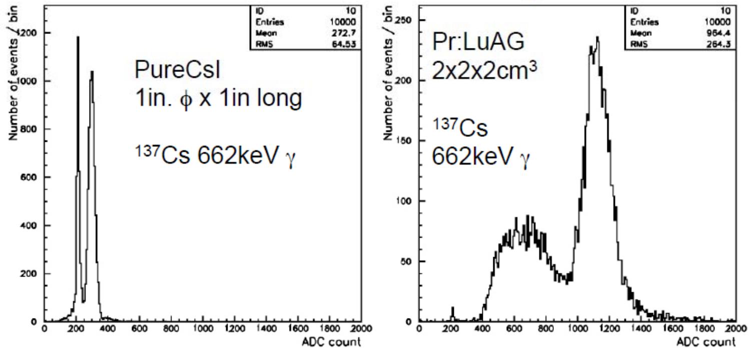
Alternative crystal under consideration

Pr:LuAG[Praseodymium doped Lutetium Aluminum Oxide ($Lu_3Al_5O_{12}$)]

Crystal with Pr doping in 0.25 atomic%.
2in. diameter ingot

- Density=6.7g/cm^3
  (CsI:4.5g/cm^3)
- X_0(LuAG)=1.47cm
  (CsI:1.86cm)
- R_M(LuAG)=2.16cm
  (CsI:3.57cm)
- Wavelength=310nm
  (not different from pure CsI)
- L.O.=BGOx3
  (pureCsIx12?)
- Decay time<22ns
- Raw material=11,000yen/300g

Much more L.O. than pureCsI



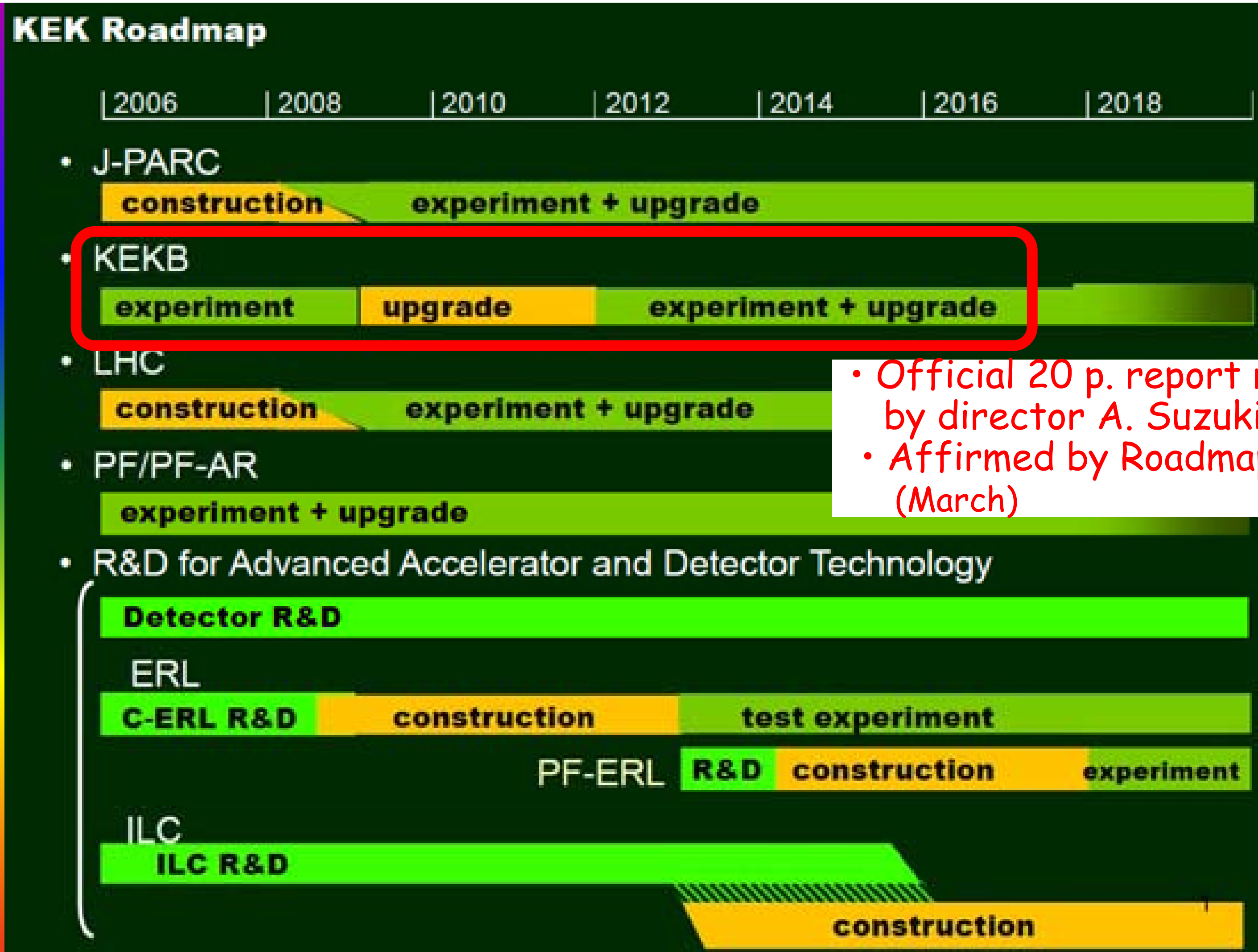
Details(difference in PMT's QE for different wavelength, etc.) are to be concerned/revisited.

Baseline design

K_L/muon detector

- reduce background in endcap

	Belle	sBelle (t>0)
Barrel	Glass RPC, streamer mode	Same RPC (avalanche mode?)
Endcap	Glass RPC, streamer mode	Plastic scintillator x-y strips



- Official 20 p. report released Jan 4, 2008 by director A. Suzuki & KEK mgmt
- Affirmed by Roadmap Review Committee (March)

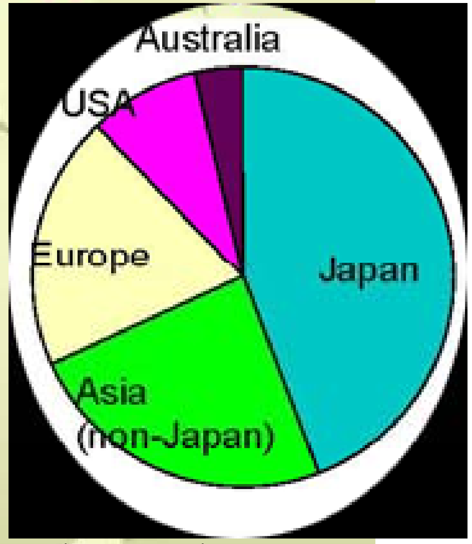
Placement of KEKB upgrade on roadmap is **significant**

- 3-year KEKB upgrade ('10–'12)
- $L \sim 8 \times 10^{35}\ cm^{-2}s^{-1}$
- Funding: KEK management in discussions w agency (MEXT)

(sBelle) Collaboration

- New experimental group being formed (not an extension of present Belle collaboration): name TBD
- First meeting of new collaboration in December 2008

Belle



Interim Steering Committee:
Hiroaki Aihara (Tokyo/IPMU), Alex Bondar (BINP), Tom Browder (Hawaii), Paoti Chang (NTU), Toru Iijima (Nagoya), Peter Krizan (Chair, Ljubljana), Thomas Muller (Karlsruhe), Henryk Palka (Crakow), Christoph Schwanda (Vienna), Martin Sevior (Melbourne), Eunil Won (Korea), Changzheng Yuan(IHEP, China), Yutaka Ushiroda, Yoshi Sakai(KEK), Masa Yamauchi (KEK)

Summary

- B-factories 1999-2009, >1.4x10^9 B pairs:
  established CKM as source of CP asymmetry in weak interaction
  multiple measurements on CKM with increasing precision:
  φ_1, φ_2, φ_3, $|V_{ub}|$,
  -> probe New Physics:
  discovered: D mixing, new hadronic states
  studied tau
  a few unresolved effects: Kπ CP asymmetry, imperfect CKM fit

- ~10^2X luminosity will probe significantly into >1 TeV mass scale
  precision CKM, CP, lepton universality, LFV
- KEKB upgrade for L=8 x 10^{35} included in KEKB Roadmap
- KEKB/Belle upgrade plans well underway
  new international collaboration forming

Backup slides