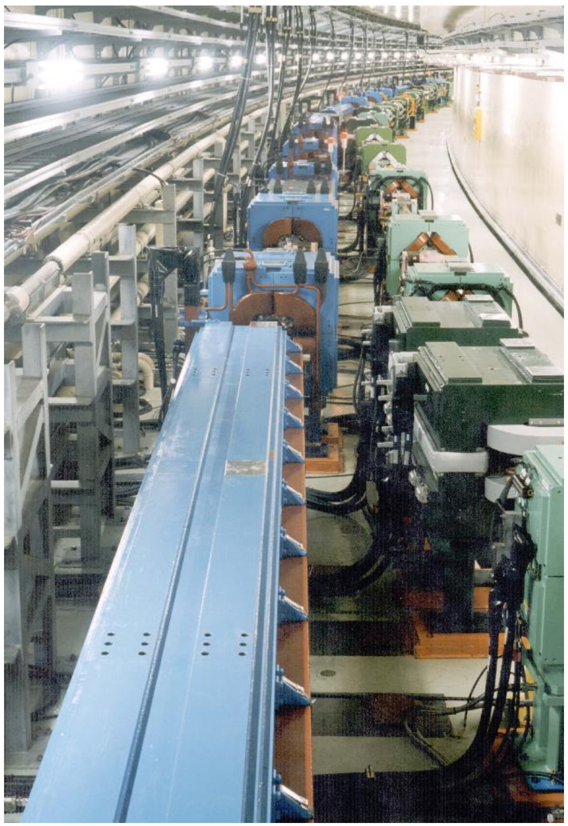
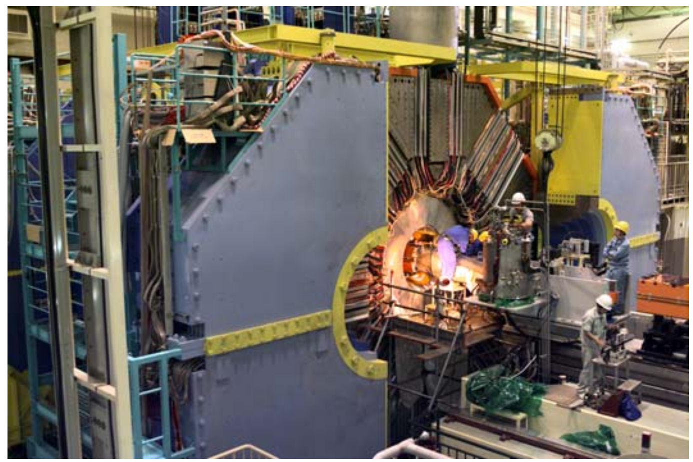
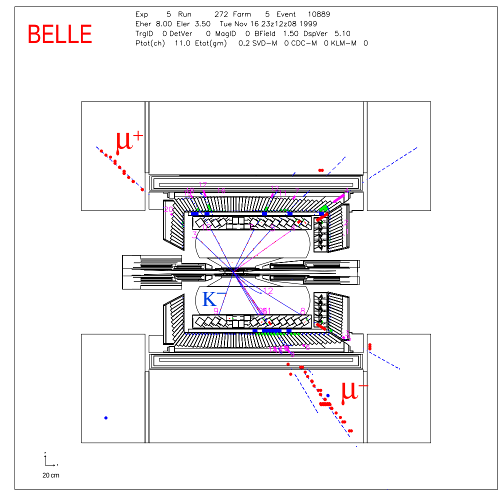
Recent results from Belle and SuperKEKB upgrade







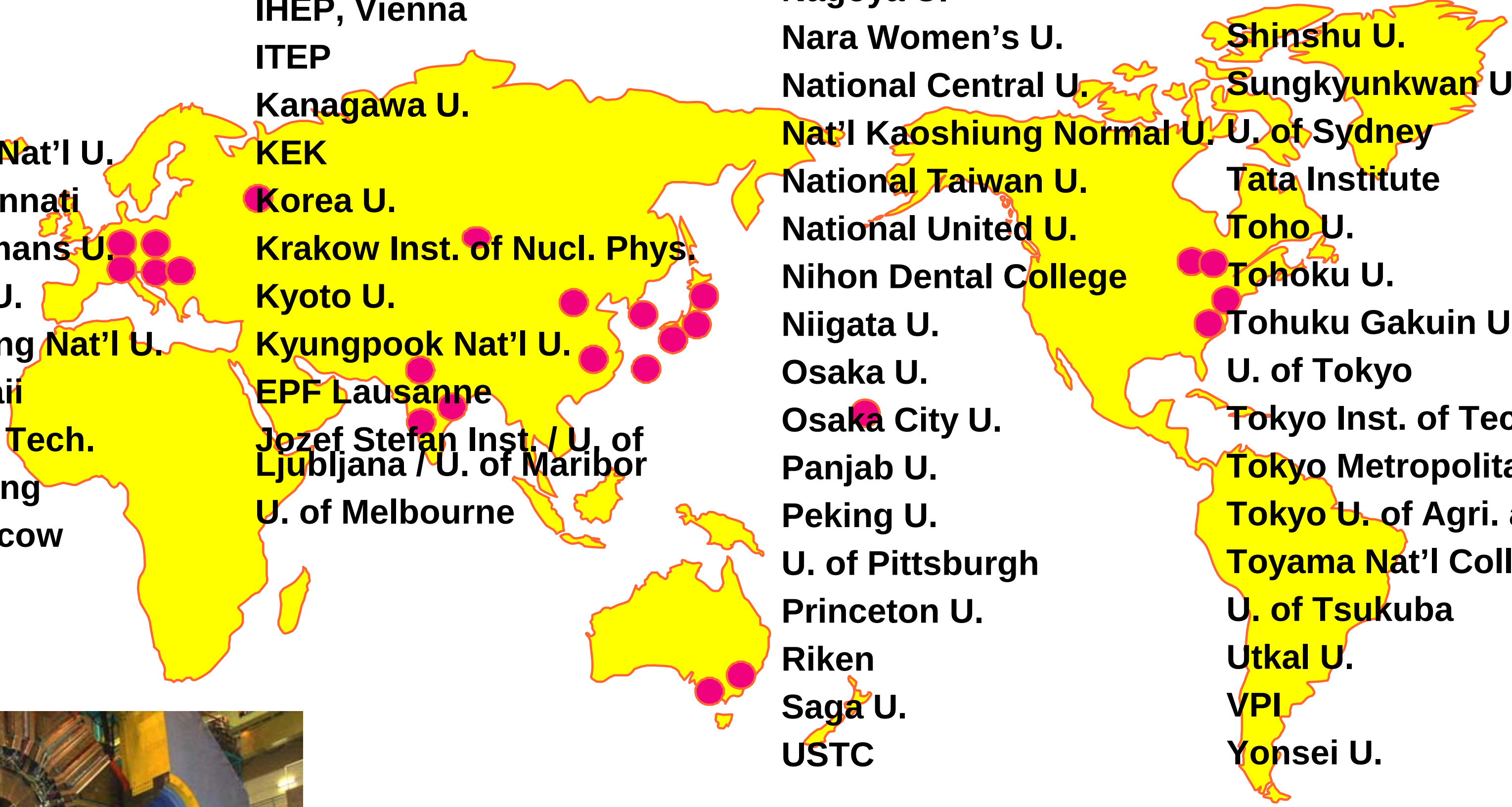
Masashi Hazumi (KEK)

DESY Seminar

Feb. 2, 2006

International Collaboration: Belle

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

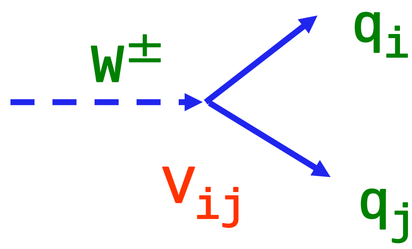
The Belle (B Factory) Physics Program

① CP Violation in B Decays

② Fundamental SM Parameters (Complex Quark Couplings)

③ Beyond the SM (BSM)

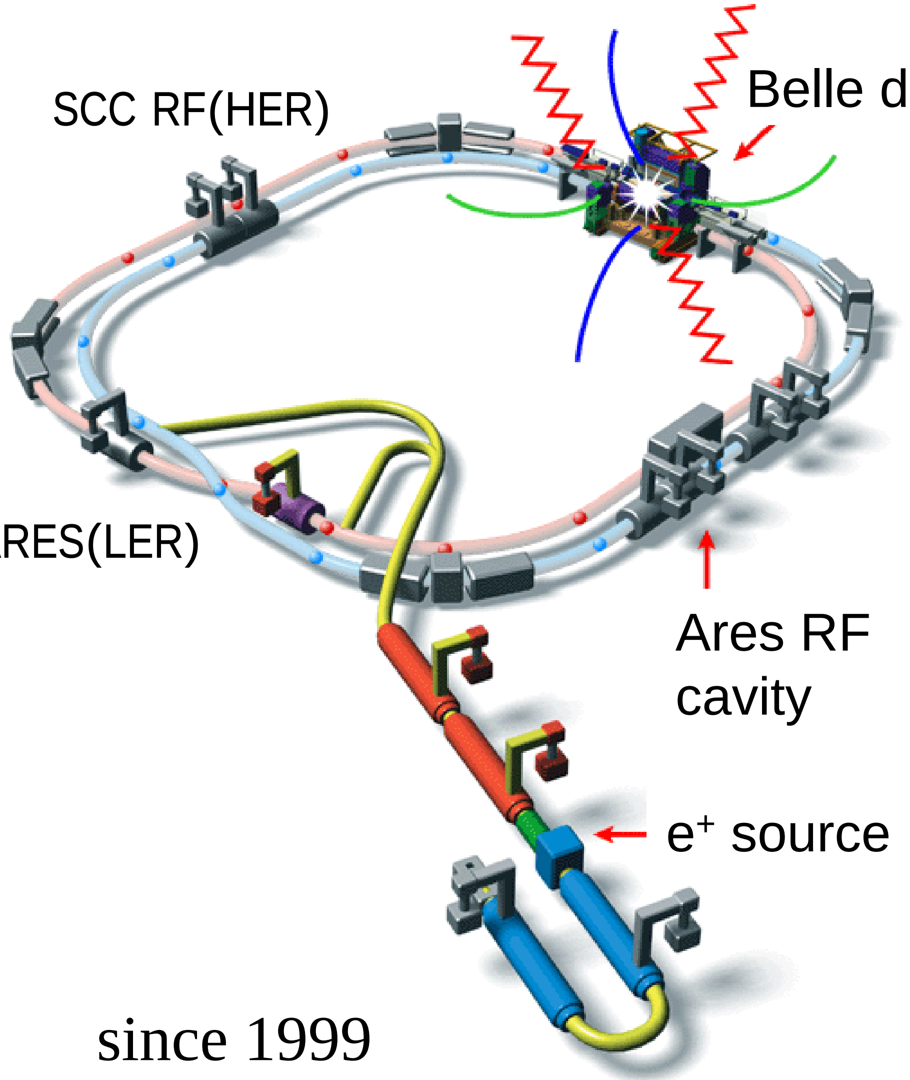
④ Unanticipated New Particles



Warning: Will focus on current results relevant to ③ and prospects for SuperKEKB. ① and ② mentioned in conjunction with ③.

Can only cover a small subset of the rich and broad physics program.

The KEKB Collider



since 1999

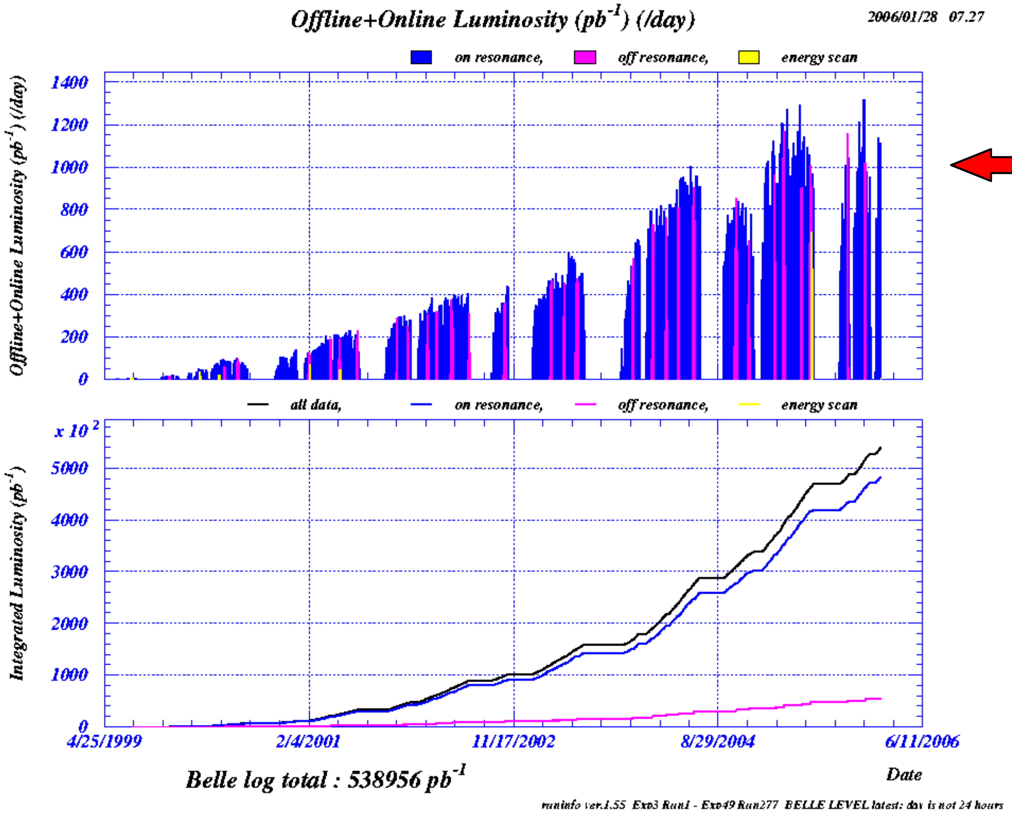
8 x 3.5 GeV
22 mrad crossing angle

World record:

$L = 1.6 \times 10^{34}/cm^2/sec$

Belle/KEKB Luminosity Milestone: 500 fb^{-1} = 0.5 ab^{-1}

(Equivalent to > 500 million BB-pairs)



1 fb^{-1} / day

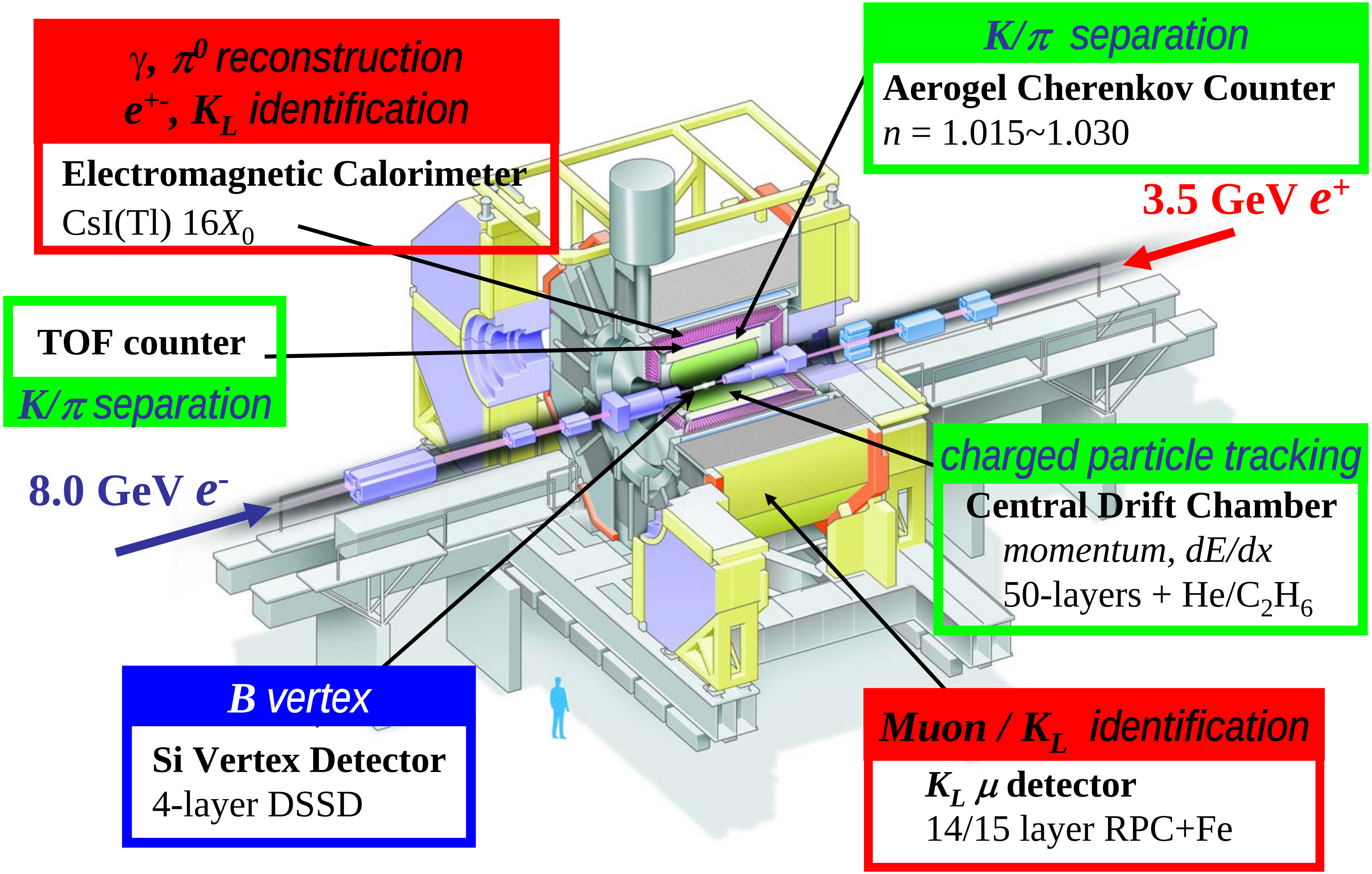
Current Total = 539 fb^{-1}

(as of Jan.28, 2006)

Today: some results with 350 fb^{-1} (386×10^6) B B pairs

as well as results based on 253 fb^{-1} (275×10^6) B B pairs

Belle detector



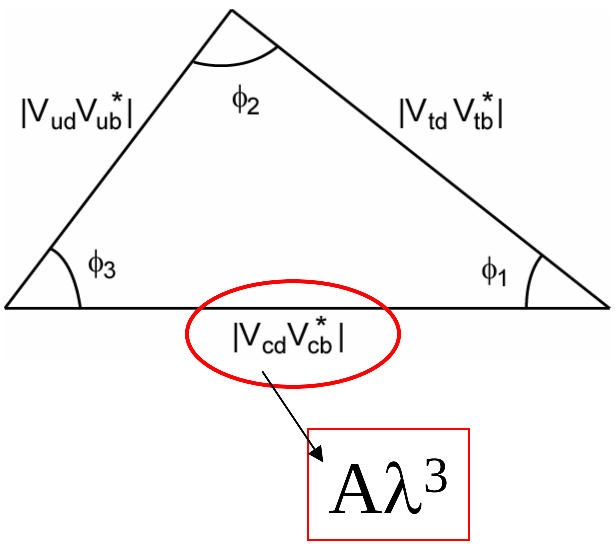
CP Violation in B Decays

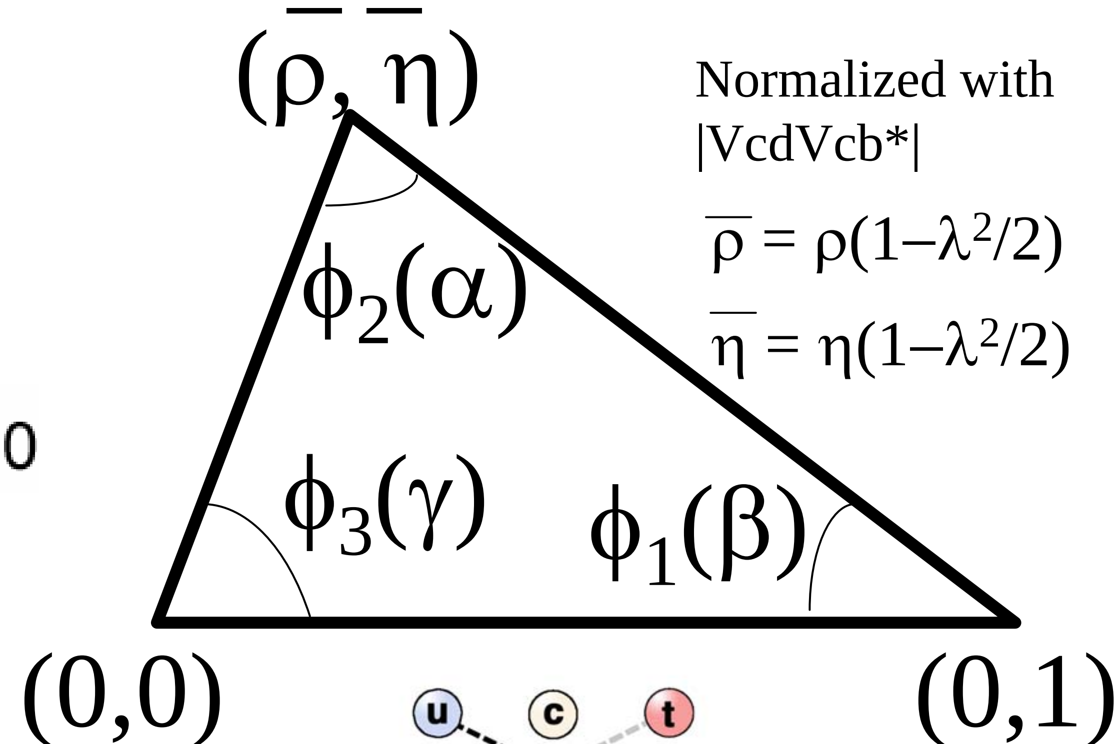
The Kobayashi-Maskawa weak phase

3 generations → CP-violating phase

$$V_{CKM}^{+}V_{CKM} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$V_{ud}V_{ub}^{*} + V_{cd}V_{cb}^{*} + V_{td}V_{tb}^{*} = 0$$

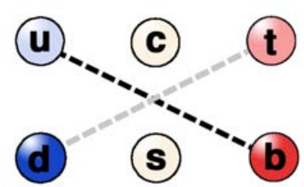




Normalized with |VcdVcb*|

$\bar{\rho} = \rho(1-\lambda^2/2)$

$\bar{\eta} = \eta(1-\lambda^2/2)$

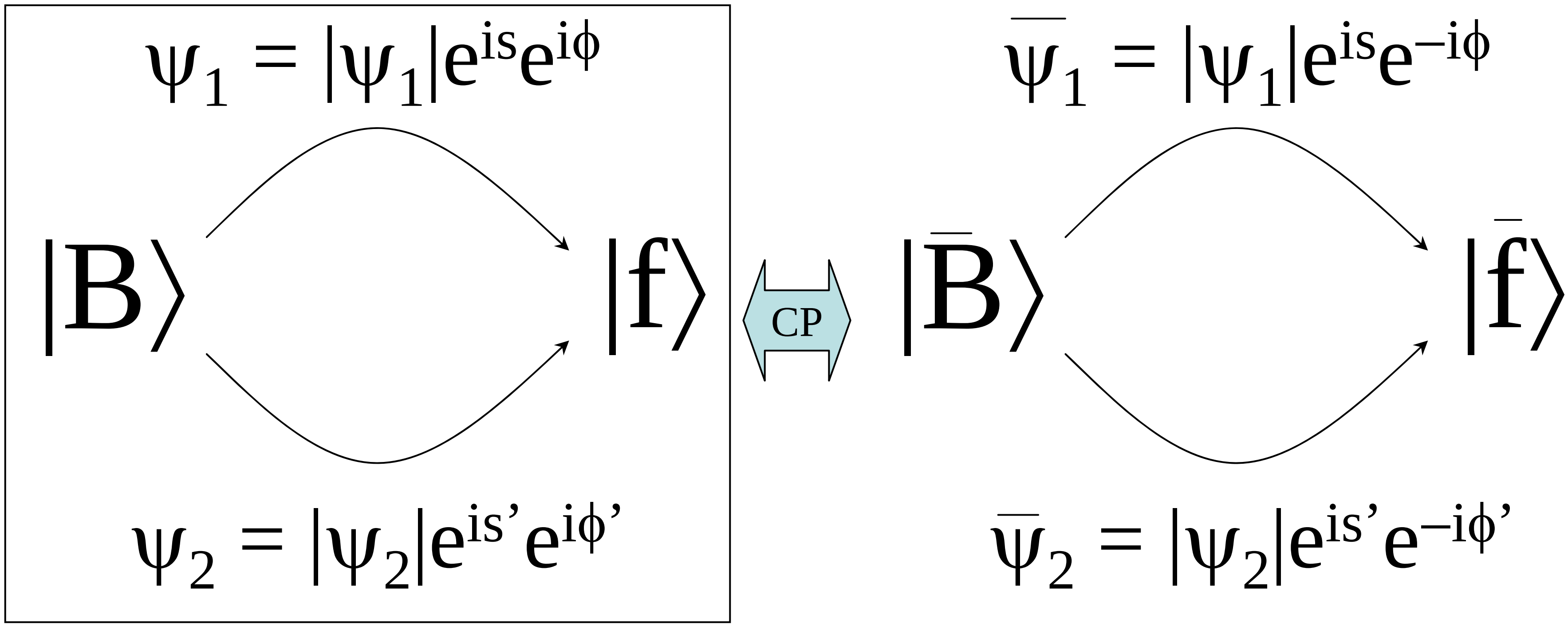


In particular, $V_{td} = |V_{td}|\exp(-i\phi_1)$

$V_{ub} = |V_{ub}|\exp(-i\phi_3)$

What's *CP* violation ?

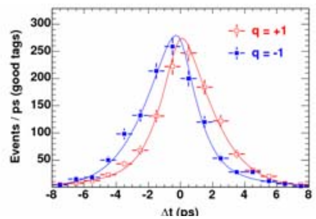
It is a partial rate asymmetry !



$$\mathcal{A}sym \equiv \frac{\Gamma(\overline{B} \to \overline{f}) - \Gamma(B \to f)}{\Gamma(\overline{B} \to \overline{f}) - \Gamma(B \to f)} = \frac{2|\psi_1||\psi_2|\sin(\phi - \phi)\sin(s - s')}{|\psi_1|^2 + |\psi_2|^2 + 2|\psi_1||\psi_2|\cos(\phi - \phi')\cos(s - s')}$$

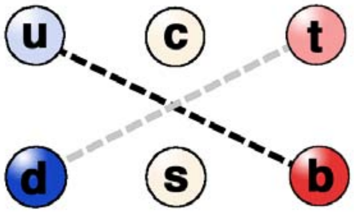
$\phi - \phi'$: weak phase diff. : previous slide

$s - s'$: static phase diff. : FSI, Resonance, Δm



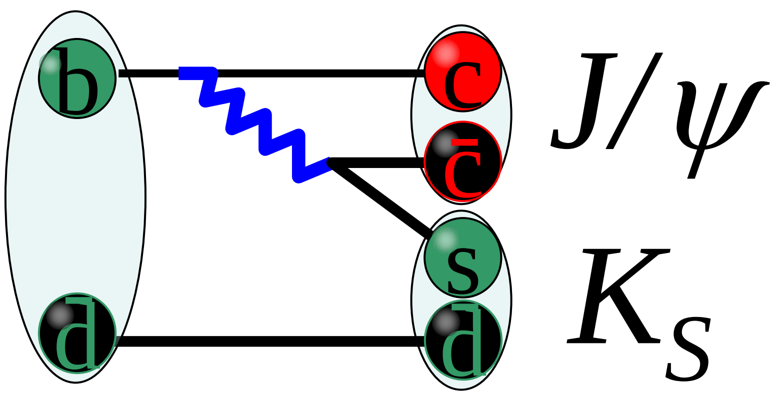
Time-dependent *CP* violation (tCPV)

“double-slit experiment” with particles and antiparticles



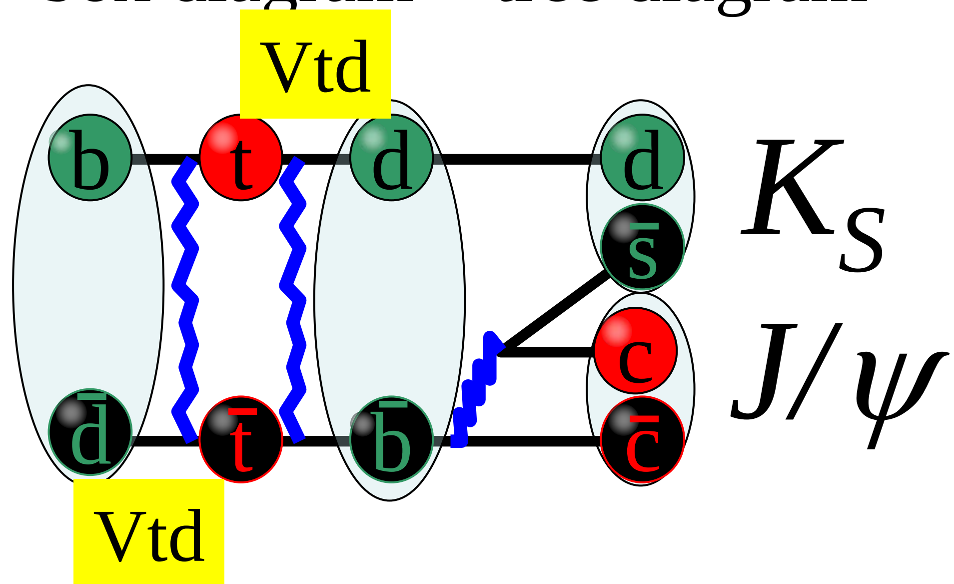
Quantum inteference b/w two diagrams

tree diagram



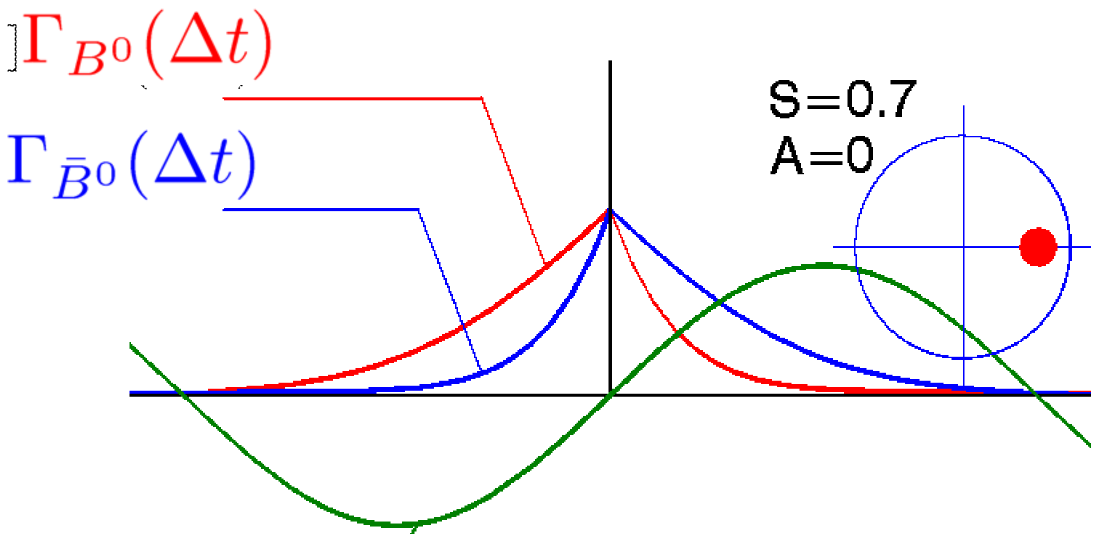
+

box diagram + tree diagram



Static phase diff. from Δm. You need to “wait” (i.e. $\Delta t \neq 0$) to have the box diagram contribution.

Time-dependent CP violation (tCPV) in B^0 decays



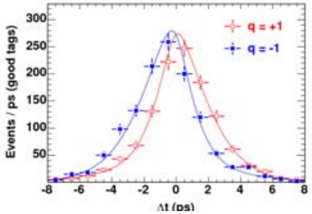
$$A_{CP}(\Delta t) \equiv \frac{\Gamma_{\bar{B}^0}(\Delta t) - \Gamma_{B^0}(\Delta t)}{\Gamma_{\bar{B}^0}(\Delta t) + \Gamma_{B^0}(\Delta t)} = \mathcal{S}\sin\Delta m\Delta t + \mathcal{A}\cos\Delta m\Delta t$$

Mixing-induced CPV

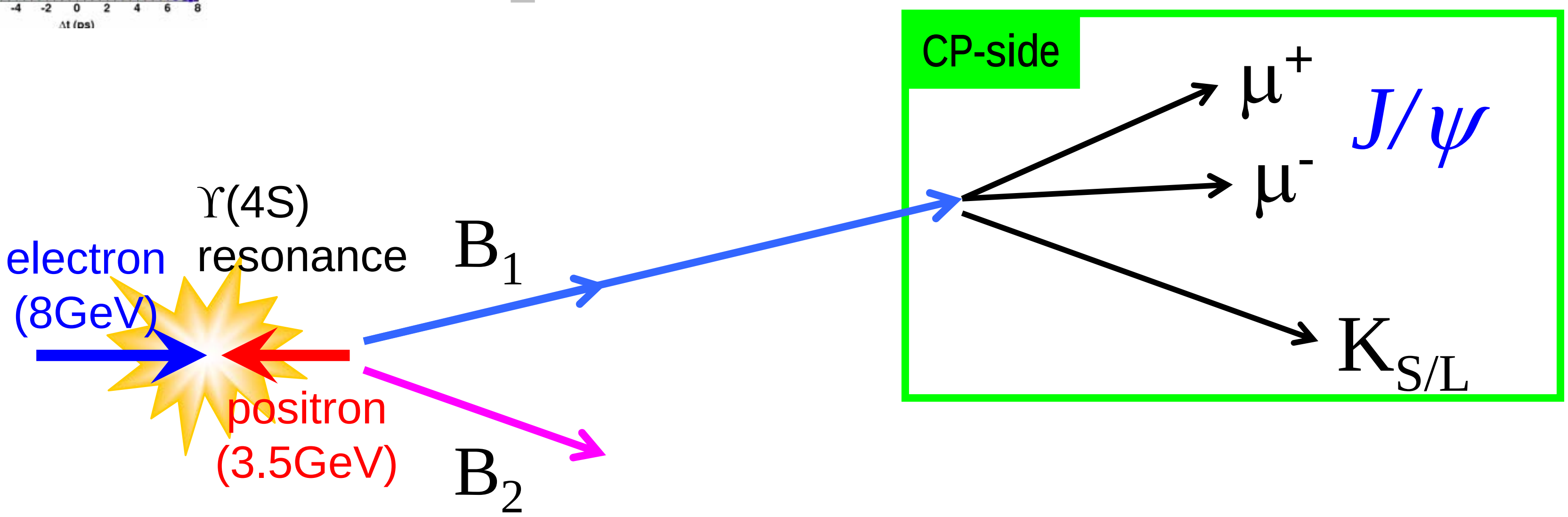
Direct CPV

e.g.
$S=\sin 2\phi_1$, $A=0$
for $J/\psi Ks$
to a good approximation

$(\mathcal{A} = -C)$

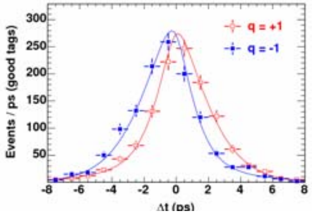


Principle of t*CP*V measurement

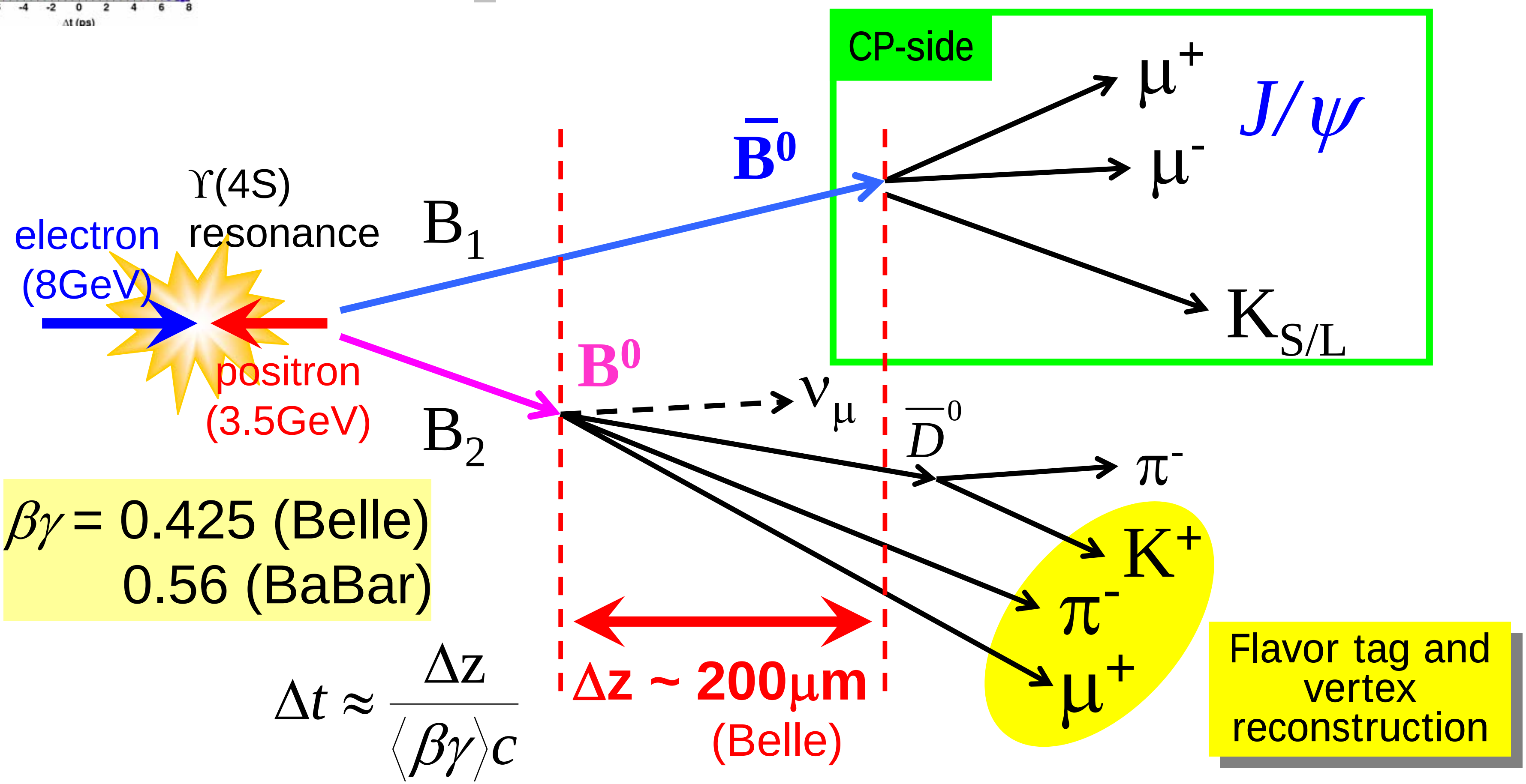


$\beta\gamma$ = 0.425 (Belle)
0.56 (BaBar)

1. Fully reconstruct one B-meson which decays to CP eigenstate



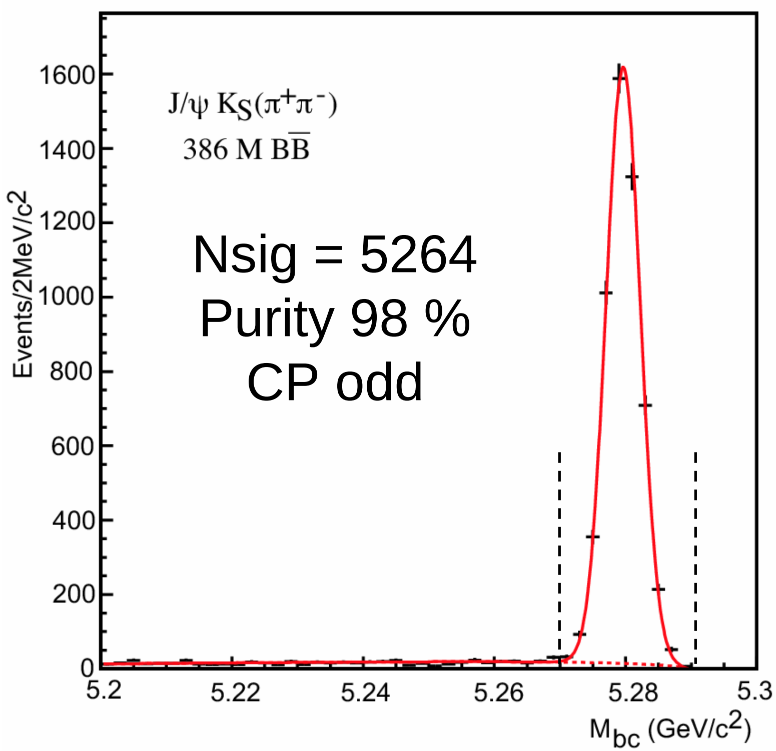
Principle of t*CP*V measurement



1. Fully reconstruct one B-meson which decays to CP eigenstate
2. Tag-side determines its flavor
3. Proper time (Δt) is measured from decay-vertex difference (Δz)

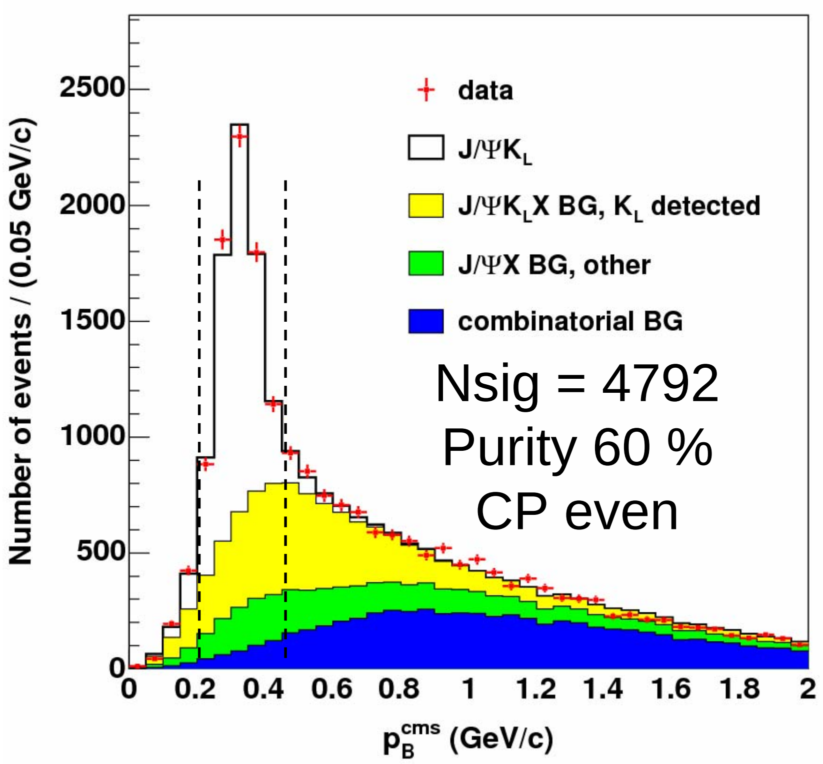
2005: $B^0 \rightarrow J/\psi \bar{K}^0$ w/386 M $B\bar{B}$ pairs

$B^0 \rightarrow J/\psi K_S^0$



$$M_{bc} = \sqrt{E_{beam}^{*2} - P_{J/\psi Ks}^{*2}}$$

$B^0 \rightarrow J/\psi K_L^0$

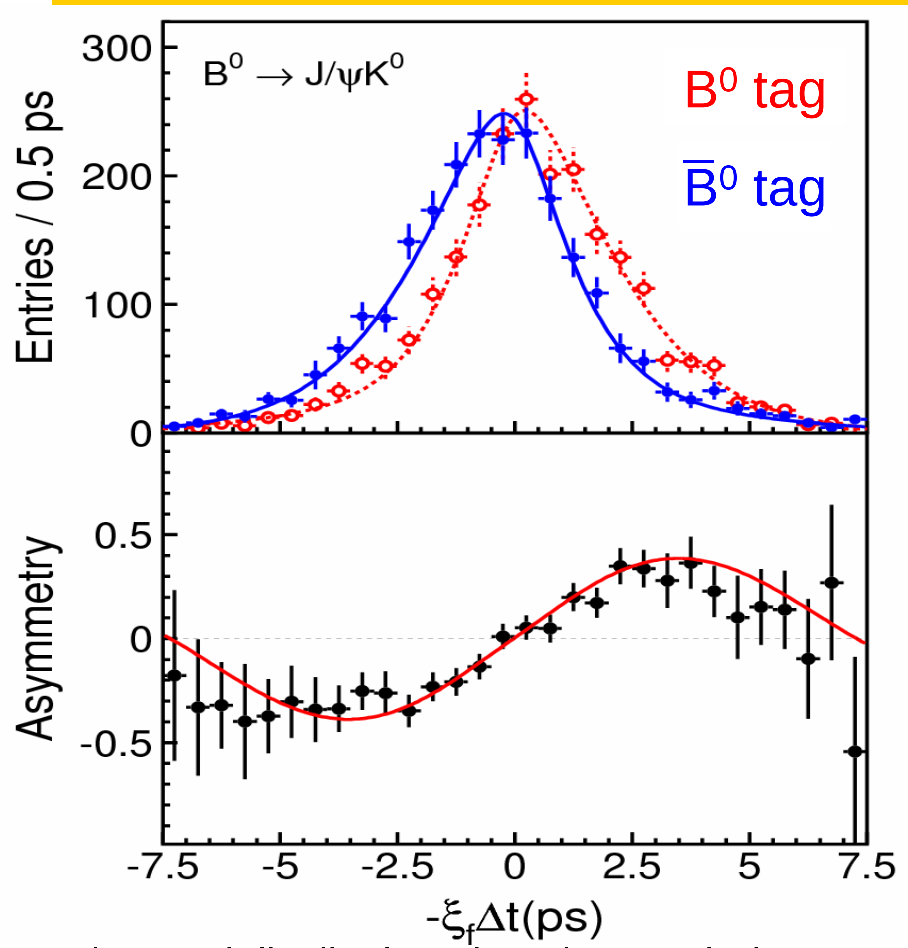


p_B^* (momentum in CM)

2005: $B^0 \to J/\psi K^0$

No DCPV

$\sin 2\phi_1$ = 0.652 ±0.039 (stat) ±0.020 (syst)
A = 0.010 ±0.026 (stat) ±0.036 (syst)



BG subtracted distributions (*good tag region*)

$\sin 2\phi_1$ still dominated by systematic err.

In previous (2003) meas. other "dirtier" modes were included (e.g. η_cKs). Now we use the cleanest mode ($J/\psi K^0$) only

Evidence and Observation of Direct CP Violation (DCPV) in B Decays

DCPV in $B \to \pi^+ \pi^-$ and $B \to K^- \pi^+$,

hep-ex/0502035 (PRL 95, 101801(2005); hep-ex/0507045

Asymmetries in the Dalitz plot of $B^\pm \to K^\pm \pi^+ \pi^-$

hep-ex/0512066, submitted to PRL

Glossary:

"Direct CP Violation" (DCPV): ***CPV in ΔS=1 or ΔB=1 transitions.***

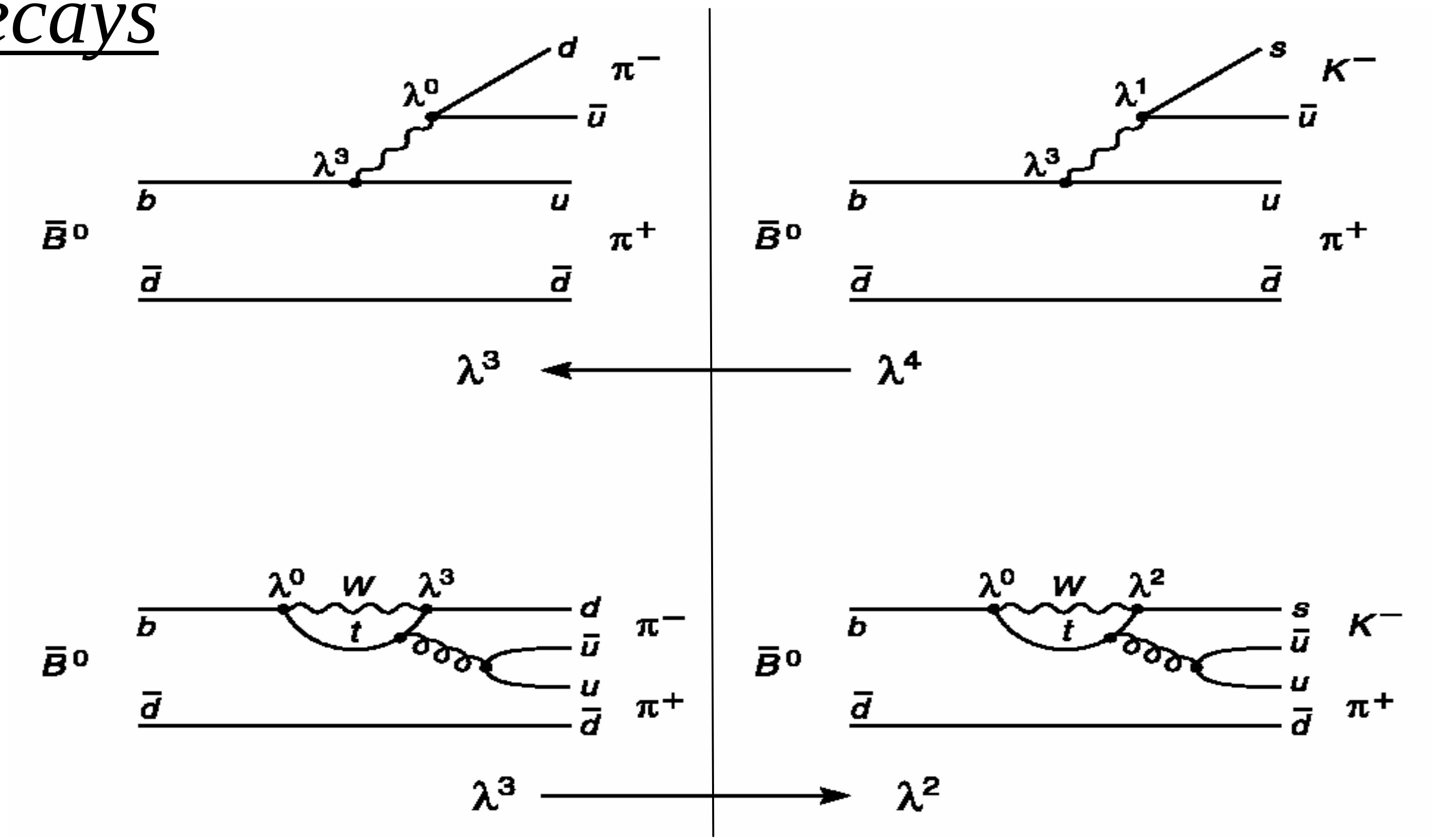
"Indirect" or "Mixing Induced" CPV: CPV in ΔB=2 transitions.

Why is direct *CP* violation (DCPV) important ?

- Already observed in K decays (ε'/ε). Important to see it in B decays ?
  - **Yes ! There are well-motivated "B-superweak" models**.
  - e.g. Superstring-inspired "B-superweak" model that also allows SUSY EW baryogenesis [M. Brhlik et al., PRL 84, 3041 (2000)].

- Many measurements will eventually provide an interesting pattern: B factories → CP factories !
  - The pattern should be explained !

Hierarchy of diagrams for B→K π, π π decays



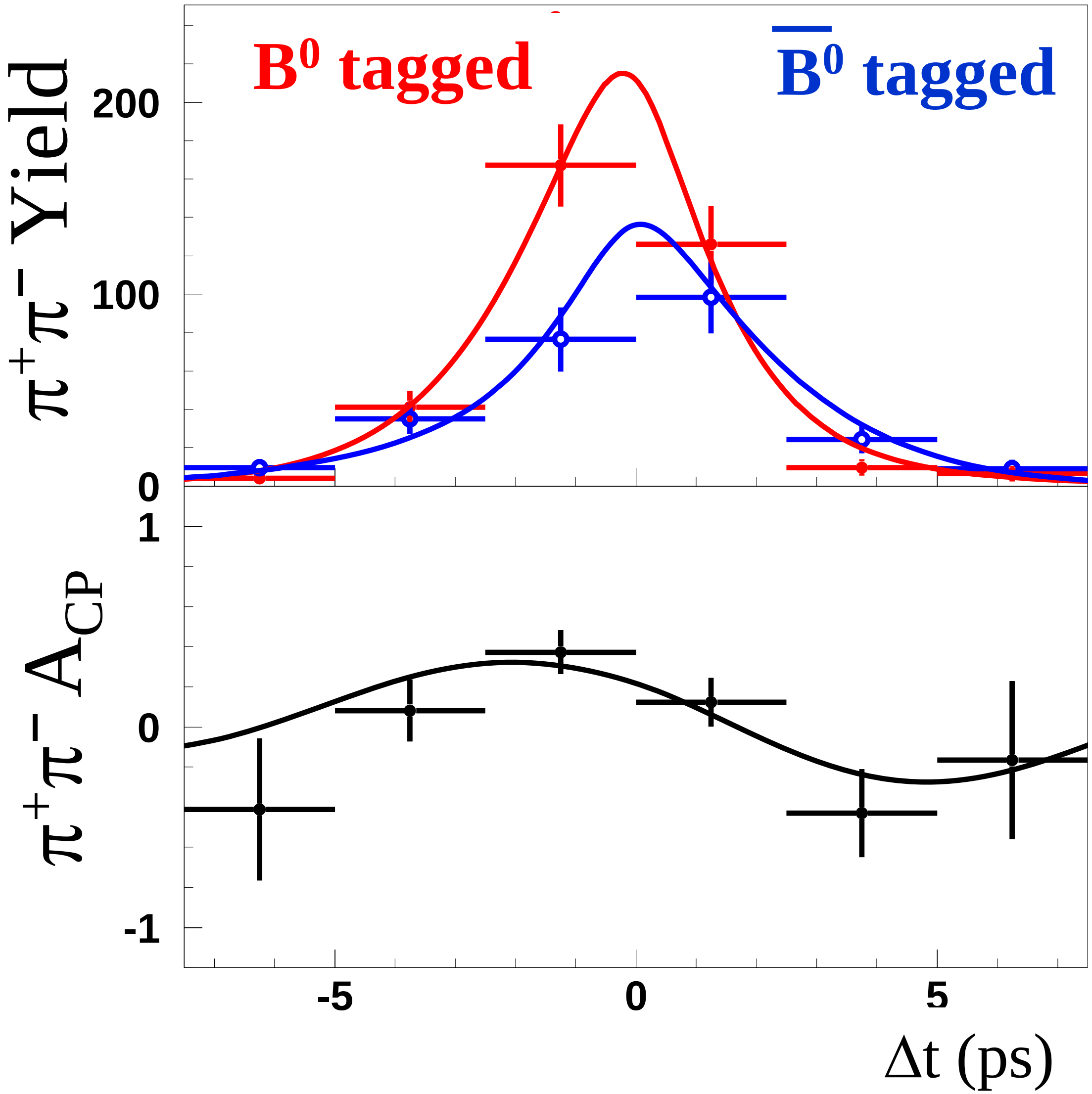
Possibility of tree-penguin interference.

N.B. in B→ππ the two diagrams are the same order in λ

static phase diff. from FSI

$$A_{\pi\pi} = +0.56 \pm 0.12 \pm 0.06$$

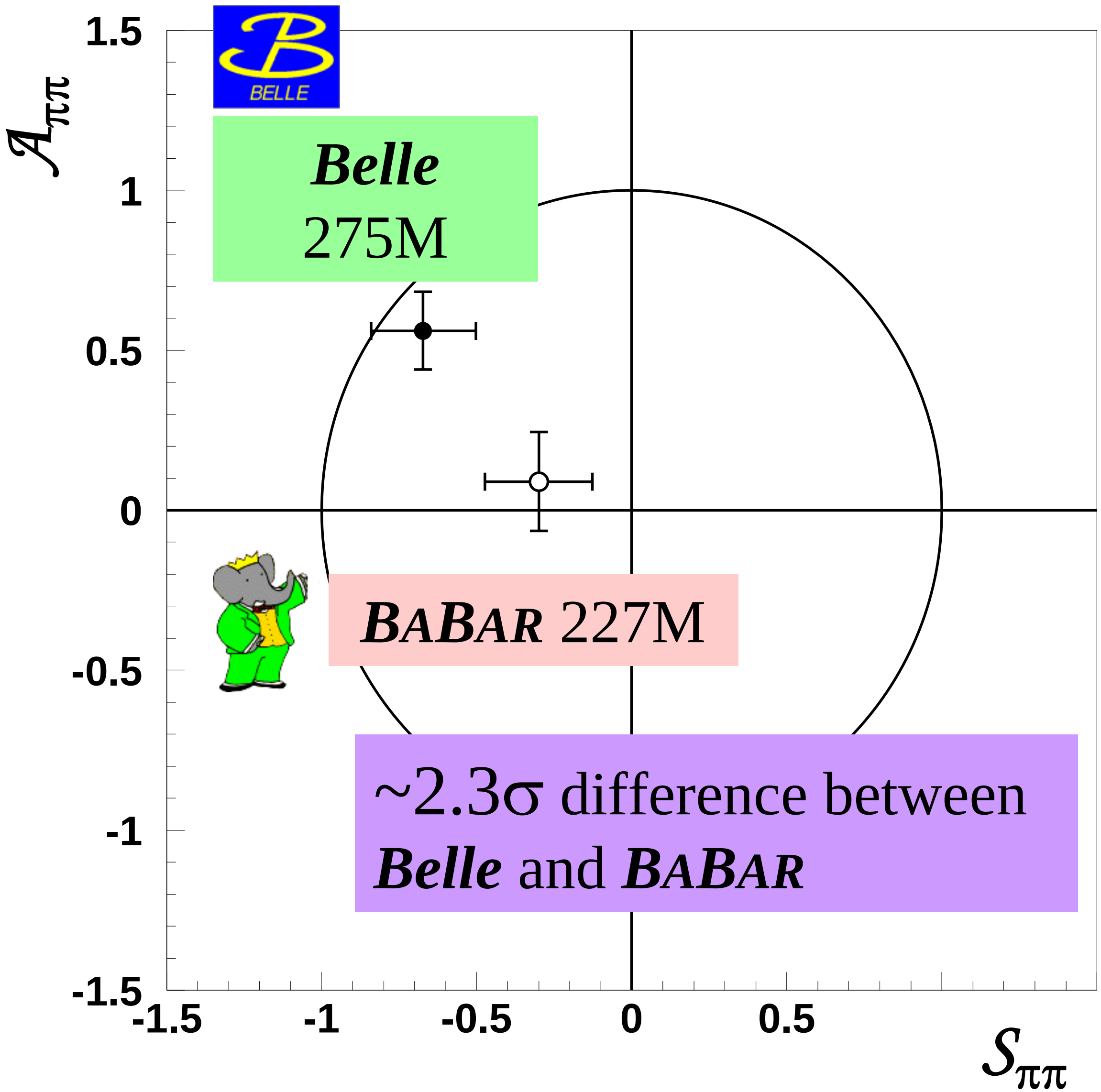
$$S_{\pi\pi} = -0.67 \pm 0.16 \pm 0.06$$



Belle
275M

Compelling evidence for direct CP violation in B→π+ π- with 4.0σ significance

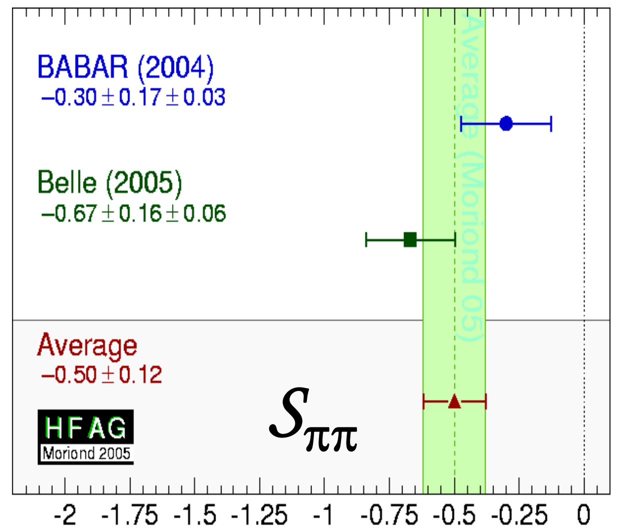
Jan 2006: Current Status of $B \rightarrow \pi^+ \pi^-$

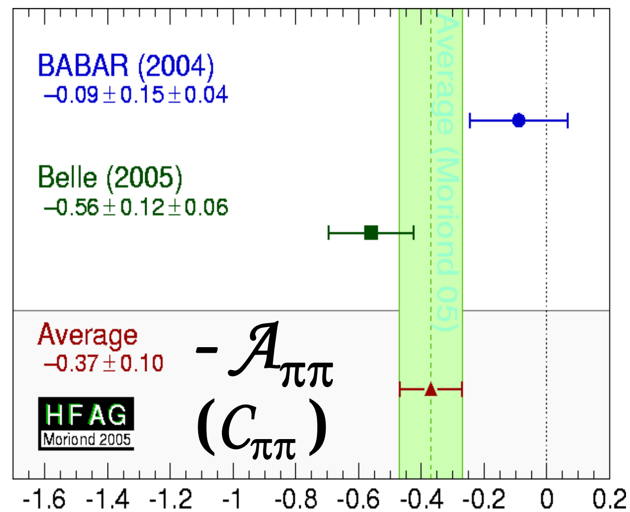


Belle 275M

BABAR 227M

~2.3σ difference between ***Belle*** and ***BABAR***

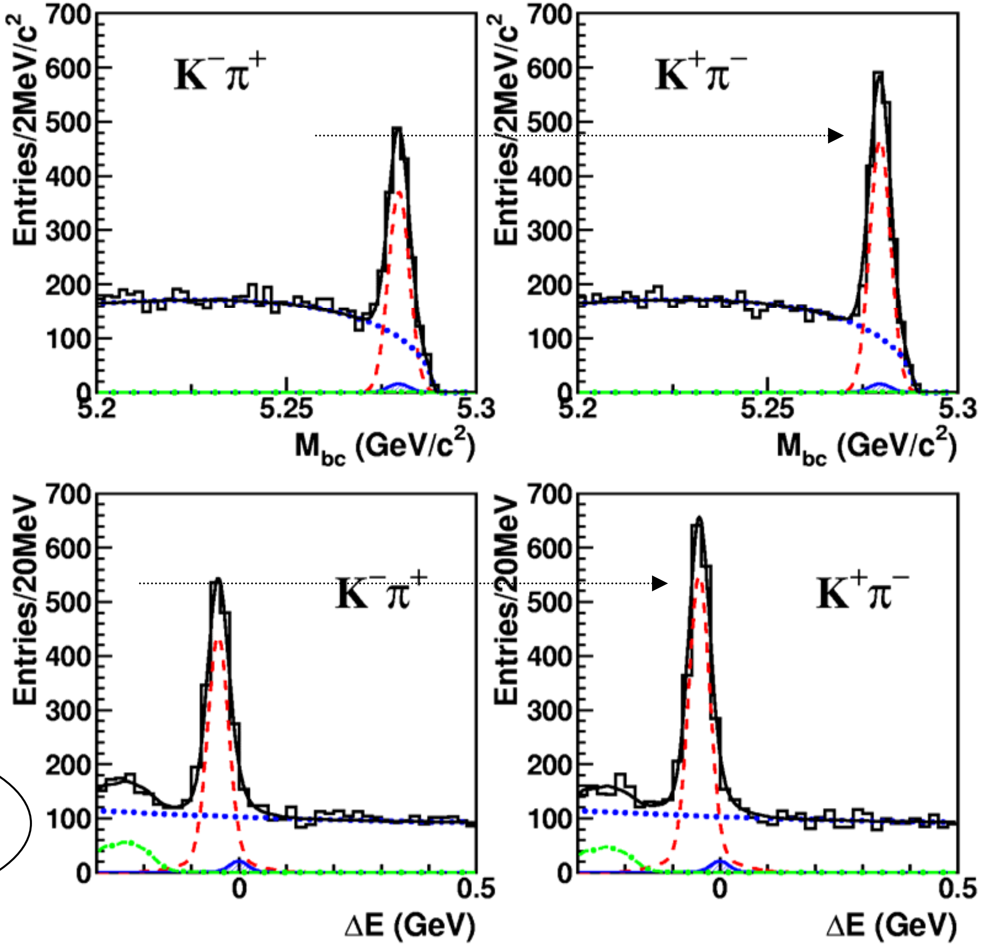




2005: "Observation" of Direct CP violation in $B \to K^- \pi^+$

Belle Update with 386×10^6 B Bbar pairs

(hep-ex/0507045)



Significance
$5.0\,\sigma$

Cf. 4.2σ(BaBar), 3.9σ(Belle) in 2004

One more nail in the Superweak coffin.

$$\mathcal{A}_{CP}(K^+\pi^-) \equiv \frac{N(\bar{B} \to K^-\pi^+) - N(B \to K^+\pi^-)}{N(\bar{B} \to K^-\pi^+) + N(B \to K^+\pi^-)} = 0.113 \pm 0.022 \pm 0.008.$$

Interpretation: Direct CP violation+SU(3)

The results support the expectation from SU(3) symmetry that

$$A_{CP}(K^+\pi^-) \sim -\frac{1}{3} A_{CP}(\pi^+\pi^-)$$

N.G. Deshpande and X.-G. He, PRL 75, 1703 (1995)

M. Gronau and J.L. Rosner, PLB 595, 339 (2004)

$$A_{CP}(K^+\pi^-) = -0.115 \pm 0.018$$

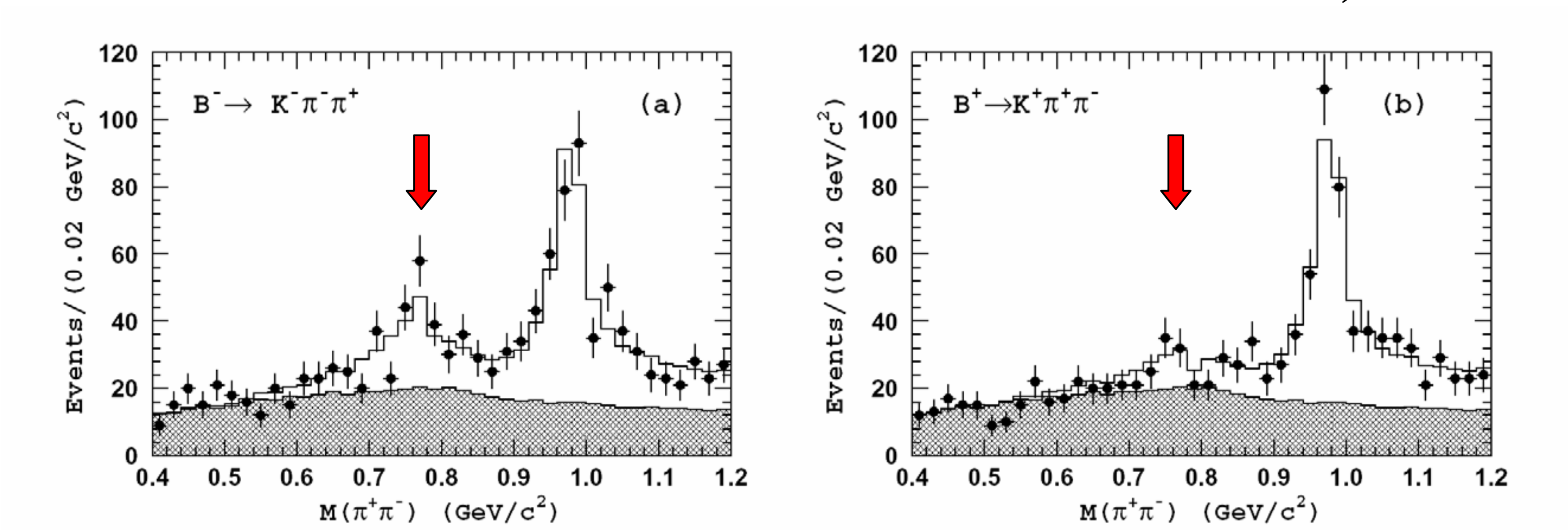
HFAG summer 2005

$$-\frac{1}{3} A_{CP}(\pi^+\pi^-) = -0.19 \pm 0.04$$

Belle measurement

First evidence for direct CP violation in charged B decays

$$A_{CP}(B^{\pm} \to \rho^0 K^{\pm}) = 0.28 \pm 0.10^{+0.07}_{-0.09} \quad (3.9\sigma)$$



static phase diff. from resonances

Conclusions on Direct CP Violation

In some B meson decays, the mixing induced CPV ($\Delta B=2$) effects are O(1).

For three B decay modes, direct CPV effects are also large, O(0.1).

Compare to the kaon system, $\varepsilon \sim 2 \times 10^{-3}$ and $\varepsilon' \sim 5 \times 10^{-6}$

Evidence of Direct CP Violation found in a charged B meson decay. Counterpart not yet established in the kaon system.

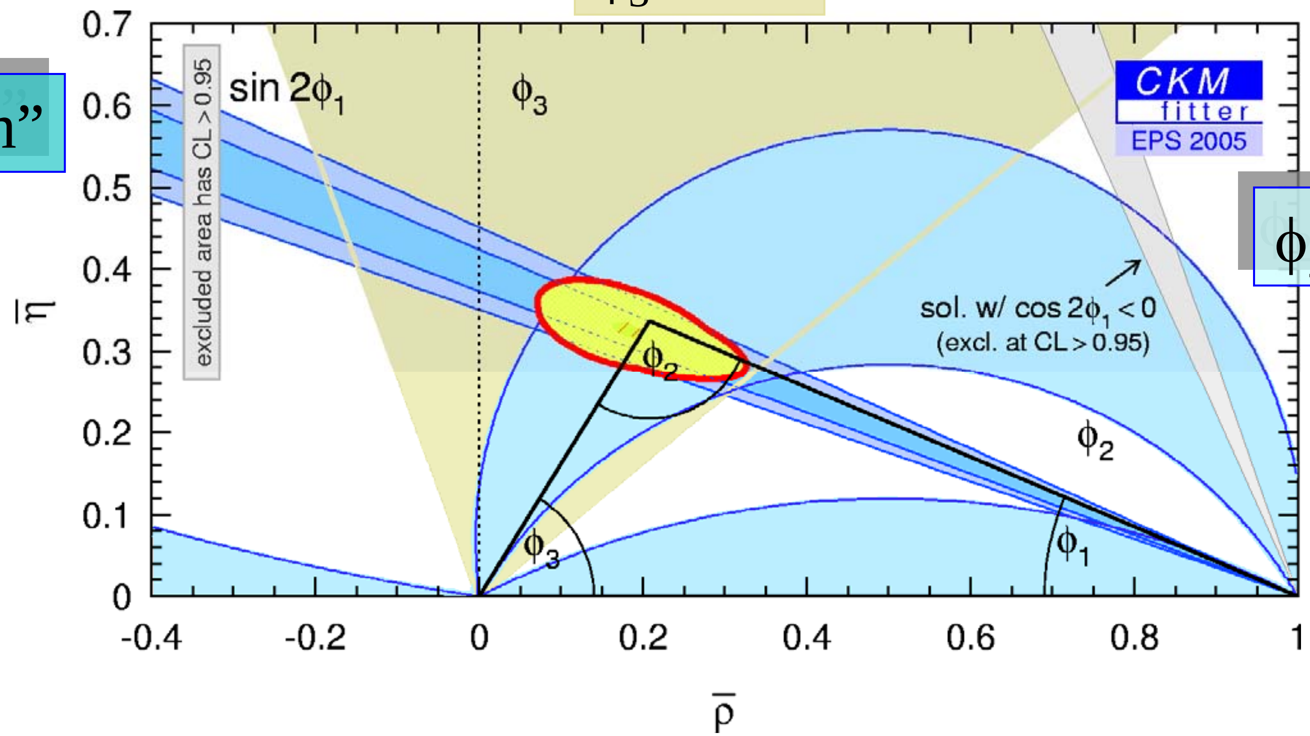
Fundamental SM Parameters

Principles of angle measurements

ϕ_3 "fan"

ϕ_1 "beam"

ϕ_2 "banana"



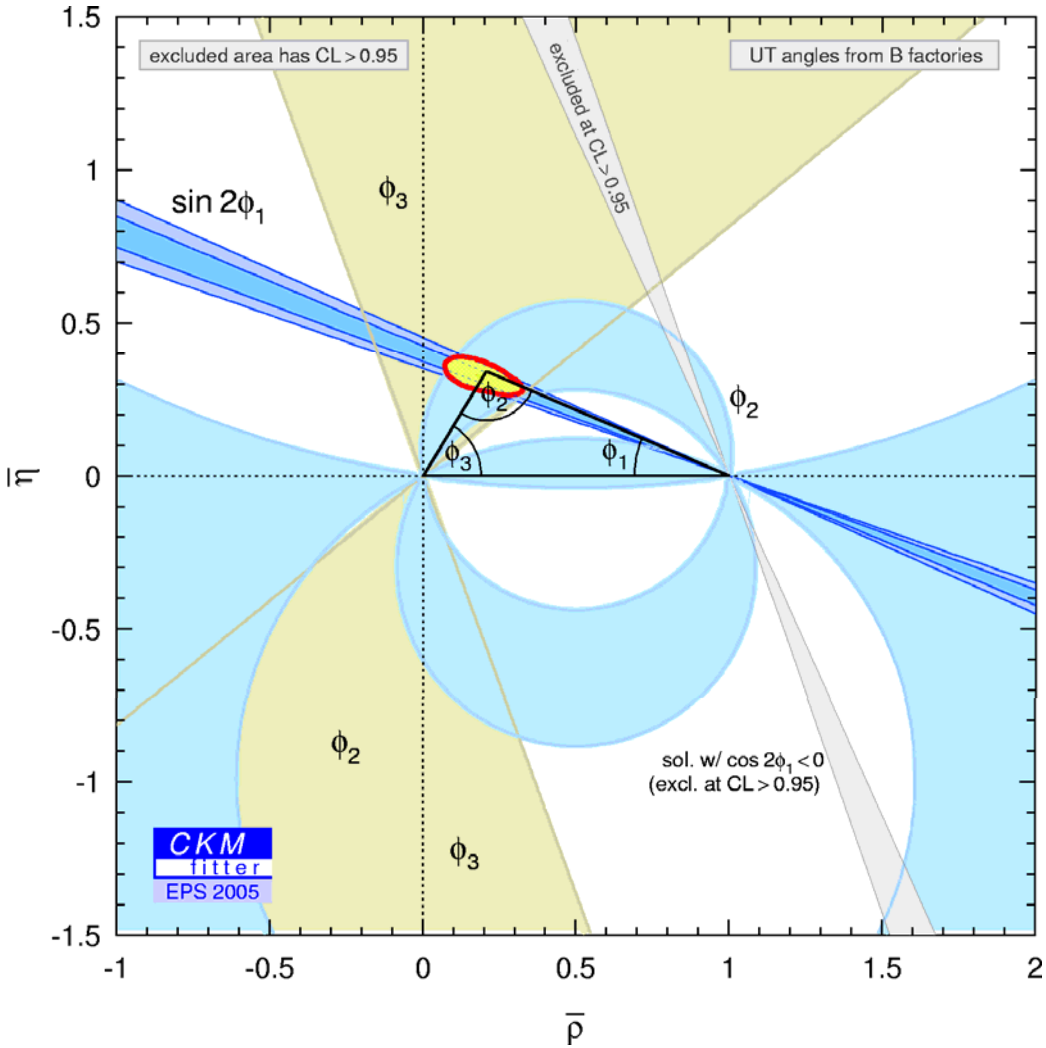
- ϕ_1 and ϕ_2 from time-dependent CP asymmetries + flavor symmetry (isospin analysis)

$B^0 \rightarrow \pi\pi, \rho\rho, \rho\pi$

- ϕ_3 from direct CP asymmetries + Dalitz analysis

$B \rightarrow D^{(*)}K^{(*)}$

Unitarity Triangle with Angle Measurements



World average values

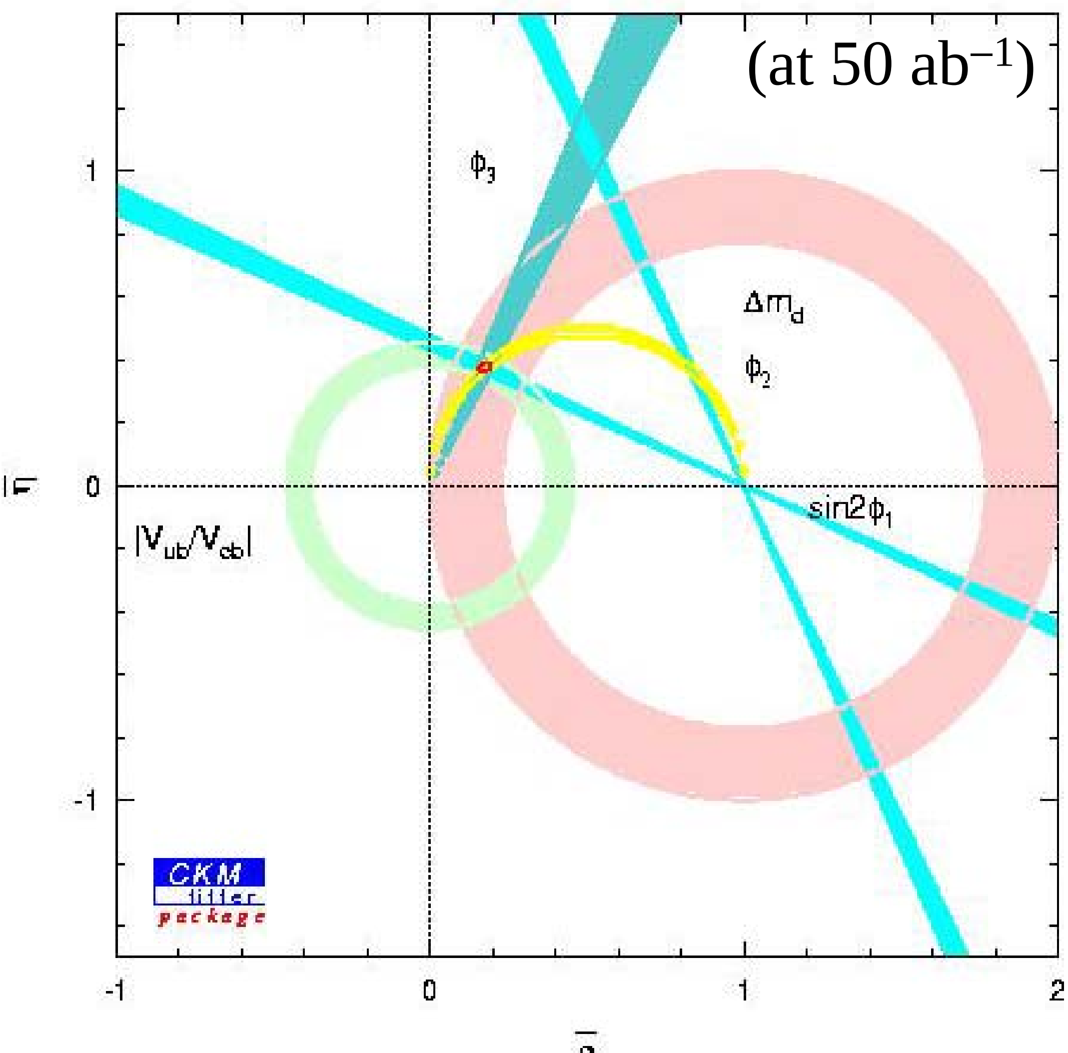
$$\phi_1 = (22 \pm 1)^o$$
$$\phi_2 = (99\,^{+13}_{-8})^o$$
$$\phi_3 = (63\,^{+15}_{-12})^o$$

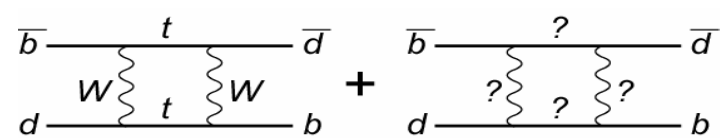
$$\phi_1 + \phi_2 + \phi_3$$
$$= (184^{+20}_{-14})^o$$

(naïve sum by the speaker)

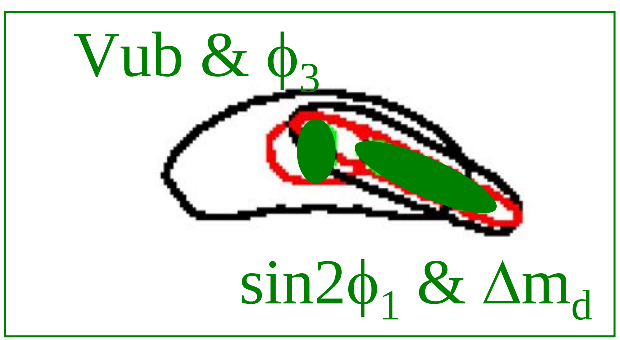
CKM Unitarity Triangle at SuperKEKB

CKM is only one part of SuperB physics programs, but
still provides model indep. approach to constrain New Physics.





$$M_{12} = M_{12}^{SM} + M_{12}^{NP}$$



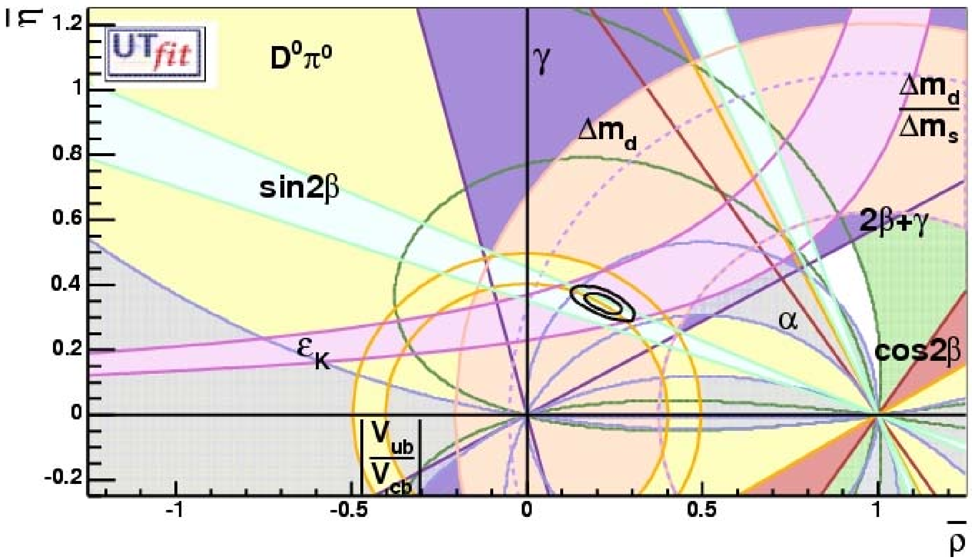
$\Delta \sin 2\phi_1 = 0.014$

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

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

$\Delta \phi_3 = 1.2^\circ$

CKM Unitarity triangle (Summer 2005)



$\bar{\rho}$ = 0.216 ± 0.036

$\bar{\eta}$ = 0.342 ± 0.022

- Now ϕ_2 (α), ϕ_3(γ), $|V_{ub}/V_{cb}|$ Δm_d dominated by Belle and BaBar
- New methods play key roles !
  - Pioneering work by Belle on ϕ3 with B → DK Dalitz
  - Pioneering work by BaBar on ϕ2 with B → $\rho\rho$
- Kobayashi-Maskawa (KM) model is now a tested theory !
- Constraints mainly from 3rd ↔ 1st and 2nd ↔ 1st transitions
  - No severe constraints yet from 3rd ↔ 2nd transitions

Beyond the Standard Model

b → s Penguin Diagrams and New Physics

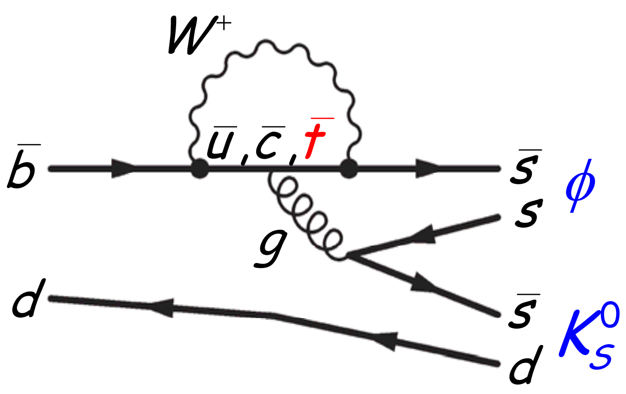
very sensitive probes for new physics

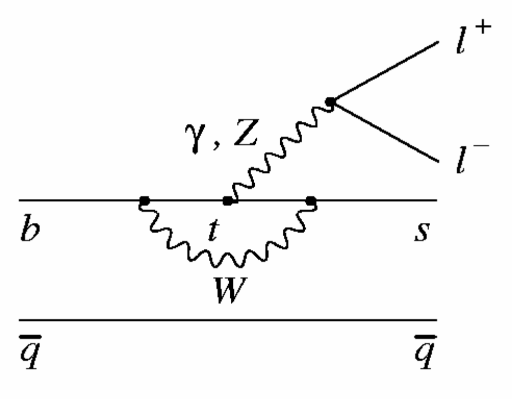
rare (or subdominant at most) decays,
lots of statistics required; just started !

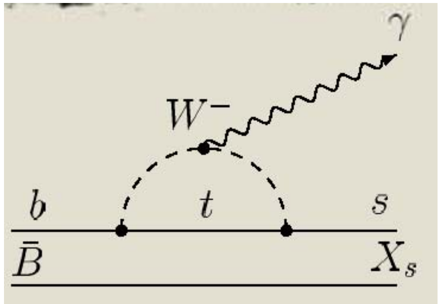
color probe
b → s g

electroweak probe
b →sl+l-

electromagnetic probe
b → s γ

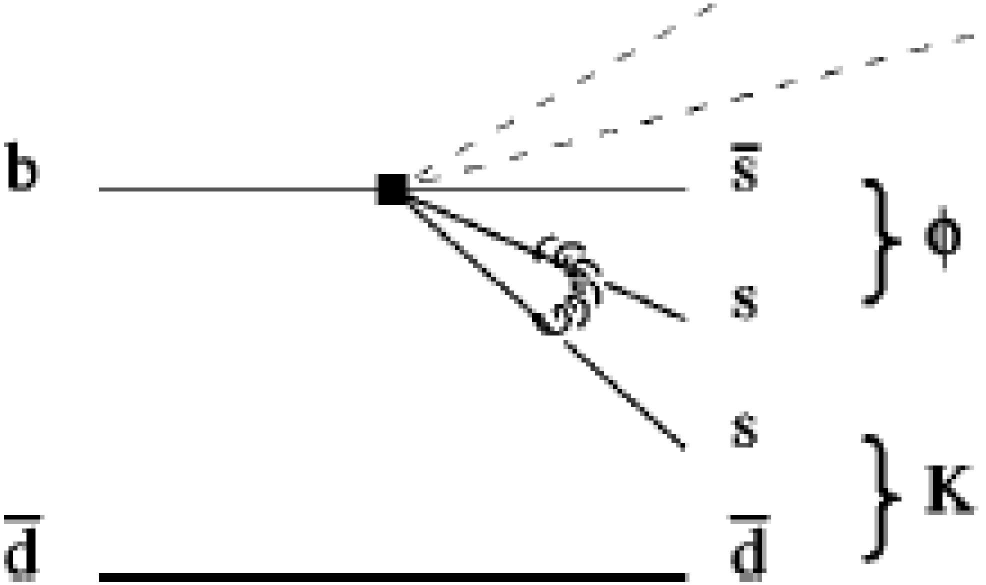


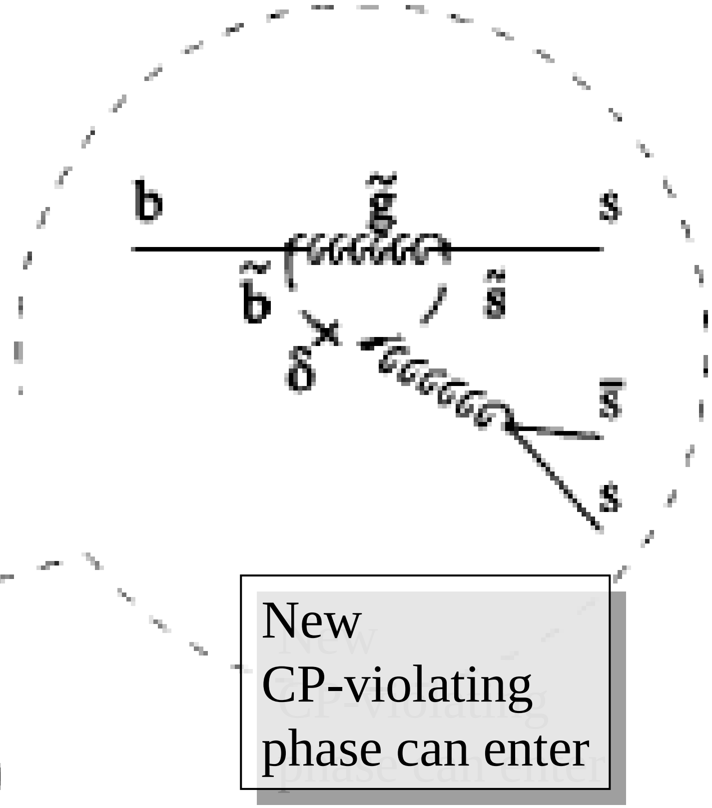




examples of SM diagrams

SUSY as an example





Why is b → s so important ?

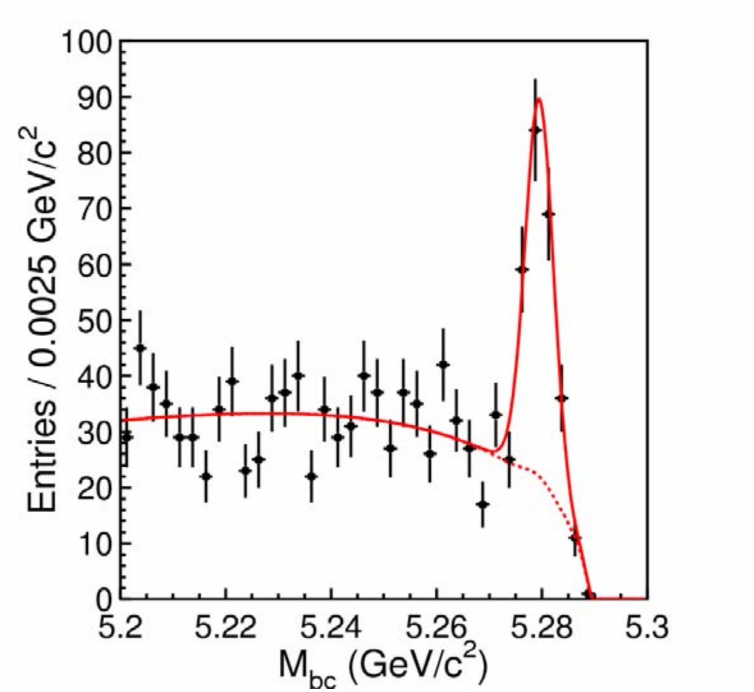
- New CP violation in b → s penguin diagram
  - Impact to Electroweak Baryogenesis

- SUSY GUT correlation between b → s and τ → μ
  - Large neutrino mixing suggests possible large effects between 3^{rd} ←→ 2^{nd} generations
    - "Atmospheric Neutrinos Can Make Beauty Strange"
    - Lepton flavor violation τ → μγ, μη, ... also very important. KEK B factory is the leading experiment !

Belle 2005 (hep-ex/0507037)

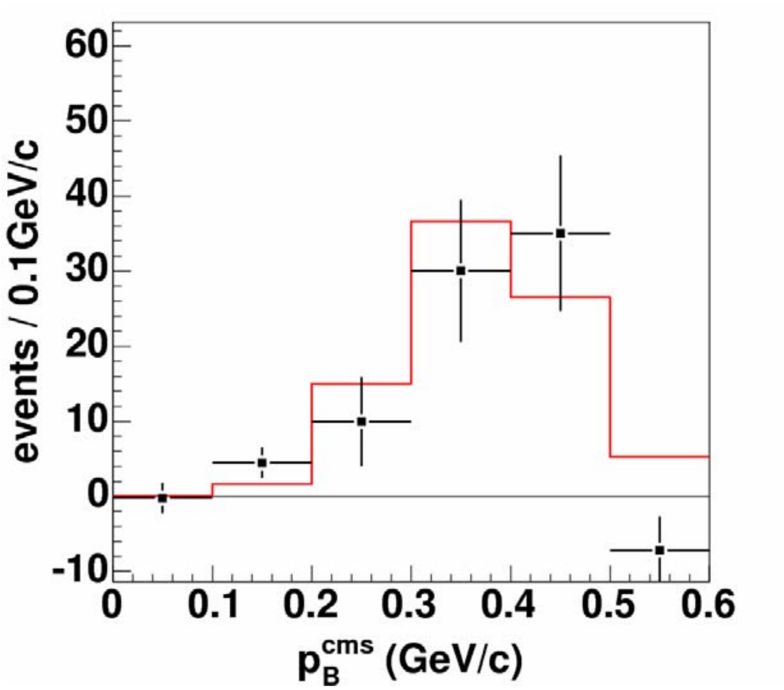
ϕK_s

180 ± 16 events



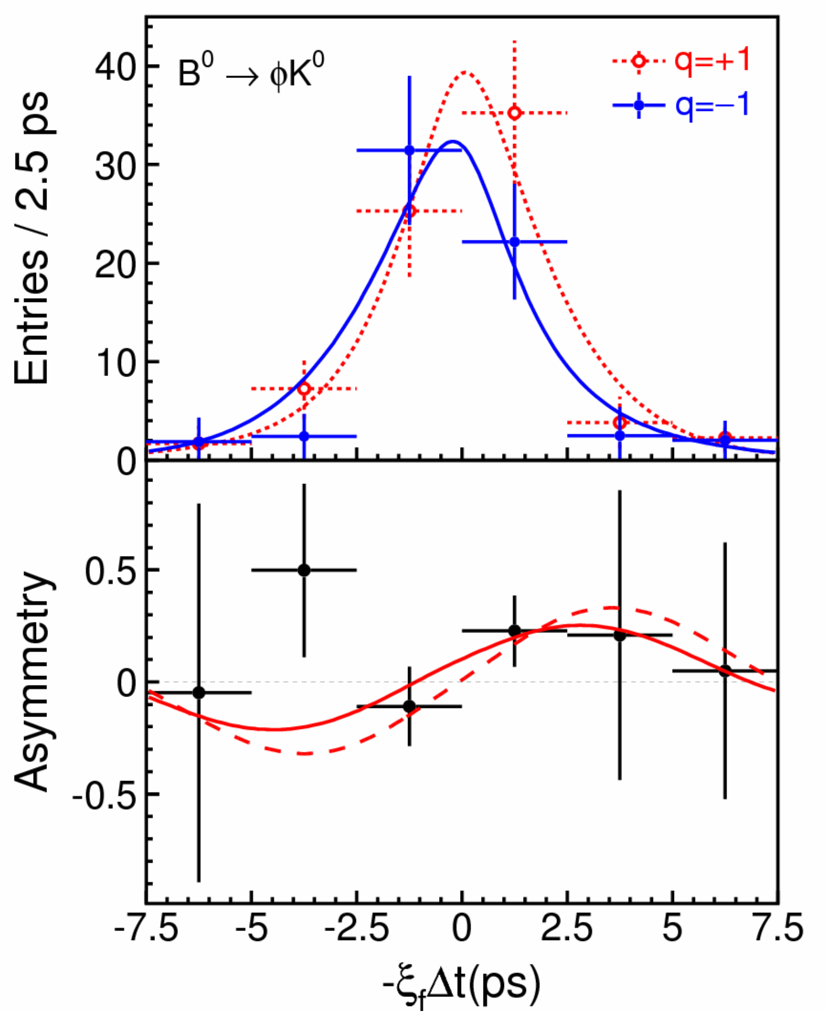
ϕK_L

78 ± 13 events



(background-subtracted)

ϕK^0: Background-subtracted asymmetry



2005 Summer

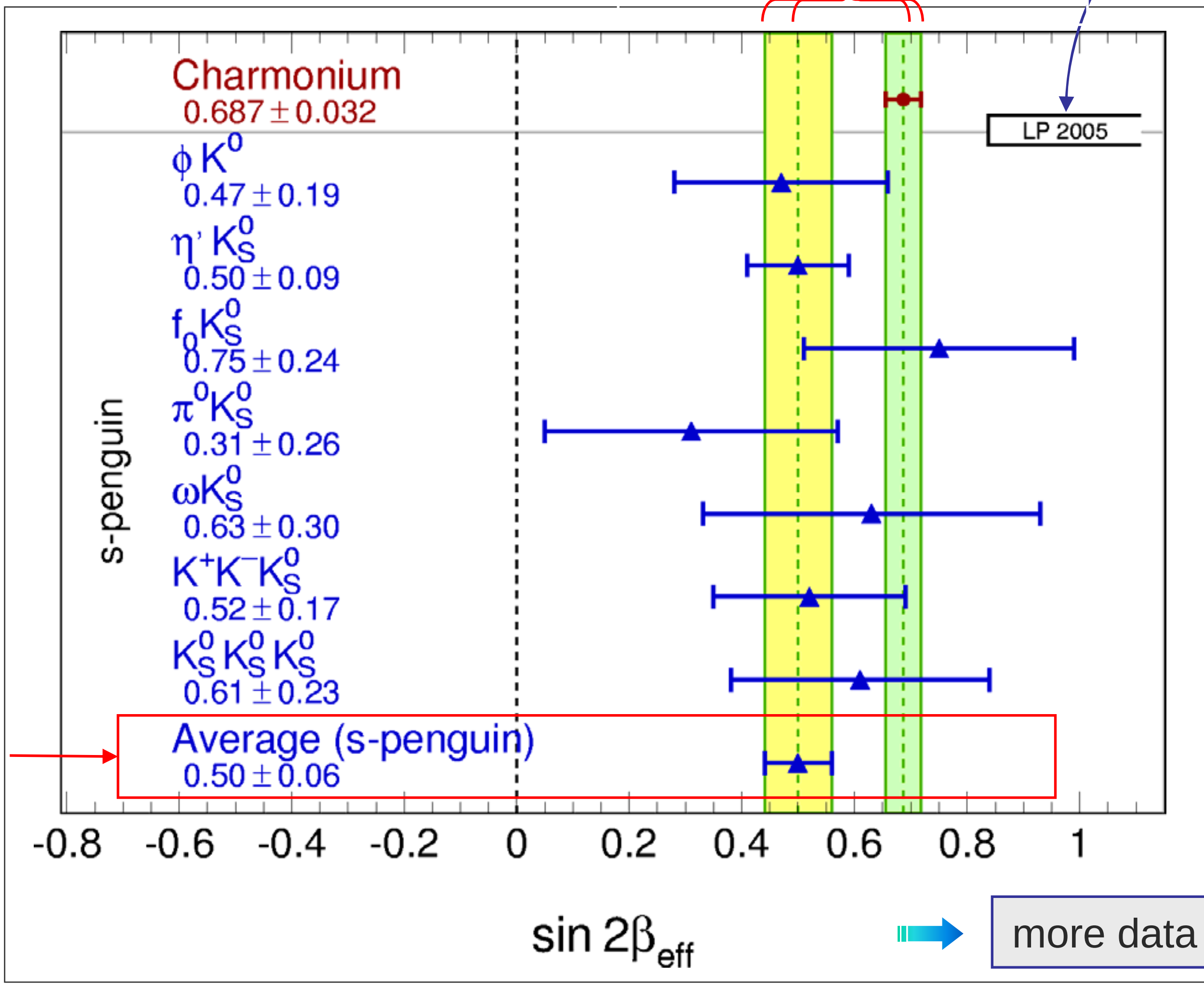
$$\mathcal{S} = +0.44 \pm 0.27 \pm 0.05$$
$$\mathcal{A} = +0.14 \pm 0.17 \pm 0.07$$

CP Violation in Penguin Modes

HFAG

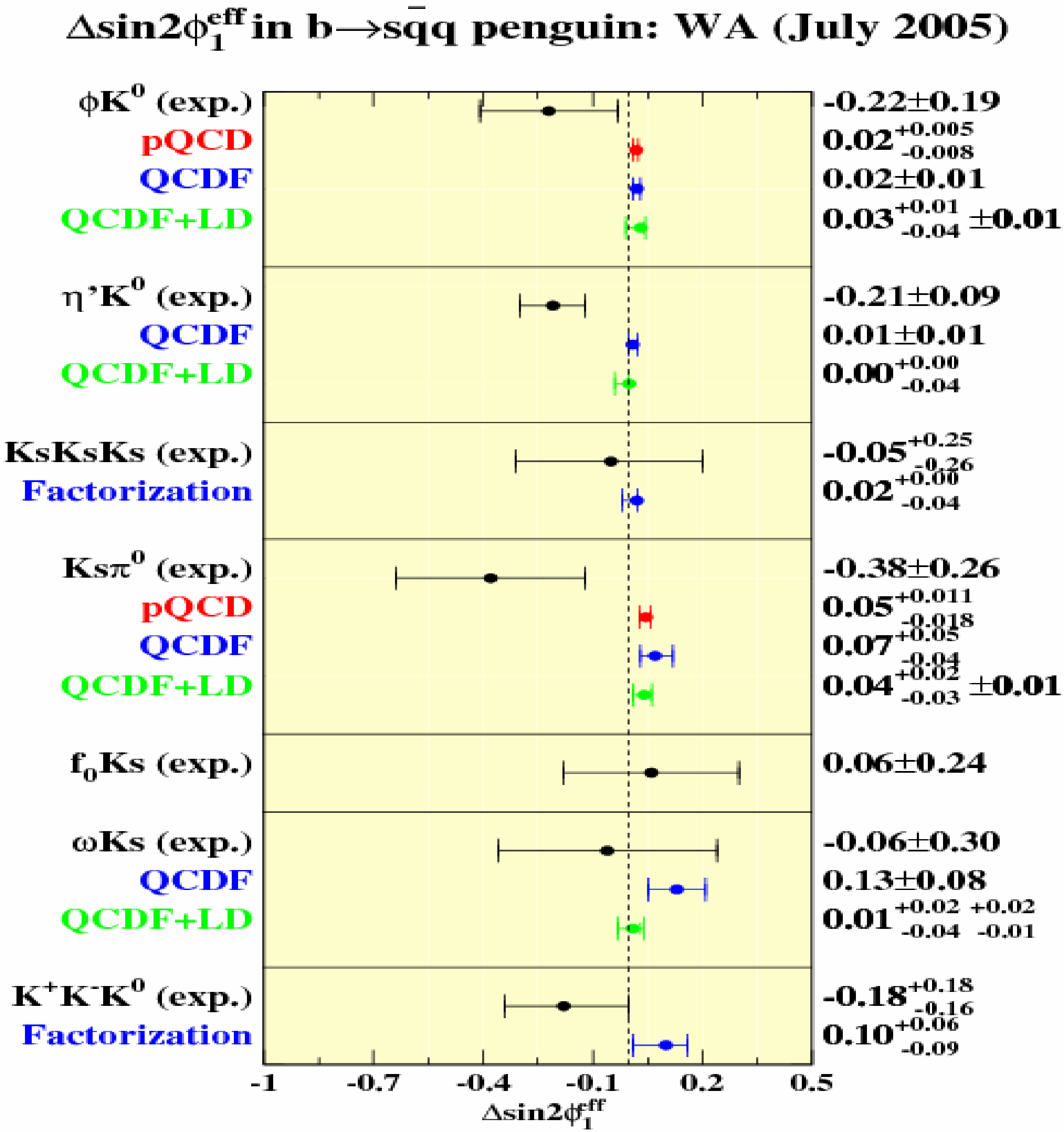
3.7σ discrepancy

Summer ‘05



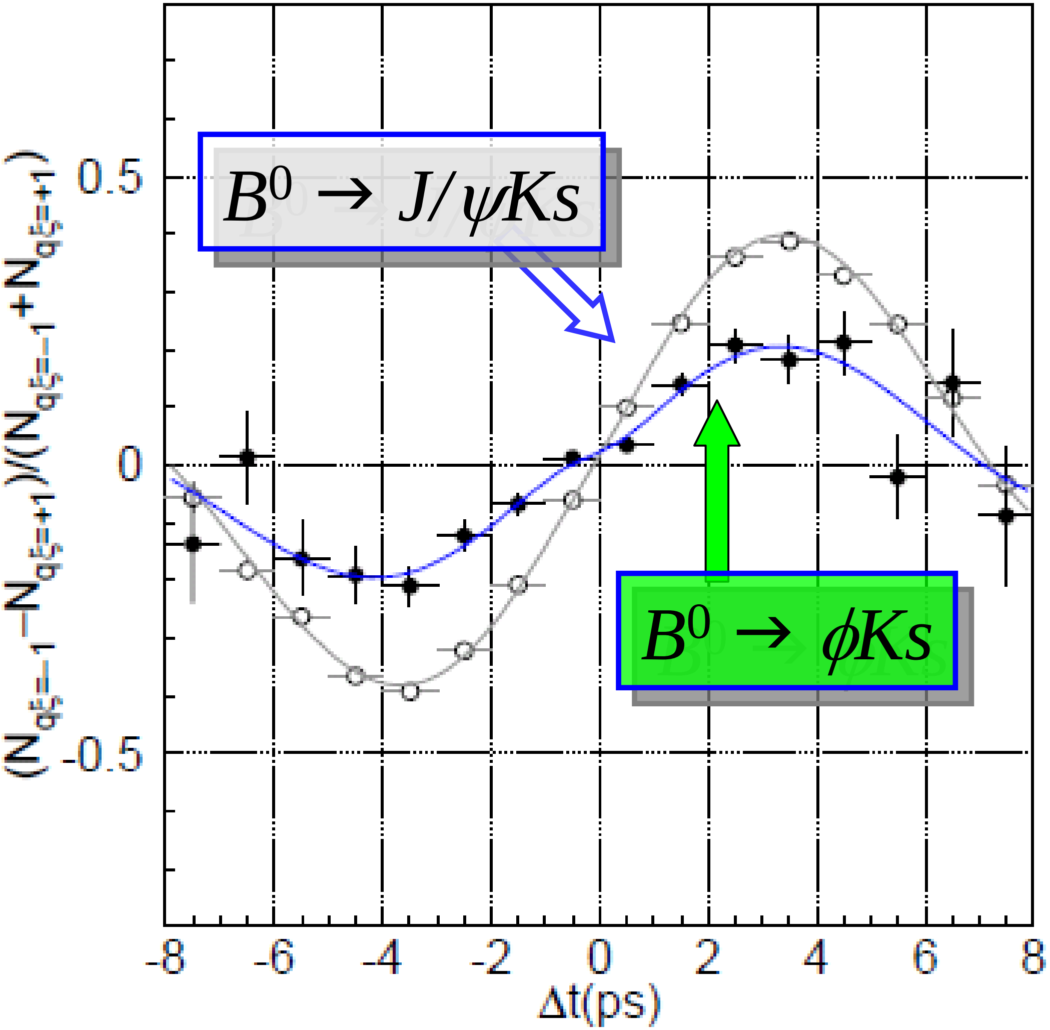
naïve average:
neglecting theory
uncertainties

more data needed !



Δsin2φ1eff in b→sq̄q penguin: WA (July 2005)
φK0 (exp.)
pQCD
QCDF
QCDF+LD
η'K0 (exp.)
QCDF
QCDF+LD
KsKsKs (exp.)
Factorization
Ksπ0 (exp.)
pQCD
QCDF
QCDF+LD
f0Ks (exp.)
ωKs (exp.)
QCDF
QCDF+LD
K+K-K0 (exp.)
Factorization
-0.22±0.19
0.02 +0.005 -0.008
0.02±0.01
0.03 +0.01 -0.04 ±0.01
-0.21±0.09
0.01±0.01
0.00 +0.00 -0.04
-0.05 +0.25 -0.26
0.02 +0.00 -0.04
-0.38±0.26
0.05 +0.011 -0.018
0.07 +0.05 -0.04
0.04 +0.02 -0.03 ±0.01
0.06±0.24
-0.06±0.30
0.13±0.08
0.01 +0.02 -0.04 +0.02 -0.01
-0.18 +0.18 -0.16
0.10 +0.06 -0.09
-1
-0.7
-0.4
-0.1
0.2
0.5
Δsin2φ1eff

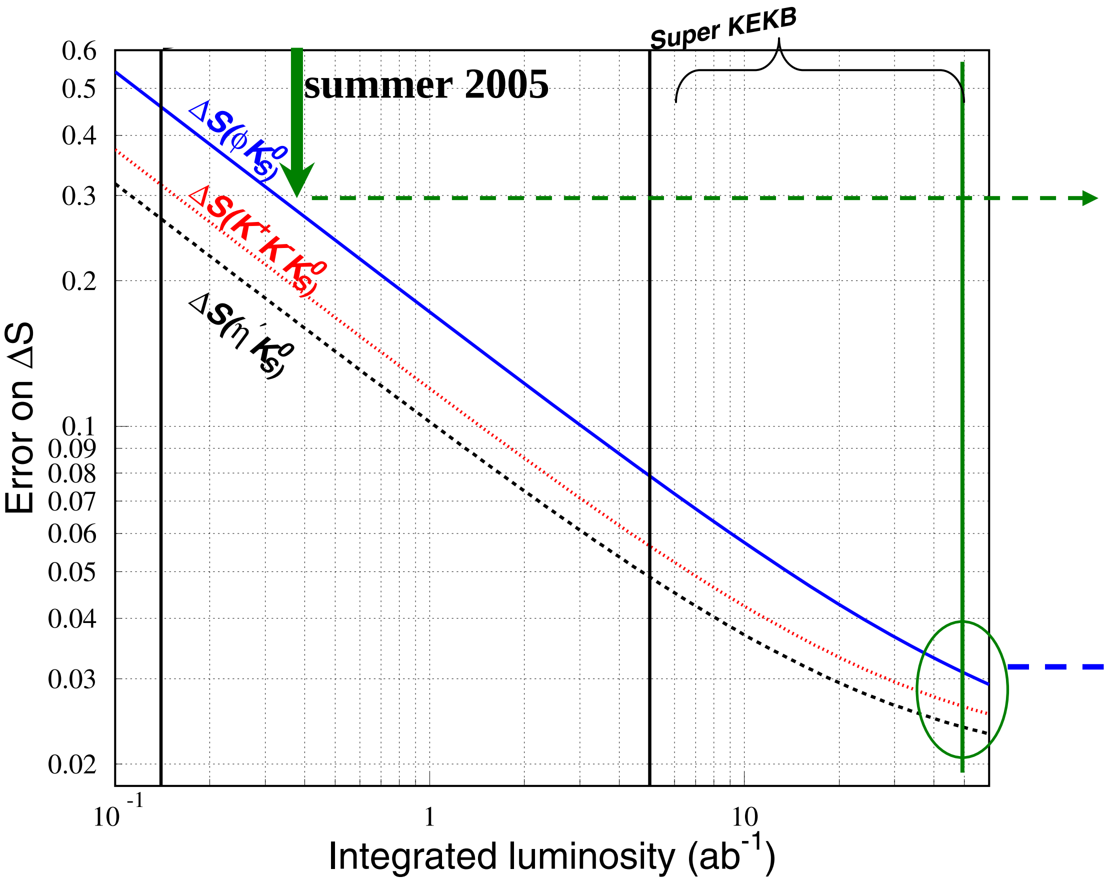
Time-dependent CPV (tCPV) at SuperKEKB (50ab^{-1})

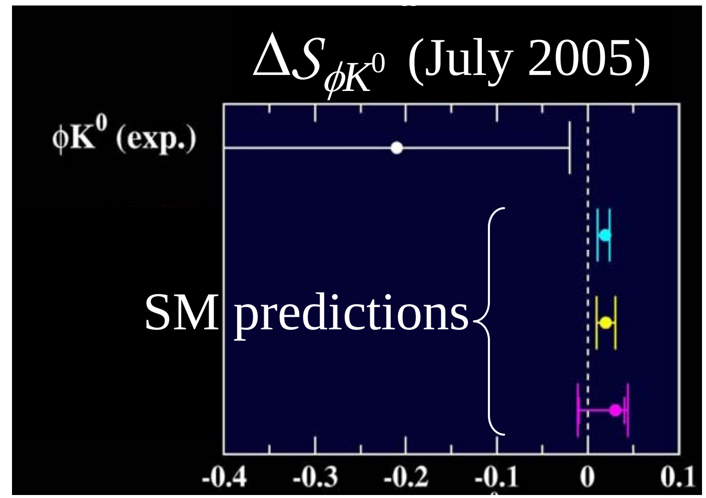


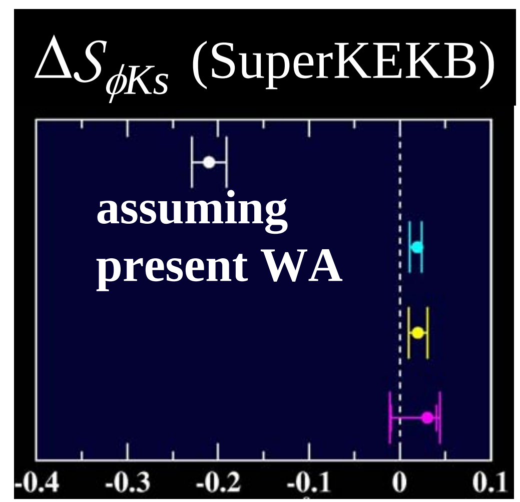
Input values from Summer 2005 world average

$\Delta S_{\phi Ks} \equiv S_{\phi Ks} - S_{J/\psi Ks} < 0$ can clearly be established

$B^0 \to \phi Ks$ at Super B ($50ab^{-1}$)



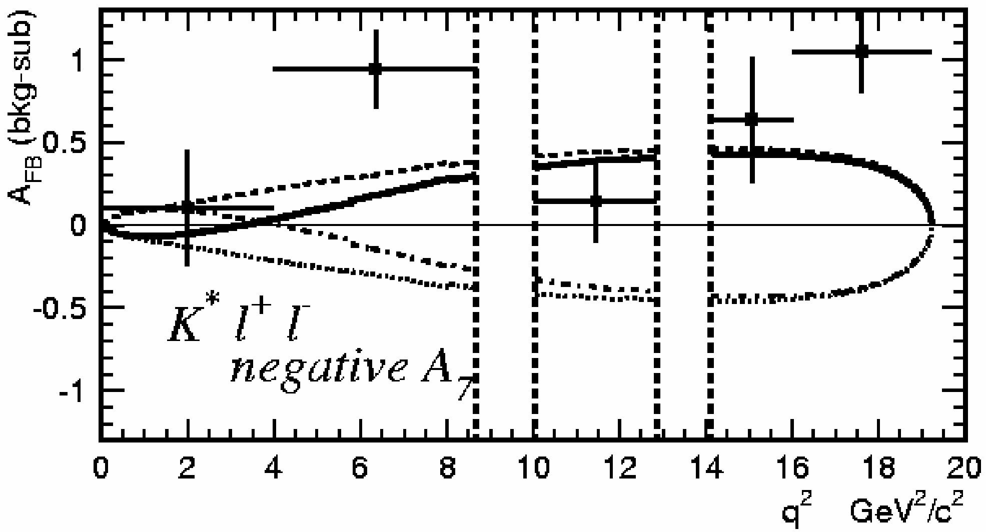




$\Delta S(\phi Ks)$ at $50ab^{-1}$
$= XX \pm 0.03(stat) \pm 0.01(syst) \pm 0.04(th)$

1^{st} Constraints on Wilson coefficients from $A_{FB}(B \rightarrow K^{*}\, l\, l)(q^2)$

Projections of the full fit to q^2, $\cos(\theta)$



hep-ex/0508009

Integrated FB asymmetries

control sample:

$$A_{FB}(B \rightarrow K^{+} l^{-} l^{+}) = 0.10 \pm 0.14 \pm 0.01$$

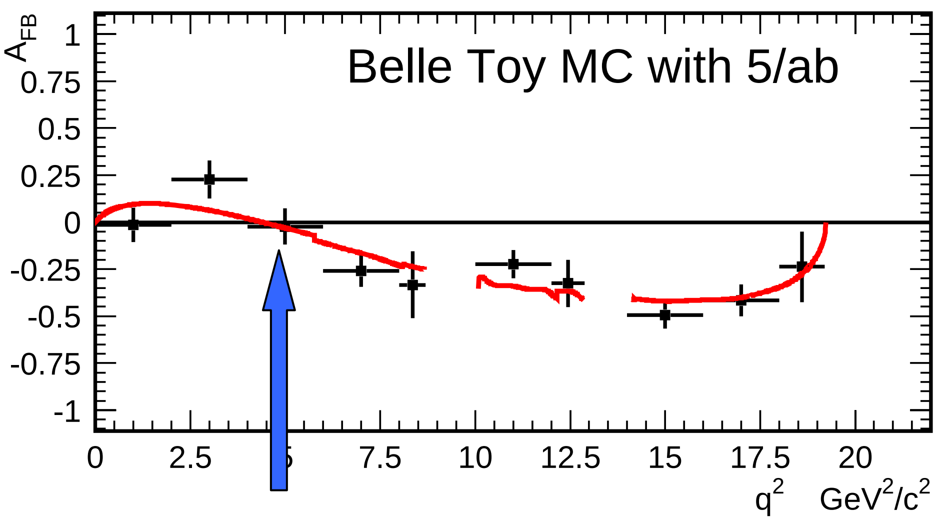
$$A_{FB}(B \rightarrow K^{*} l^{-} l^{+}) = 0.50 \pm 0.12 \pm 0.02; (3.4\sigma)$$

Observe integrated A_{FB} and as a result can rule out some radical New Physics Models with incorrect signs/magnitudes of C_9 and C_{10}

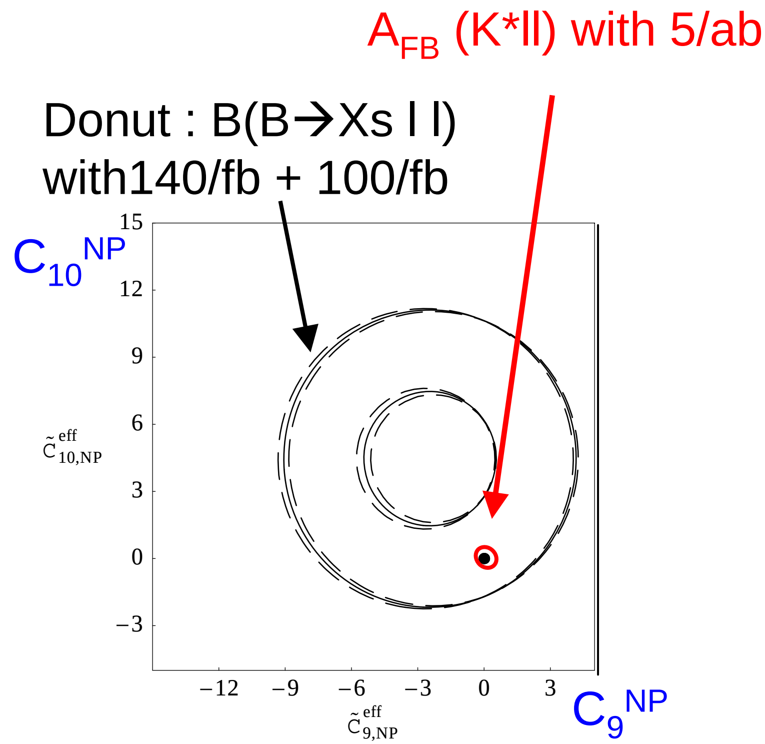
$A_{FB}(B \rightarrow K^* l^+ l^-)[q^2]$ at a Super B Factory

- Assume 1 year of running at $5\text{x}10^{35}$/nb/sec
- → 5/ab integrated luminosity, 10 billion B mesons

  $\Delta A_9/A_9 \sim 11\%$, $\Delta A_{10}/A_{10} \sim 13\%$
  - A_7 fixed to SM value



Determine location of the zero crossing precisely with 50 ab^{-1}



Near Future (till ~2008)

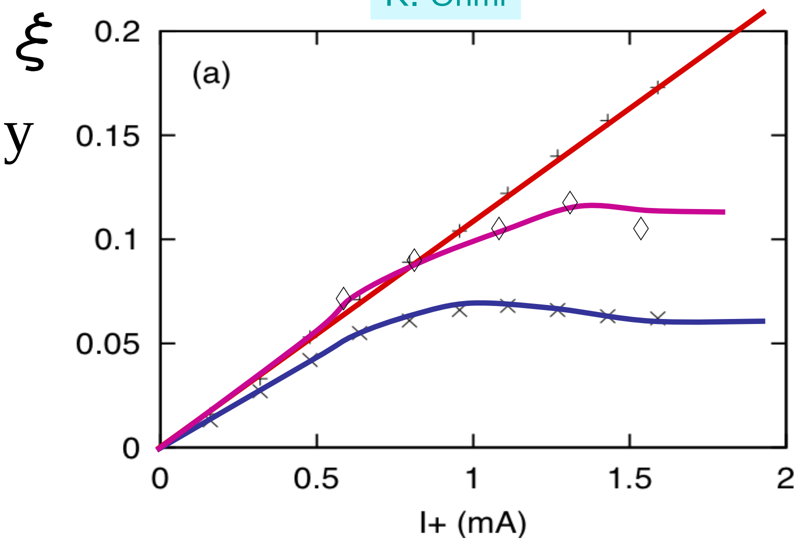
- Room for some surprise if new physics energy scale is close to the present limit.
  - $L = 3 \times 10^{34}$ with crab cavities
- In the LHC era (i.e. 2010's), however, obviously needed is a major upgrade for much higher statistics !

Super *B* factory needed !

Crab crossing: beginning of SuperB !

- Crab crossing may increase the beam-beam parameter up to 0.19 !

K. Ohmi



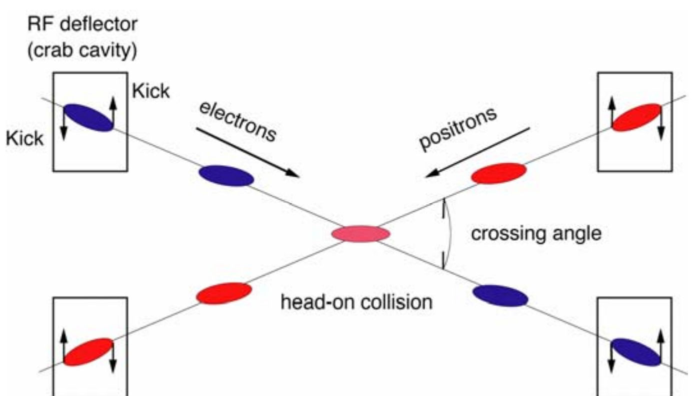
(Strong-weak simulation)

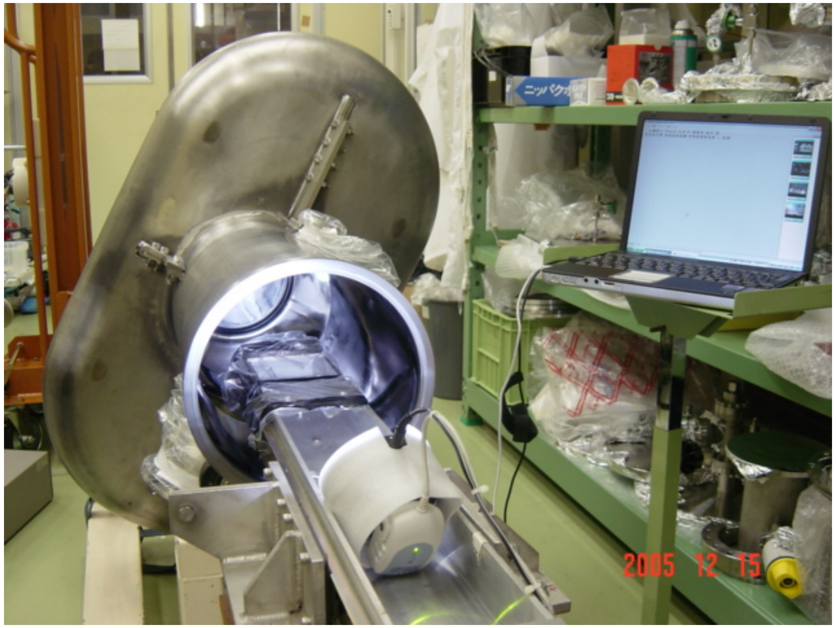
Head-on (crab)

(Strong-strong simulation)

crossing angle 22 mrad

- Superconducting crab cavities are now being tested, will be installed in KEKB around March 2006.

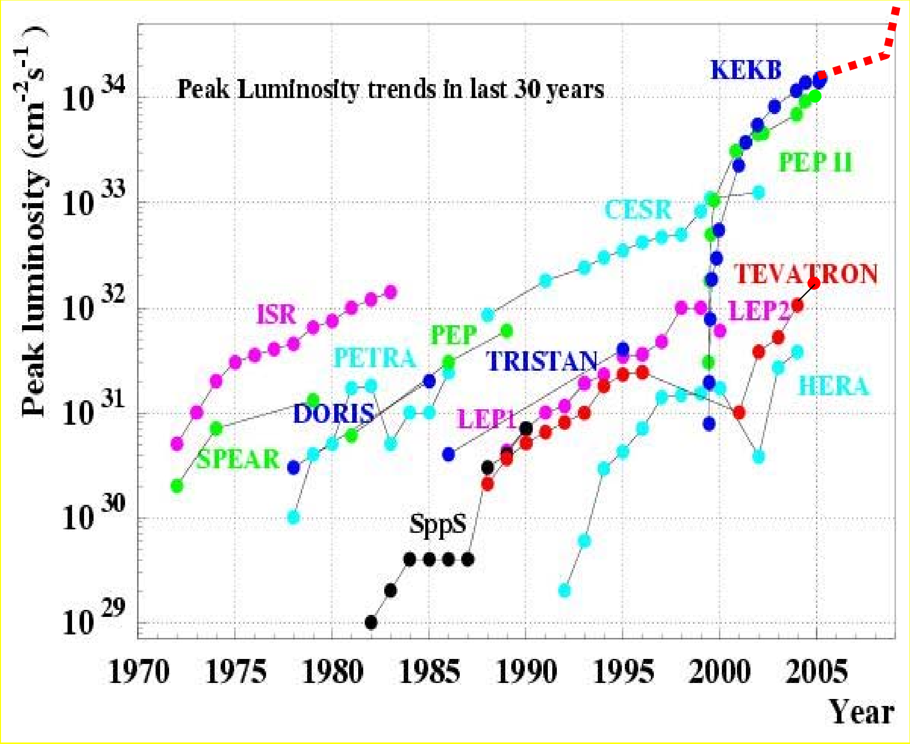




SuperKEKB
a new luminosity frontier

Peak Luminosity

Super B
(4×10³⁵cm⁻²s⁻¹)

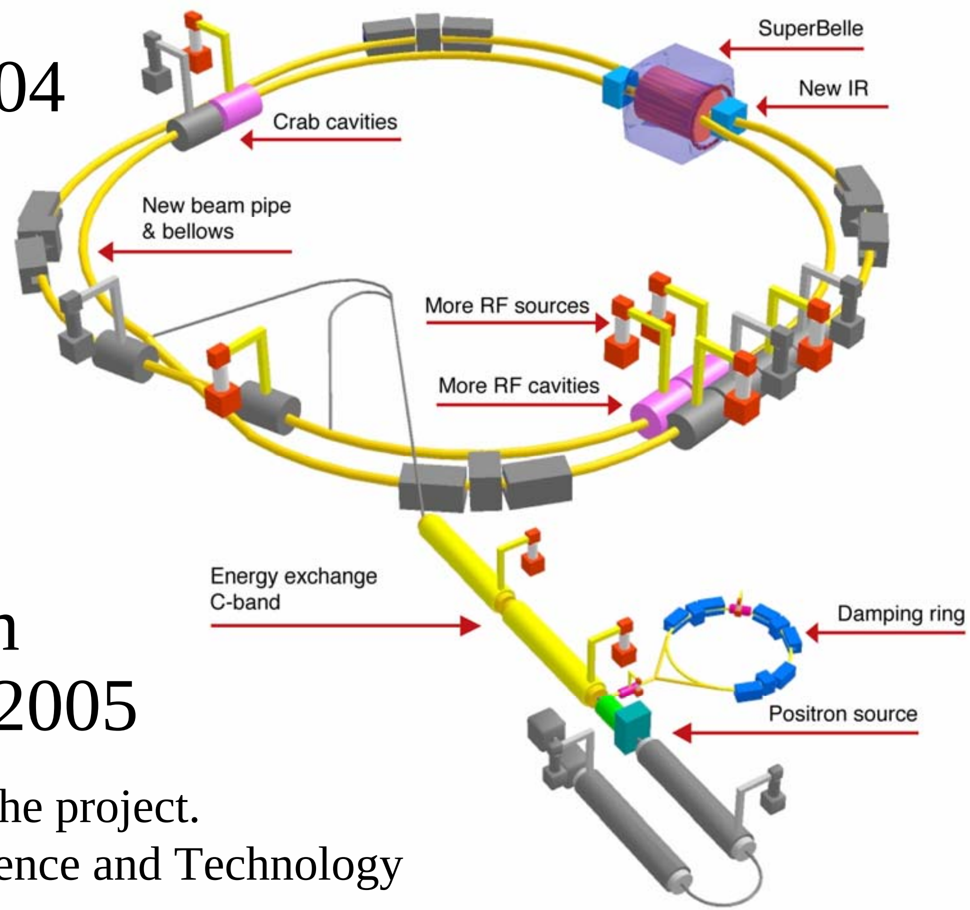


SuperKEKB overview

- Super-high luminosity $\simeq 4\times10^{35}$ cm^{-2}s^{-1}
  - ➢ 5×10^9 $B\overline{B}$ per yr.
  - ➢ 4×10^9 $\tau^+\tau^-$ per yr.

40 × KEKB design goal
25 × present world record from KEKB

- Letter of Intent (LoI) in 2004
  - ➢ 276 authors from 61 institutions
  - ➢ available at http://belle.kek.jp/superb/loi
  - ➢ "Physics at Super B Factory" hep-ex/0406071

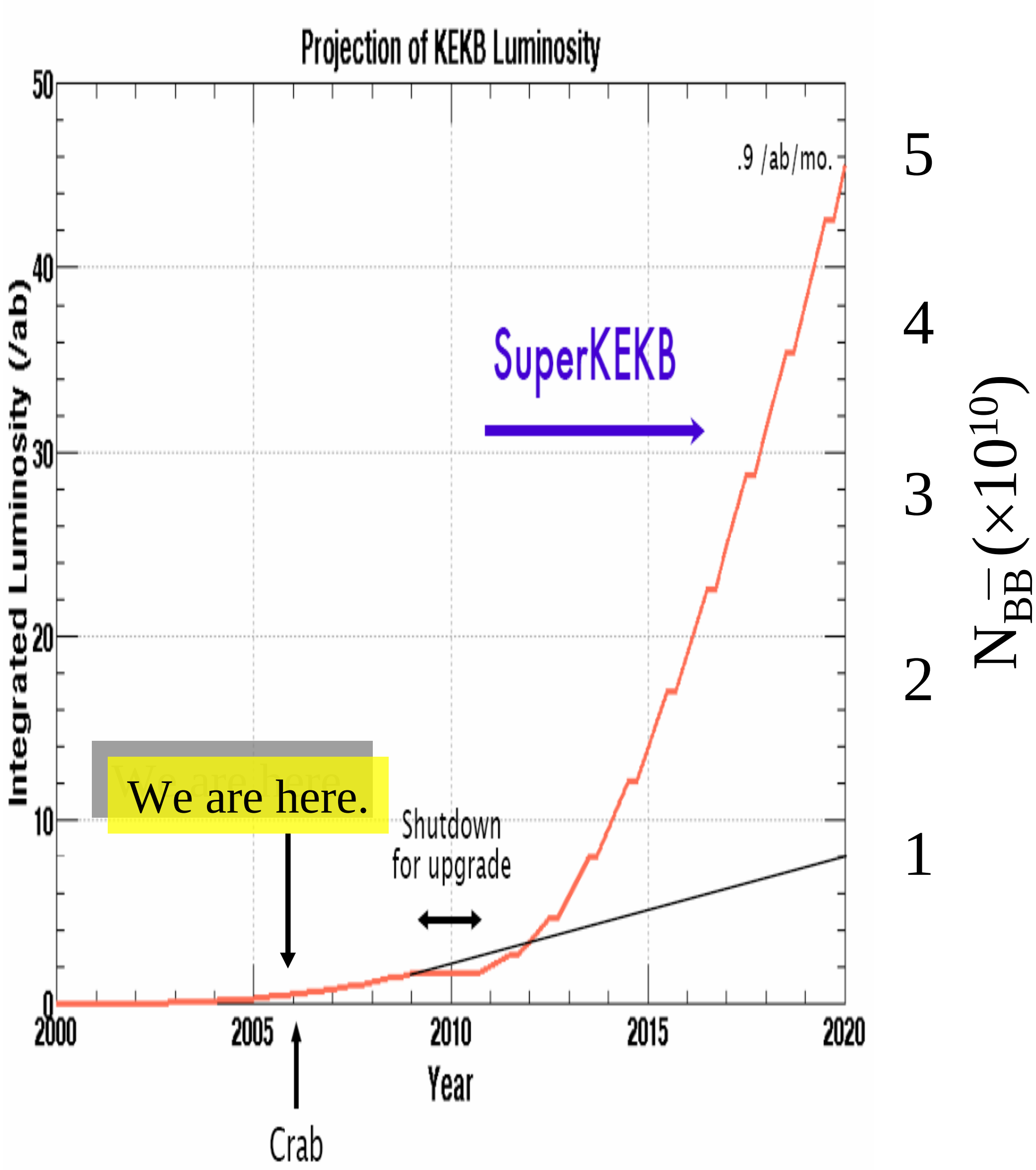


- Official budget request* ("gaisan" request) sent from KEK to MEXT** in Aug. 2005

*This does not mean the official approval of the project.

**Ministry of Education, Culture, Sports, Science and Technology

Projection of integrated luminosity



- **Crab cavity installation in 2006**
- **~2×10⁹ BB pairs by 2008 (4×now)**
- **Long shutdown (14months) in 2009-2010**
- **Constant improvement from 2010**
  - **realistic and reliable plan based on experiences at KEKB**
  - **Crab cavities well tested before 2010: a big advantage !**

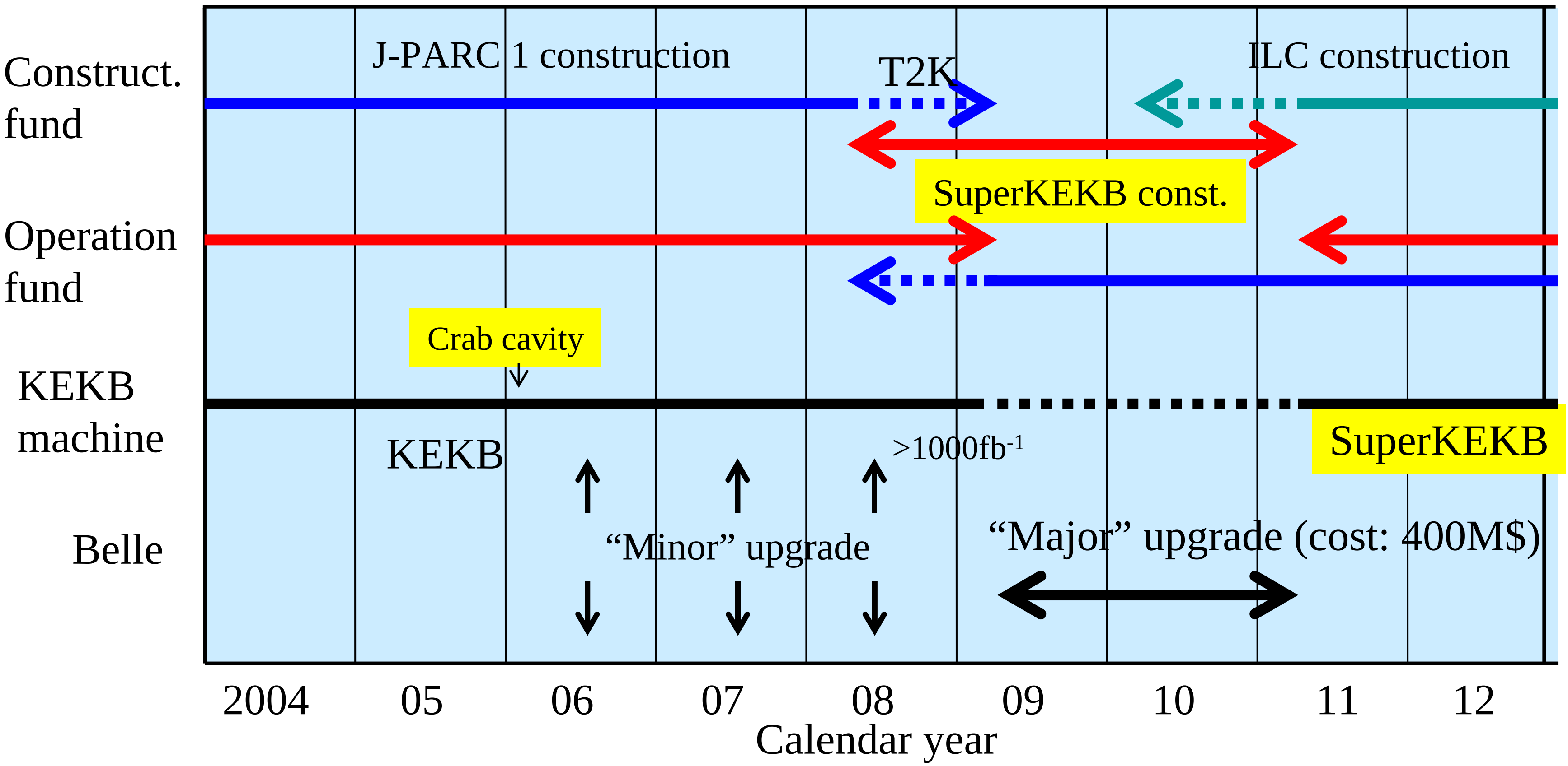
$N_{B\bar{B}}$ ~100 × now !
in the LHC era

Yamauchi's Schedule for Super B

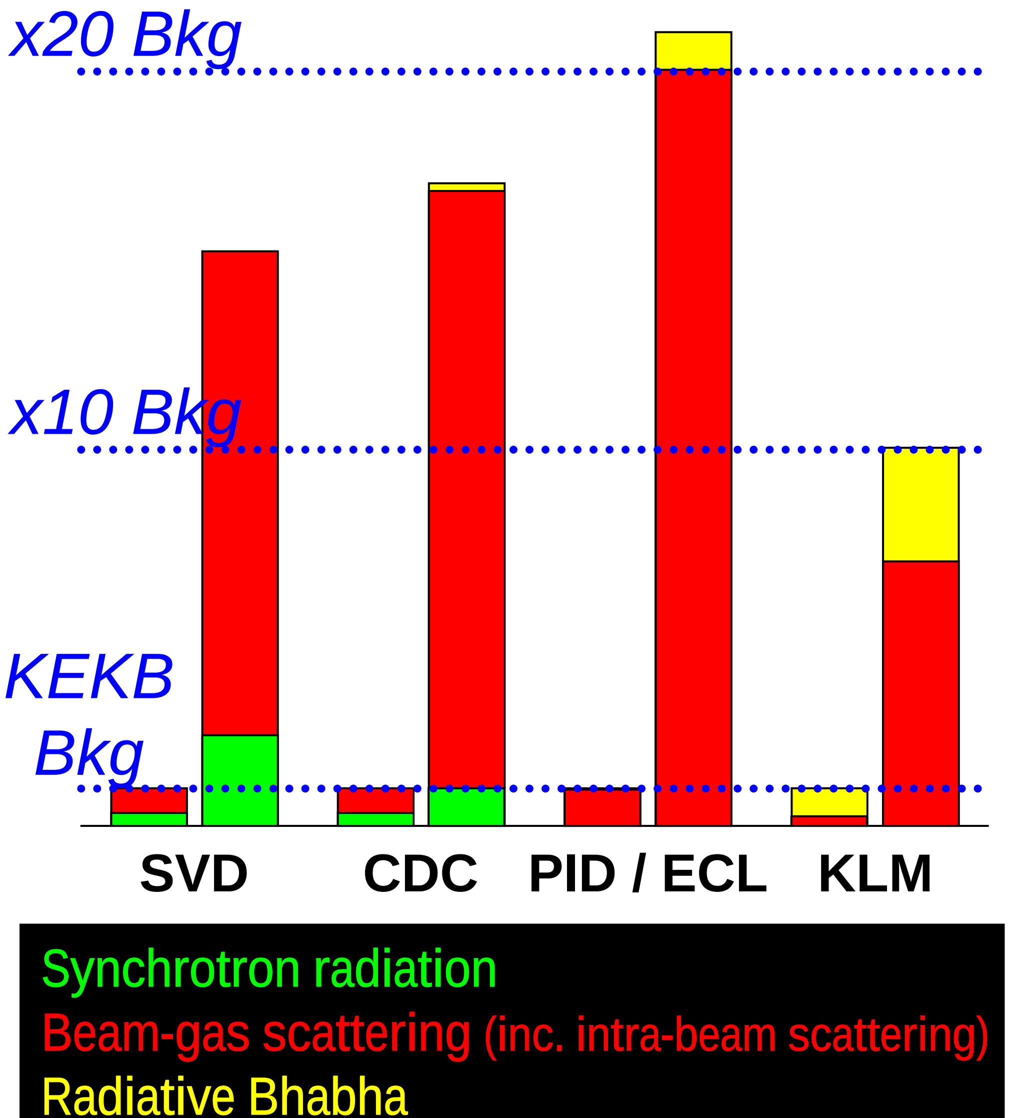
Super B Letter of Intent (KEK Report 2004-4) in April 2004

A Super B proposal was submitted from KEK to MEXT in August 2005.

KEKB/Belle project receives a grade of S (i.e. A+) in gov. reviews

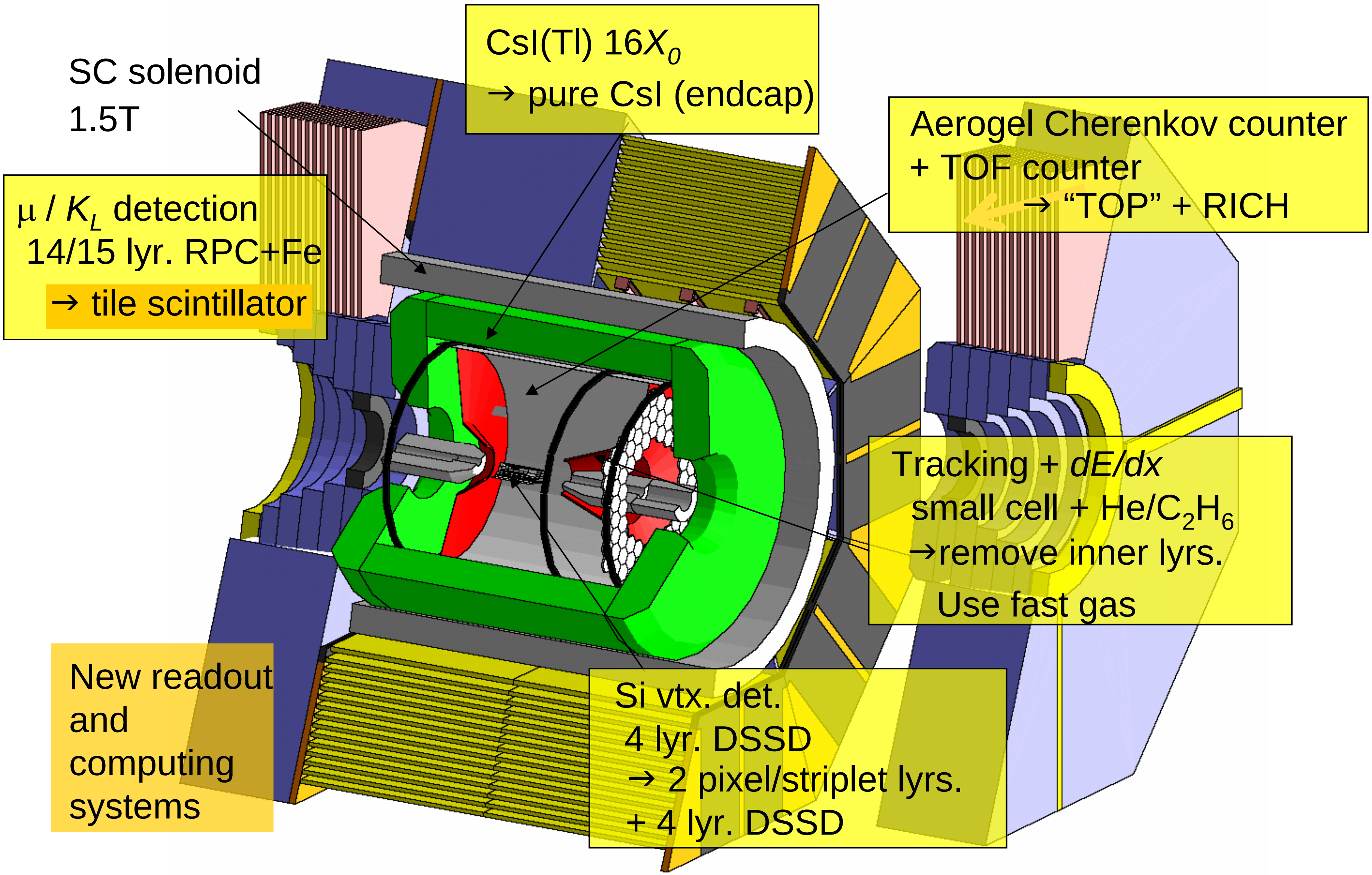


Bkg & TRG rate in future



	KEKB	SuperB
Luminosity ($10^{34}cm^{-2}sec^{-1}$)	~1	40
HER curr. (A)	1.2	4.1
LER curr. (A)	1.6	9.4
vacuum (10^{-7}Pa)	~1.5	5
Bkg increase	-	x 20
TRG rate (kHz)	0.4	14
phys. origin	0.2	10
Bkg origin	0.2	4

SuperBelle detector



In general, requirements less severe than those for LHC

Extended flavor structure

Left-handed current,
quark mixing and CPV

$$\frac{g}{\sqrt{2}} W_\mu^\dagger \left[\bar{\mathbf{u}}\gamma^\mu (1-\gamma_5)\mathbf{V_{CKM}}\mathbf{d}\right] + h.c.$$

$$V_{CKM}(A, \lambda, \rho, \eta)$$

Right-handed current,
quark mixing and CPV

New left-handed current,
quark mixing and CPV

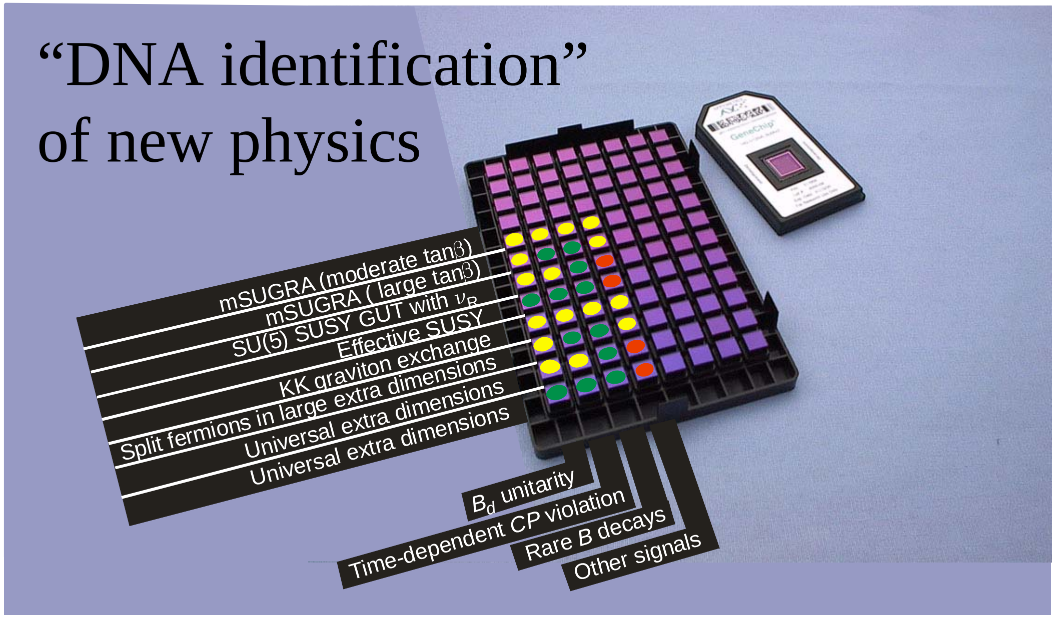
Left-Right mixing

How do we study the extended flavor structure ?

- **Many clean/unique measurements (both exp. & th.) at e^+e^- SuperB**
  - **New CPV phase(s) in $b \to sqq$:e.g. tCPV in $B^0 \to \phi Ks$, $\eta' Ks$, $KsKsKs$**
  - **Right-handed current in $b \to s\gamma$:e.g. tCPV in $B^0 \to Ks\pi^0\gamma$**
  - **Lepton flavor violation in τ decays :e.g. $\tau \to \mu\gamma$**
  - **Charged Higgs in tree diagram :e.g. $Br(B \to D\tau\nu)/Br(B \to D\mu\nu)$**
  - **<u>Many other studies !</u>**

Just a minimal set of examples shown in this talk

All modes above are sensitive to TeV new particles



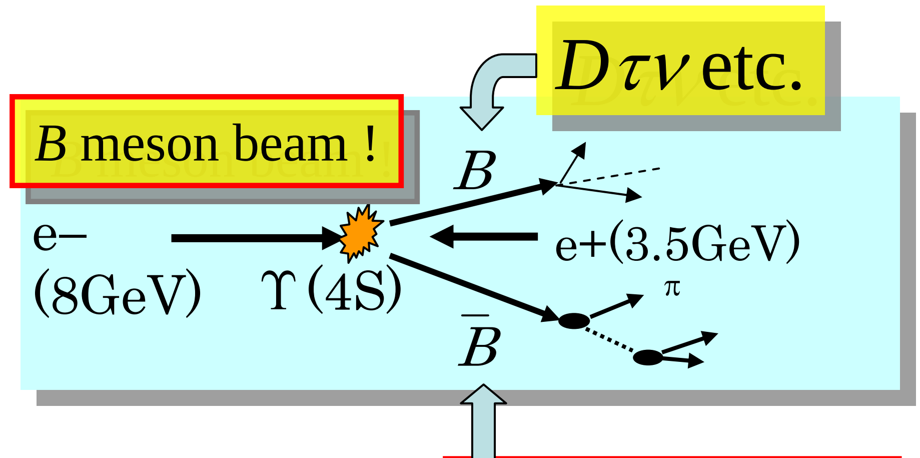
Measurements in clean environment !

- *B* decays with neutrinos

  $B \to \underline{D\tau\nu, \tau\nu}, \underline{ul\nu}$ etc.

  Charged Higgs

  Vub



full (0.1~0.3%) reconstruction
B→*Dπ* etc.

- *B* decays with γ, π^0

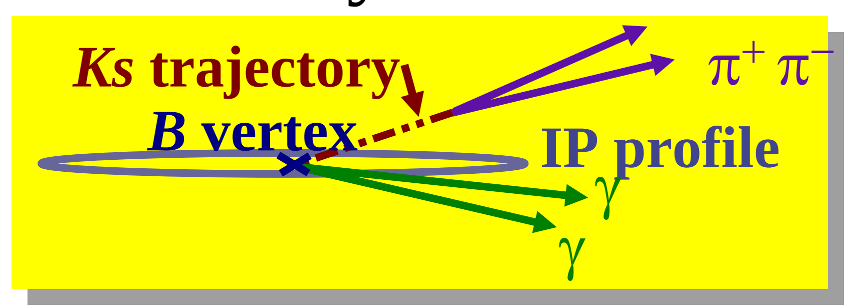
  $B \to Xs\gamma, \pi^0\pi^0$ etc.

  direct *CPV*

  $\phi_2(\alpha)$ isospin analysis

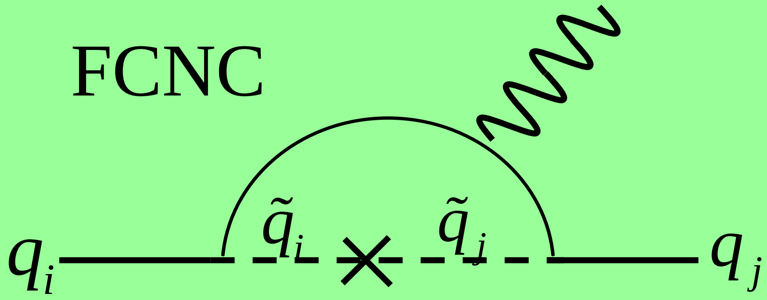
- *B* vertex reconstruction with *Ks* only !

  $B \to Ks\pi^0, Ks\pi^0\gamma$ etc.



MSSM Flavor Physics as an example

FCNC



$$\left(m^2_{\tilde{q}}\right)_{23(13)}$$

squark/slepton mass matrix

$$\left(m^2_{\tilde{q}}\right)_{ij} = \begin{pmatrix} m^2_{11} & m^2_{12} & m^2_{13} \\ m^2_{21} & m^2_{22} & m^2_{23} \\ m^2_{31} & m^2_{32} & m^2_{33} \end{pmatrix}$$

Off-diagonal terms
Flavor Structure
Luminosity frontier

Diagonal terms
Mass Spectrum
Energy frontier (LHC, LC)

Generic parameterization
for $b \to s$ (23→13 for $b \to d$)

$M_{\tilde{q}}$: average squark mass

Left-handed

Right-handed

$$(\delta^d_{LL})_{23} = \frac{(m^2_{\tilde{d}_L})_{23}}{M^2_{\tilde{q}}} \qquad (\delta^d_{RR})_{23} = \frac{(m^2_{\tilde{d}_R})_{23}}{M^2_{\tilde{q}}}$$

$$(\delta^d_{LR})_{23} = \frac{(m^2_{\tilde{d}_{LR}})_{23}}{M^2_{\tilde{q}}} \qquad (\delta^d_{RL})_{23} = \frac{(m^2_{\tilde{d}_{RL}})_{23}}{M^2_{\tilde{q}}}$$

MSSM: Squark mass matrix (*down-type*)

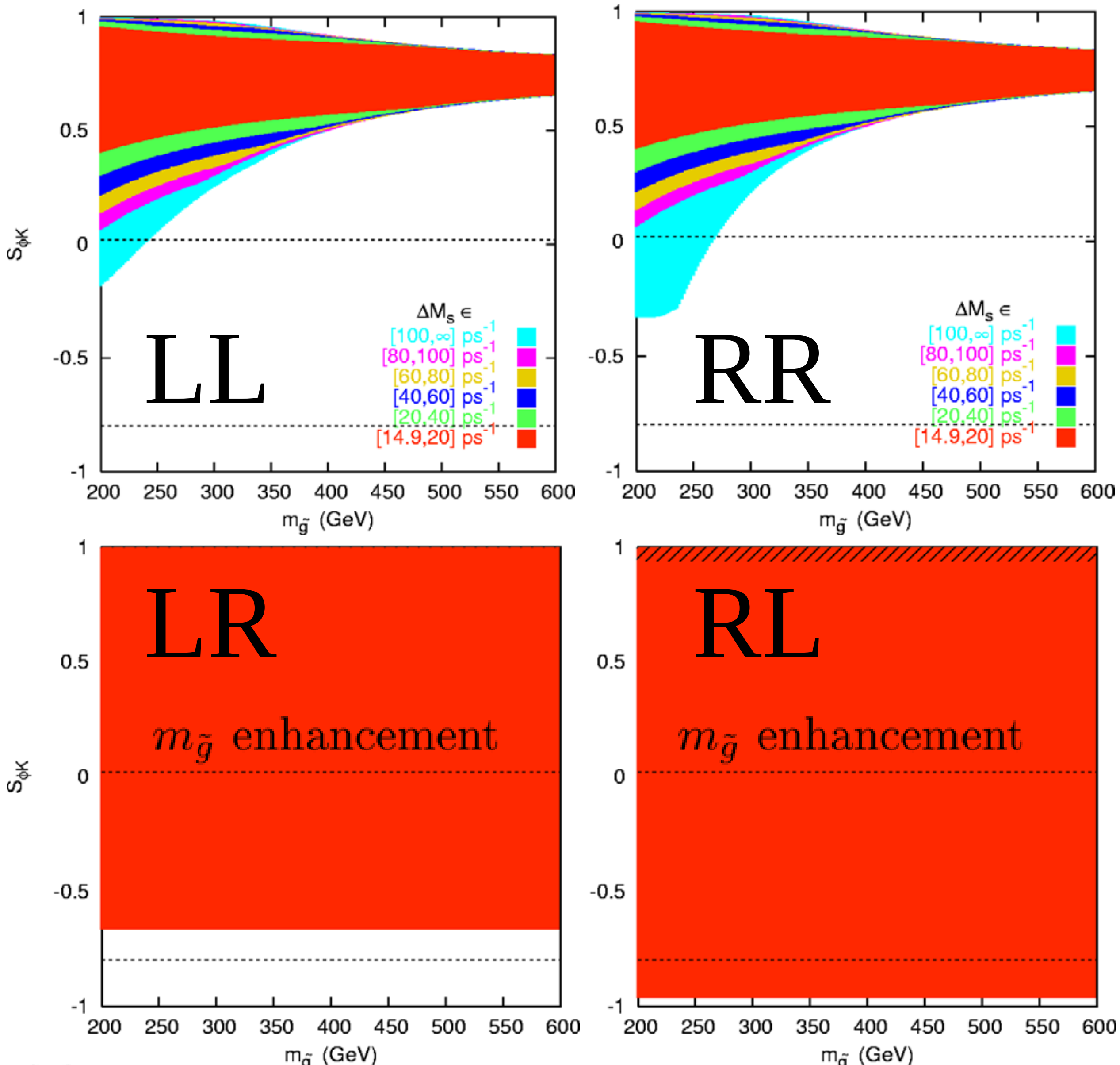
Super B factory

$$\begin{pmatrix} m^2_{\tilde{d}_L} & m_d(A_d - \mu\tan\beta) & (\Delta^d_{12})_{LL} & (\Delta^d_{12})_{LR} & (\Delta^d_{13})_{LL} & (\Delta^d_{13})_{LR} \\ & m^2_{\tilde{d}_R} & (\Delta^d_{12})_{RL} & (\Delta^d_{12})_{RR} & (\Delta^d_{13})_{RL} & (\Delta^d_{13})_{RR} \\ & & m^2_{\tilde{s}_L} & m_s(A_s - \mu\tan\beta) & (\Delta^d_{23})_{LL} & (\Delta^d_{23})_{LR} \\ & & & m^2_{\tilde{s}_R} & (\Delta^d_{23})_{RL} & (\Delta^d_{23})_{RR} \\ & & & & m^2_{\tilde{b}_L} & m_b(A_b - \mu\tan\beta) \\ & & & & & m^2_{\tilde{b}_R} \end{pmatrix}$$

Assuming all Δ's small and squarks nearly degenerate, we can use mass insertion approximation (MIA):

$$(\delta^d_{ij})_{AB} = \frac{(\Delta^d_{ij})_{AB}}{\tilde{m}^2}$$

New particles must come with New Flavor Mixing.



$$\Delta\mathcal{S}_{\phi K_S} \propto \frac{\delta_{LL(RR)}}{M_{\tilde q}^2}$$

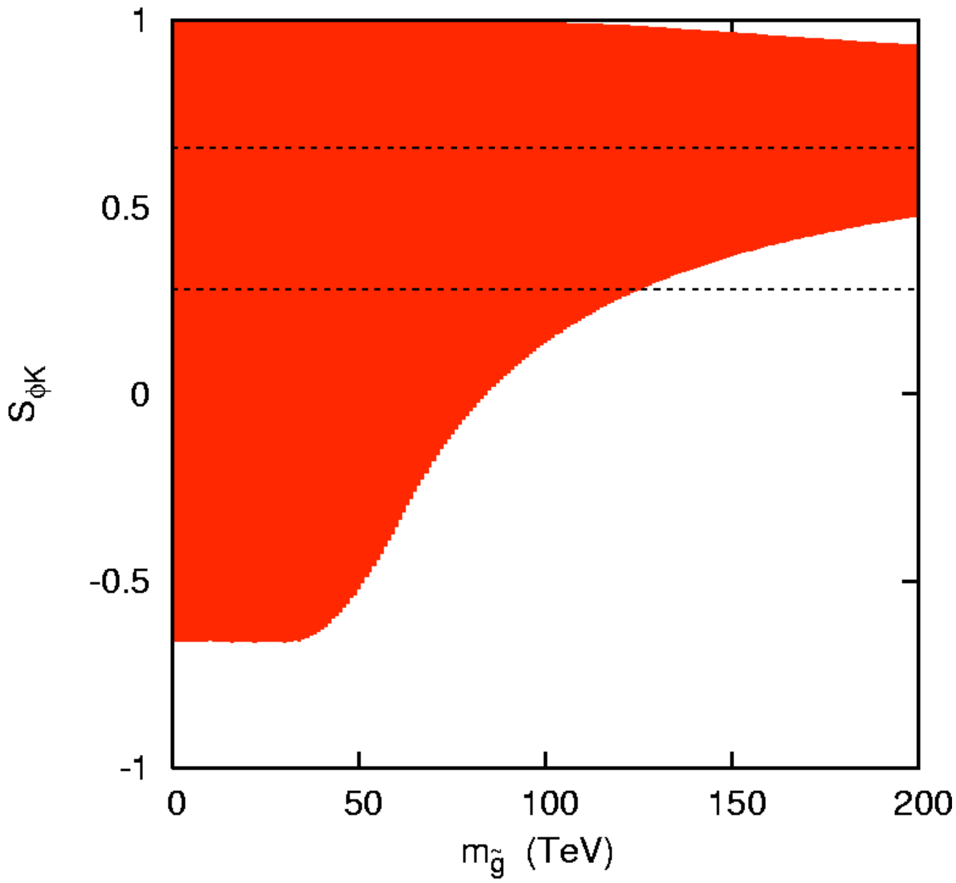
$$\Delta\mathcal{S}_{\phi K_S} \propto \frac{m_{\tilde g}}{M_{\tilde q}^2}\delta_{LR(RL)}$$

$\rightarrow$ Remain constant up to $M_{\tilde q}^2 \sim 5$ TeV$/c^2$.

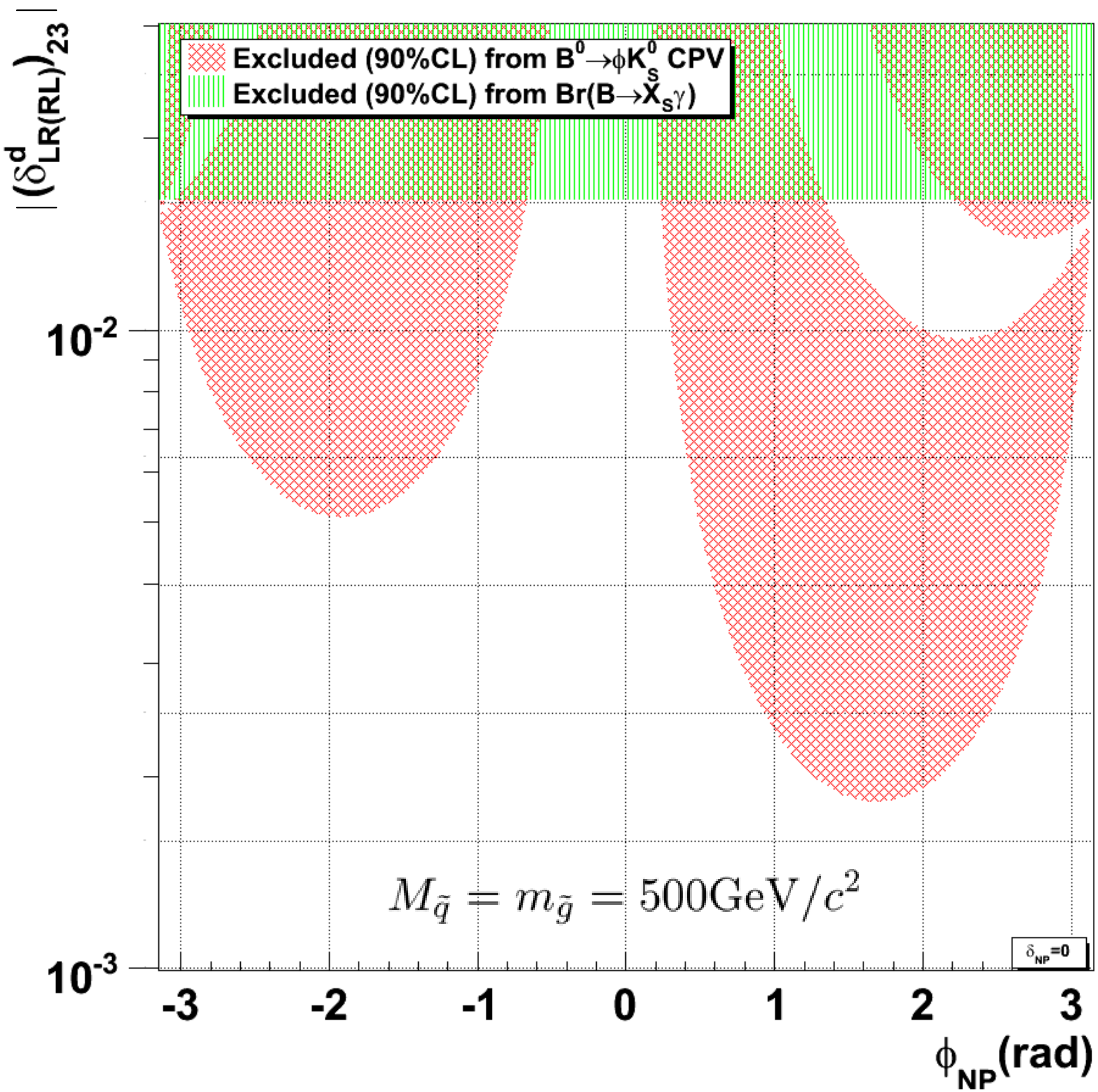
$M_{\tilde q} = m_{\tilde g}$

G.L.Kane, P.Ko, Haibin Wang, C.Kolda, Jae-hyeon Park, Lian-Tao Wang, PRD70, 035015 (2004)

Caution !
This fig. does not
take into account
SUSY breakdown
at large mass.
Used just for
illustration purpose.



- Mass reach in general is much higher than O(TeV).

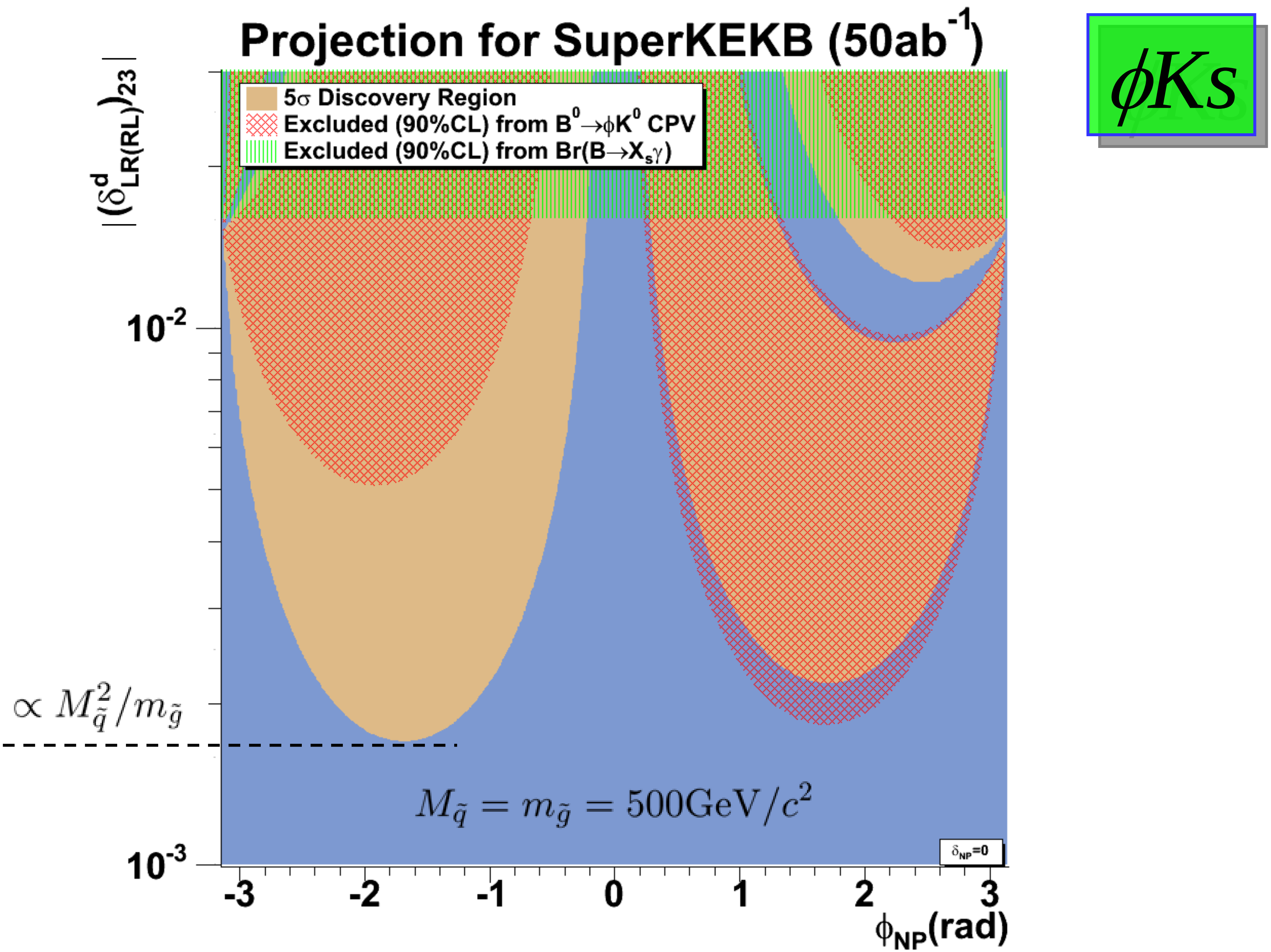


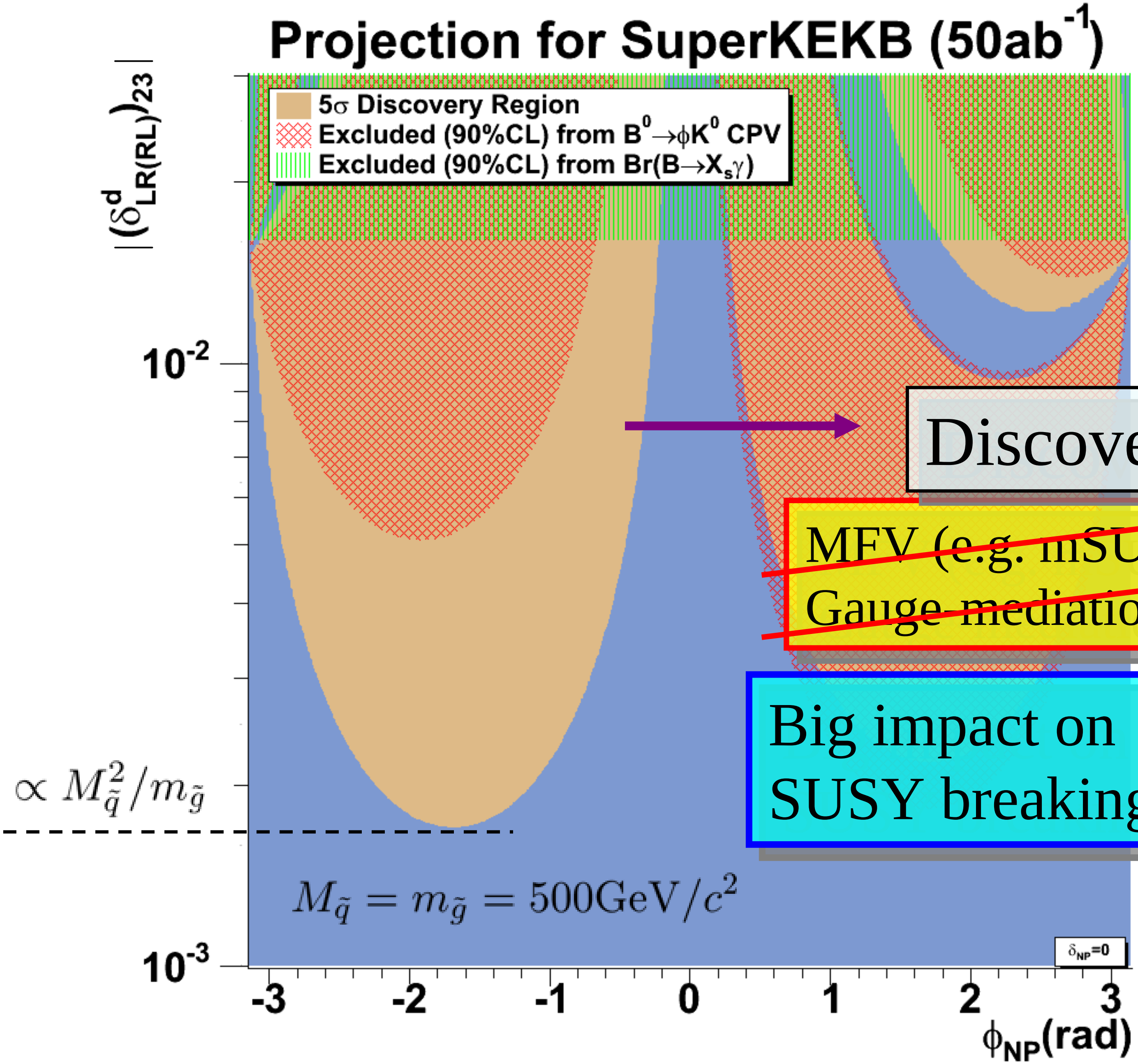
$= \arg(\delta^d_{LR(RL)})_{23}$

ϕKs

Summer 2005

based on
S.Khalil and E.Kou
PRD67, 055009 (2003)
and SuperKEKB LoI


Projection for SuperKEKB (50ab^{-1})
ϕKs
5σ Discovery Region
Excluded (90%CL) from $B^0 \to \phi K^0$ CPV
Excluded (90%CL) from $Br(B \to X_s \gamma)$
$|(\delta^d_{LR(RL)})_{23}|$
10^{-2}
10^{-3}
$\propto M_{\tilde{q}}^2 / m_{\tilde{g}}$
$M_{\tilde{q}} = m_{\tilde{g}} = 500\mathrm{GeV}/c^2$
$\delta_{NP}=0$
-3
-2
-1
0
1
2
3
ϕ_{NP}(rad)

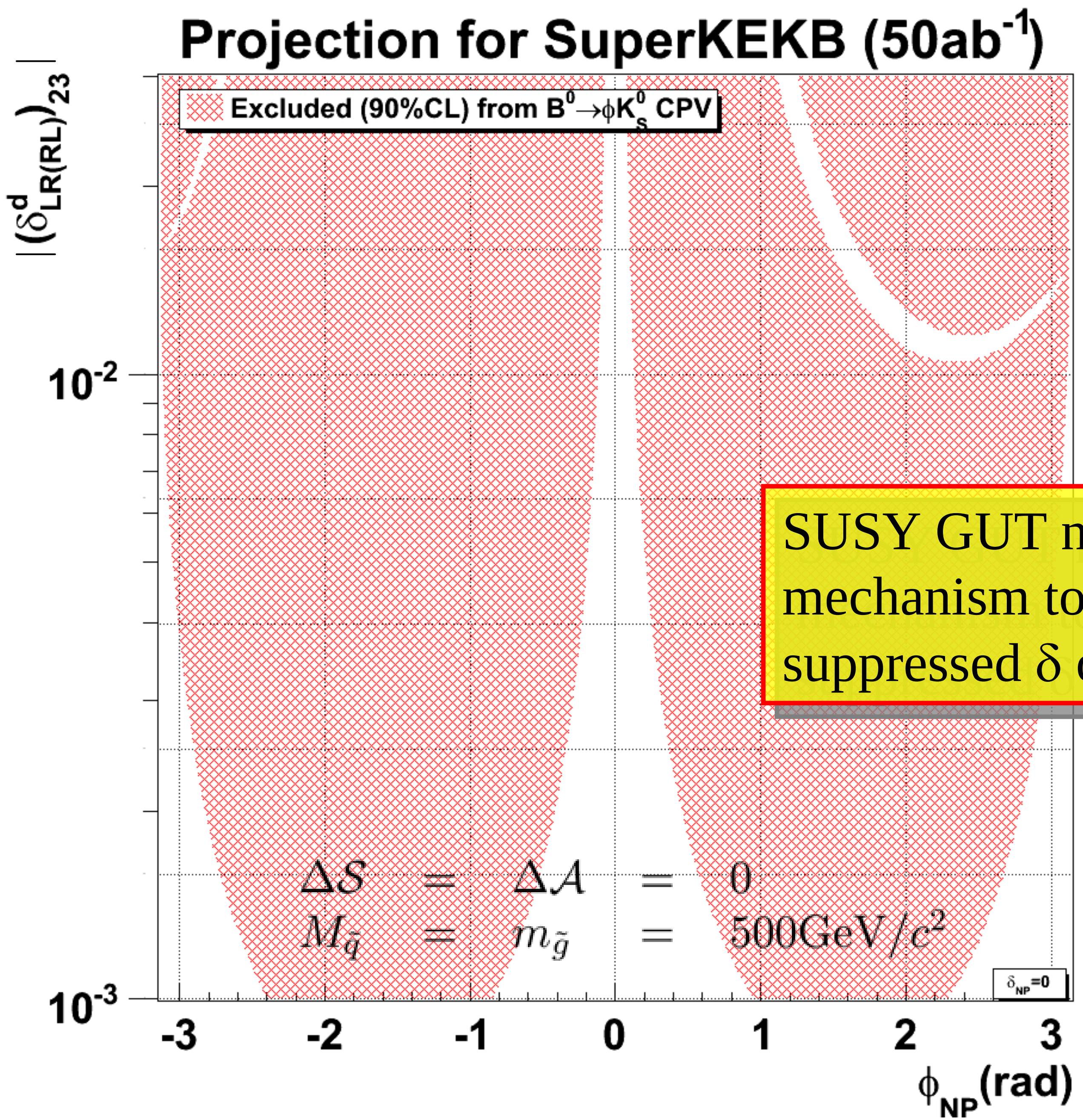


ϕKs

Discovery means

~~MFV (e.g. mSUGRA) ?~~
~~Gauge-mediation ?~~

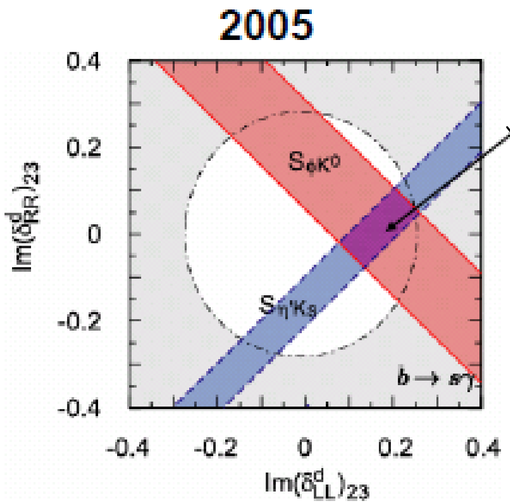
Big impact on
SUSY breaking scenario



ϕKs

SUSY GUT needs some mechanism to explain suppressed δ or φ

from slides by
M. Endo at HL06 workshop, 2004
M. Yamaguchi at ICFP2005



Parity of new physics

M. Endo, S. Mishima, M. Yamaguchi
PLB609, 95 (2005)

$(\delta^d_{LL,RR})_{23} = (m^2_{\tilde{d}_{L,R}})_{23}/m^2_{\tilde{q}}$

$m_{\mathrm{soft}} = 500$ GeV, $\tan\beta = 10$

GF: $q^2 = m_b^2/2$

		$S_{\phi K^0}$	$S_{\eta' K_S}$	$S_{K^*\gamma}$	$A_{\mathrm{CP}}(b \to s\gamma)$
LL or LR	left-handed	+	+	×	○
RL or RR	right-handed	+	-	○	×

magnetic-dipole relevant

LL/RR vs LR/RL?

ΔM_s enhanced by a product of LL and RR

[Ball,Khalil,Kou]

EDMs chargino diagrams are sensitive to $\not{C}\not{P}$ of LL

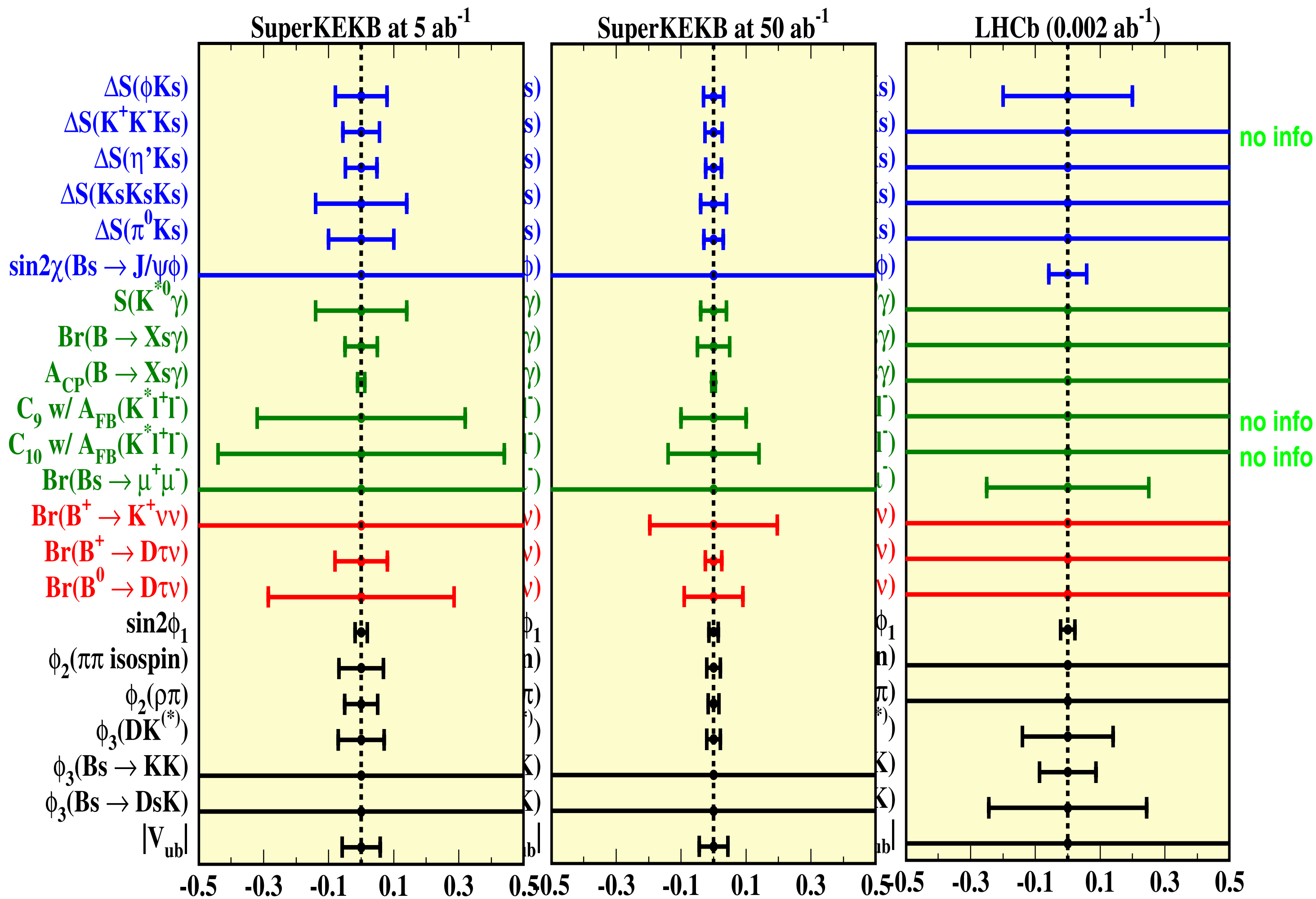
[ME,Kakizaki,Yamaguchi]

⋮

Comparison with LHCb

		SuperKEKB (5 ab^{-1})	SuperKEKB (50 ab^{-1})
CPV ($b \to s$)		0.079	0.031
		0.056	0.026
		0.049	0.024
		0.14	0.04
		0.10	0.03
		×	×
FCNC		0.14	0.04
		5%	5%
		0.011	5×10^{-3}
		32%	10%
		44%	14%
		×	×
w/ ν			5.1σ
		8%	2.5%
		3.5σ	9%
CKM		0.019	0.014
		3.9°	1.2°
		2.9°	0.9°
		4°	1.2°
		×	×
		×	×
		5.8%	4.4%

SuperKEKB 5ab^{-1} 50ab^{-1} LHCb 2fb^{-1}

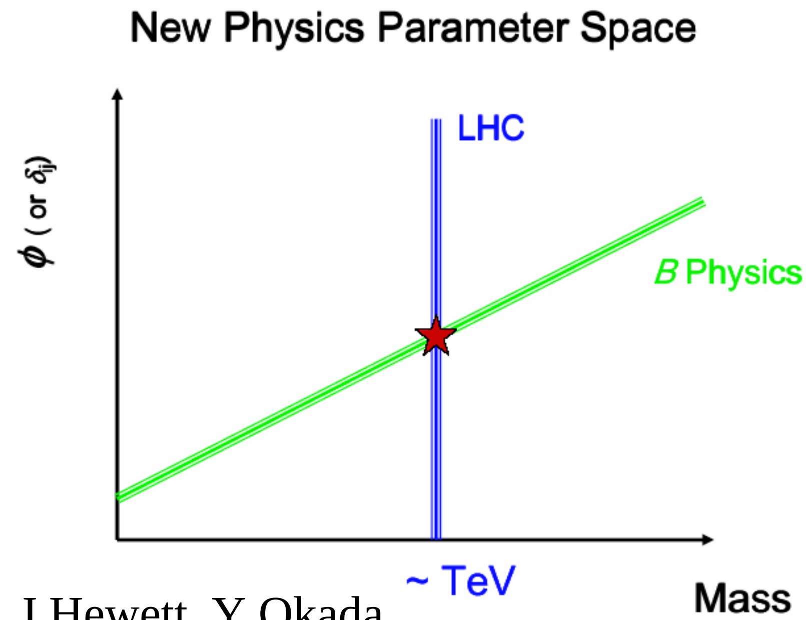


and rich τ physics

# of produced B's irrelevant to physics reach comparison

Synergy with LHC

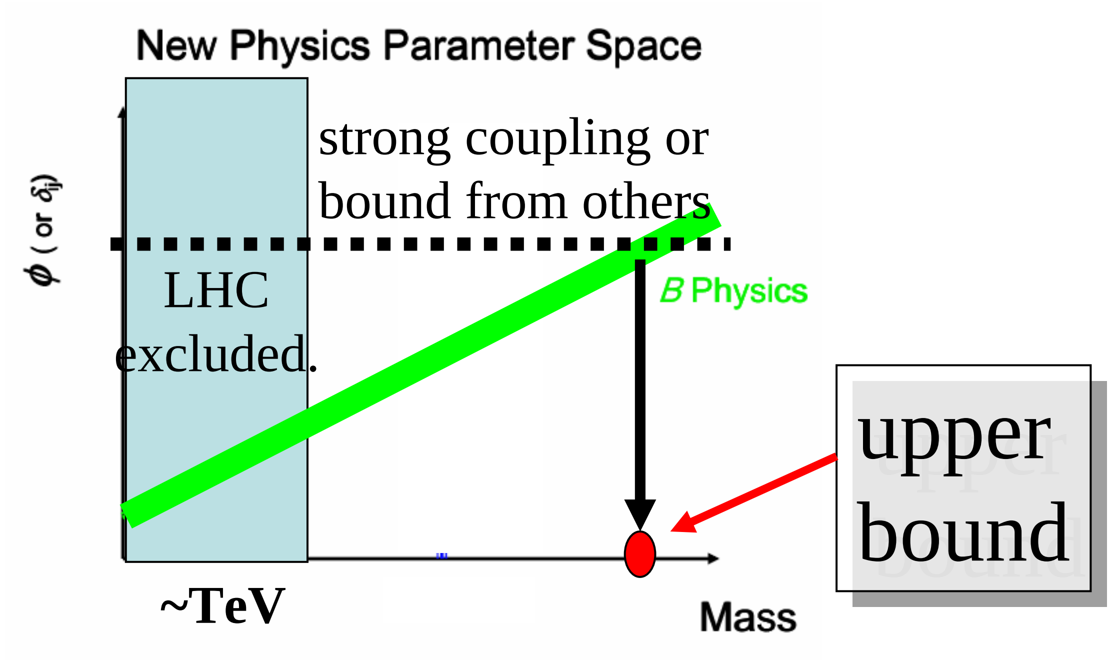
- If LHC finds TeV New Physics,
  - **its flavor structure must be examined experimentally. A super B factory is a powerful tool for this purpose.**
- If LHC finds nothing but SM-like Higgs,
  - **search for deviations from the SM in flavor physics will be one of the best ways to obtain a hint of new physics energy scale.**
  - **Large discovery potential at SuperKEKB, regions well above the LHC direct search limit can be explored.**



J.Hewett, Y.Okada

Measurements at SuperB important in any case

With new flavor mixing at SuperB but no new particle at LHC



Measurements at SuperB will imply an upper bound of new physics scale !

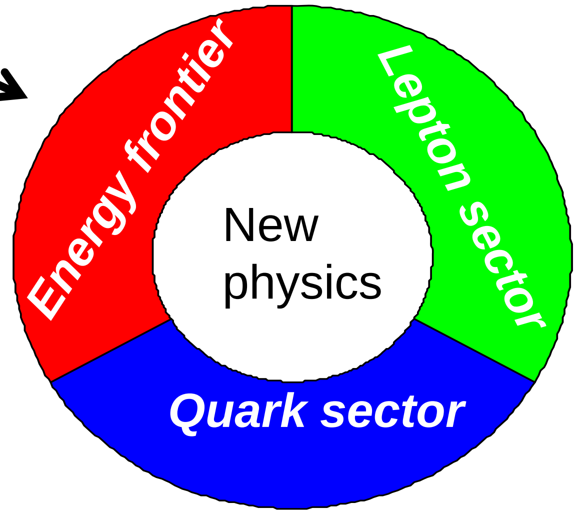
A Unified and Unbiased Attack on New Physics

ν experiments,
g_μ-2, $\mu \rightarrow e\gamma$, etc.

LHC, ILC

Mass spectrum,
interactions

ν mass and mixing,
CPV, and LFV



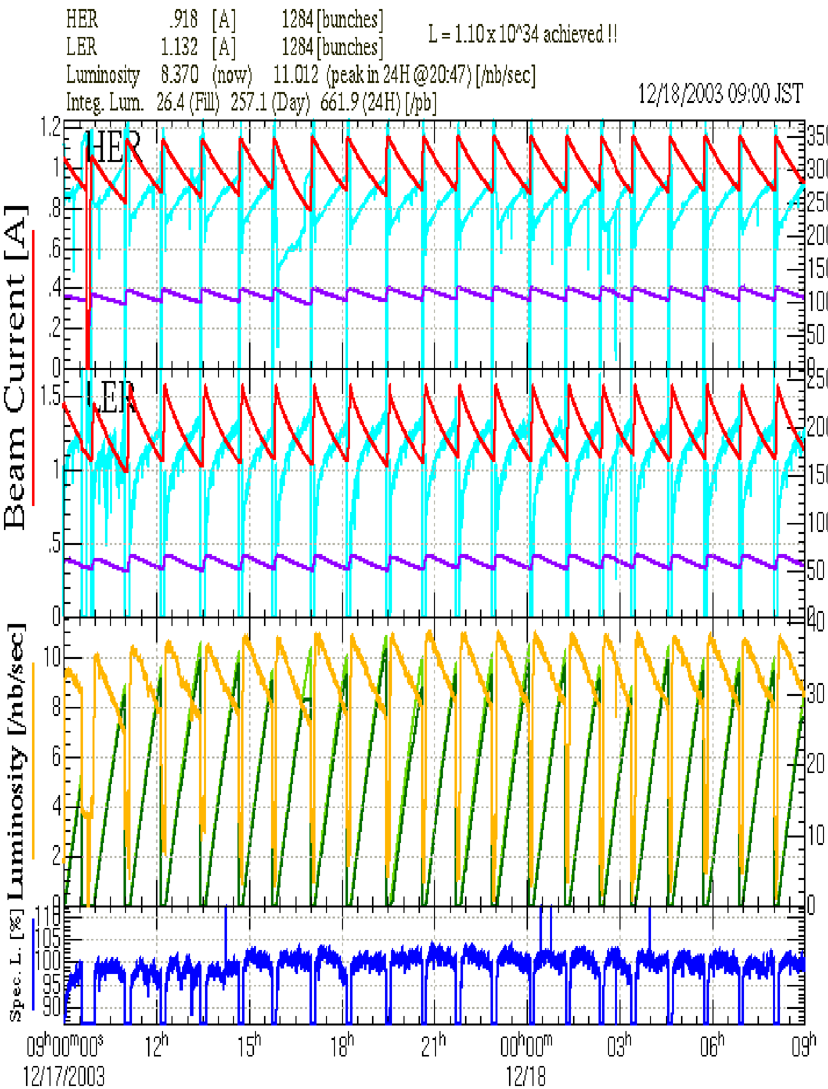
τ LFV,
τ CPV

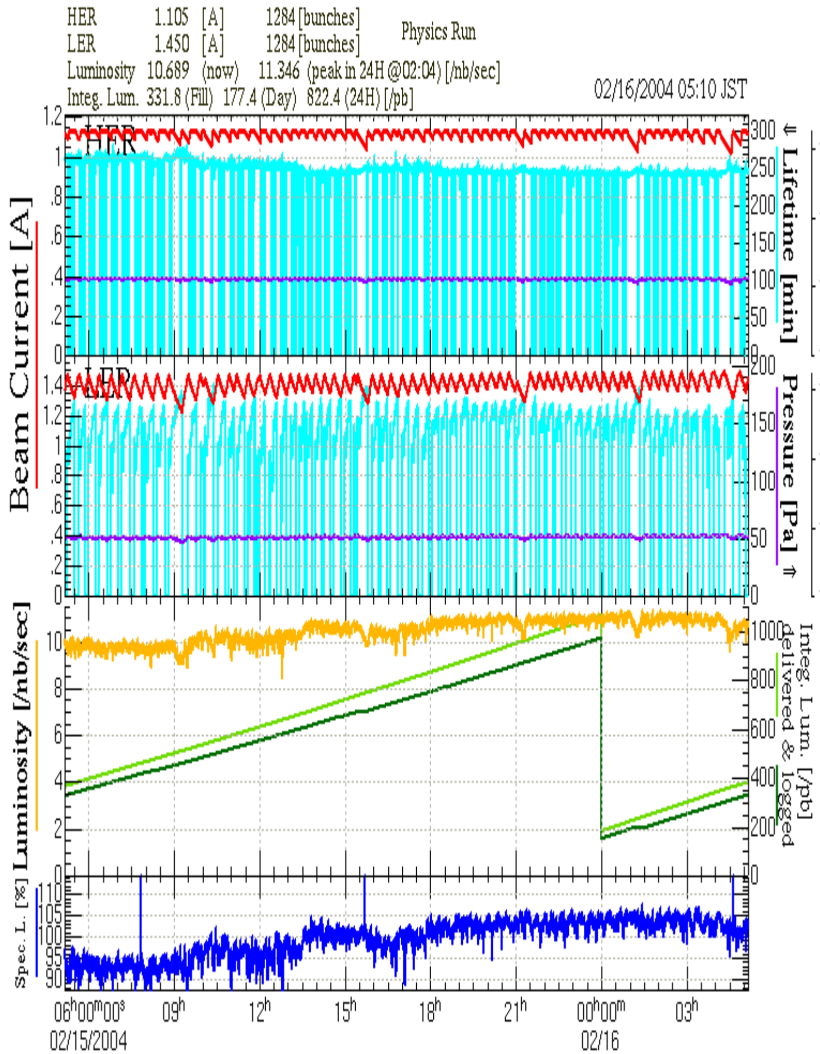
Flavor mixing,
CPV phases

Super B factory,
LHCb, *K* experiments…

Backup Slides

Normal injection → *Continuous injection*





661/pb/day ***→1182 pb/day***

How to achieve the super-high luminosity

Stored current:
1.34 / 1.8 A (KEKB)
→ 4.1 / 9.4 A (SuperKEKB)

Beam-beam parameter:
0.057 (KEKB)
→ 0.19 (SuperKEKB)

Crab cavity

Lorentz factor

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

Classical electron radius

Beam size ratio

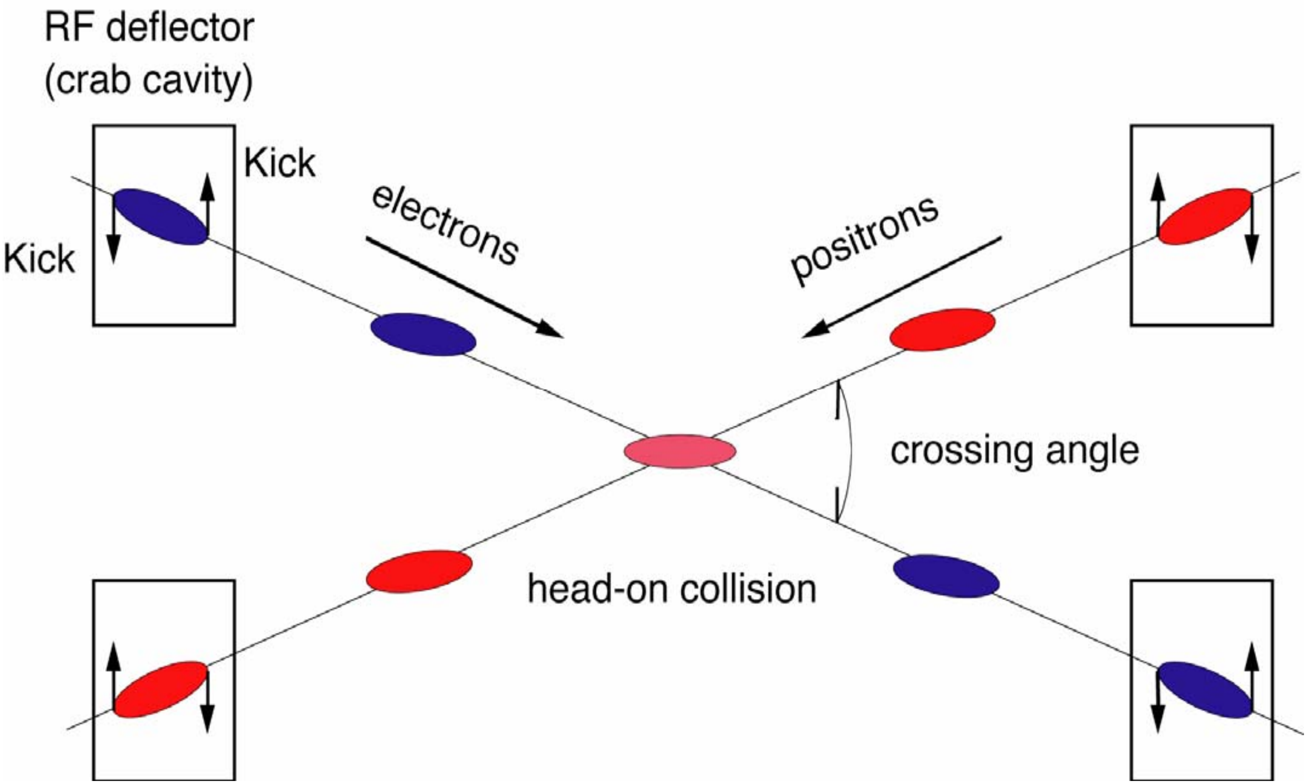
Geometrical reduction factors due to crossing angle and hour-glass effect

Luminosity:
0.15×10^{35} cm^{-2}s^{-1} (KEKB)
4×10^{35} cm^{-2}s^{-1} (SuperKEKB)

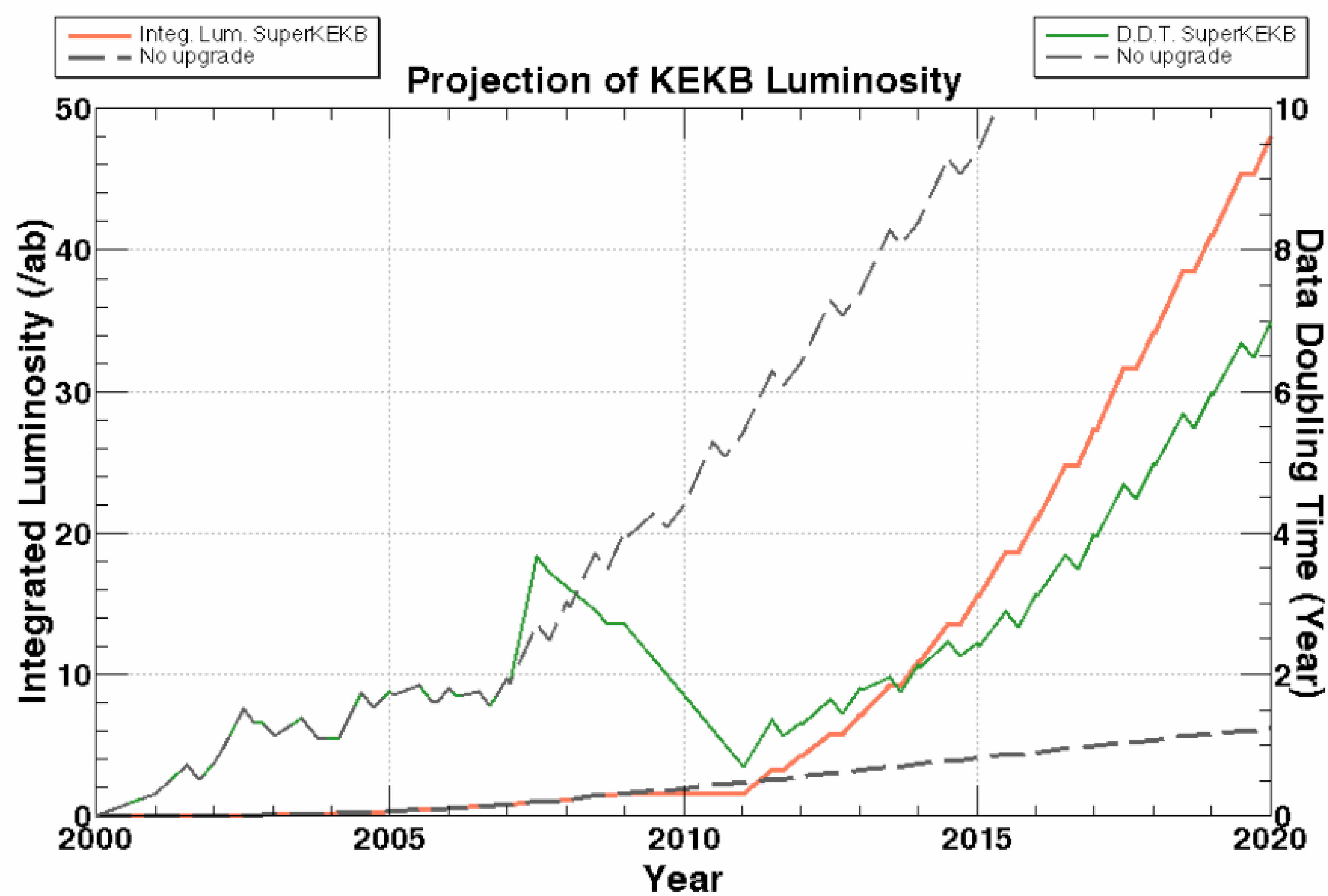
Vertical β at the IP:
5.2/6.5 mm (KEKB)
→ 3.0/3.0 mm (SuperKEKB)

Bunch length (σ_s)
7 ~ 9 mm -> 3 mm

Crab cavity: a new idea for higher luminosity



- Head-on collisions with finite crossing angle !
  - avoid parasitic collisions
  - collisions with highest symmetry → large beam-beam parameter



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
0
2
4
6
8
10
2000
2005
2010
2015
2020

Wolfenstein parameterization

$$s_{12} = \lambda,\ s_{23} = A\lambda^2,\ s_{13}e^{-i\delta} = A\lambda^3(\rho - i\eta)$$

$$\begin{aligned}
V_{\text{CKM}} &= \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cs} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \\
&= \begin{pmatrix} 1 - \frac{\lambda^2}{2} - \frac{\lambda^4}{8} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \frac{\lambda^2}{2} - \frac{1}{8}(1 + 4A^2)\lambda^4 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 + A\lambda^4(\frac{1}{2} - \rho - i\eta) & 1 - \frac{A^2}{2}\lambda^4 \end{pmatrix} \\
&+ \ \mathcal{O}(\lambda^5)
\end{aligned}$$

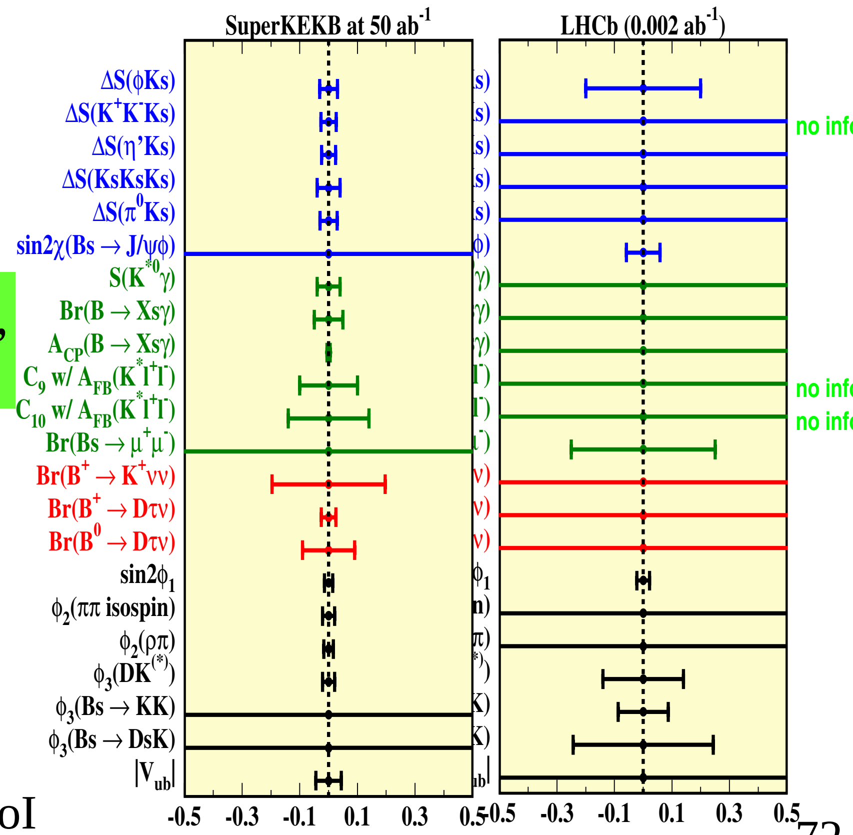
Comparisons with LHCb

- 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.



from
SuperKEKB LoI

Many other new measurements

- A_{FB} in $B \to K^*ll$
- $B \to K^*\nu\nu$, $\tau\nu$
- $b \to d\gamma$
- Observation of direct/mixing-induced CPV in many decays
- $\sin 2\theta_W$ from $e^+e^- \to \mu^+\mu^-$ FB asymmetry
- T violation in 3-body baryonic decays within SM
- Light DM in Y(1S) decays
- New hadrons (X, Y, Z, ...)

A large number of b→s modes are known, where are the b→d penguins ?

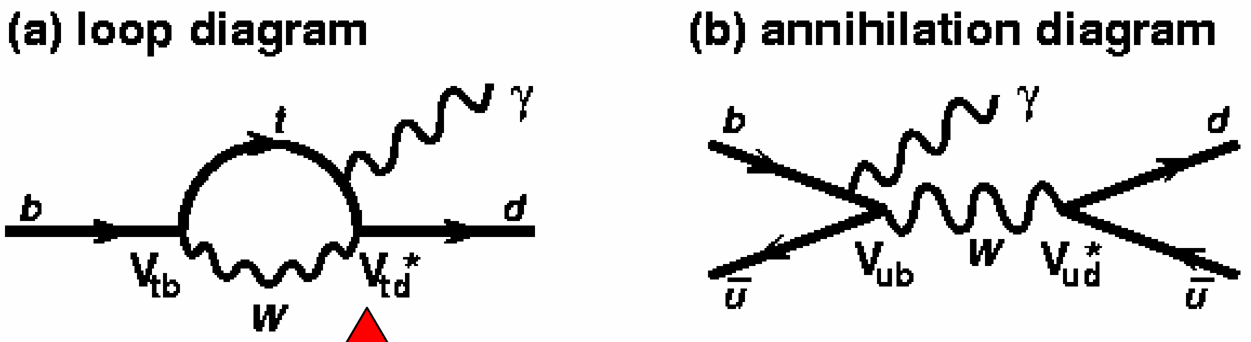
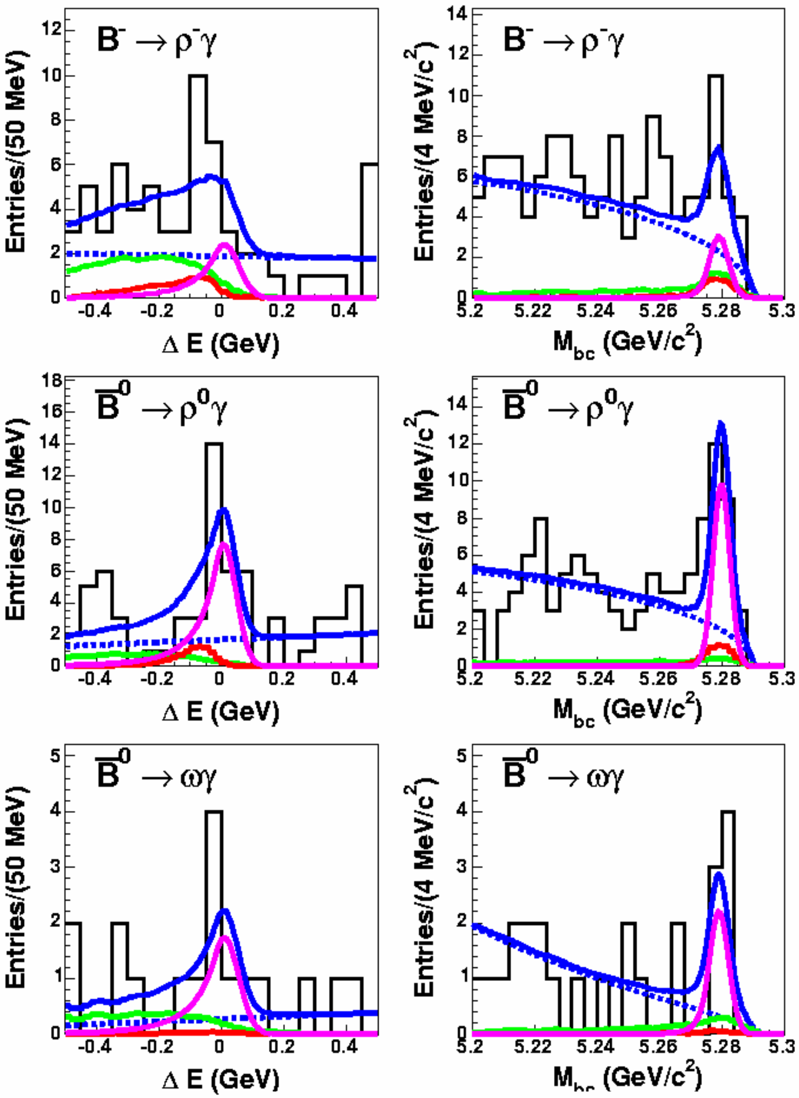


FIG. 1: (a) Loop diagram for $b \to d\gamma$ and (b) annihilation diagram for $B^- \to \rho^-\gamma$ only.

$$\frac{\mathcal{B}(B \to (\rho,\omega)\gamma)}{\mathcal{B}(B \to K^*\gamma)} = S_\rho \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1 - m_\rho^2/M_B^2}{1 - m_{K^*}^2/M_B^2}\right)^3 \zeta^2 \left[1 + \Delta R\right]$$

First Observation of b→d γ



Yields and significances

$$B \to \rho^- \gamma : 8.1^{+6.4+1.8}_{-5.5-1.6}; 1.5\sigma$$

$$B \to \rho^0 \gamma : 20.8^{+6.2+1.2}_{-5.5-1.4}; 5.1\sigma$$

$$B \to \omega \gamma : 8.9^{+3.5+0.8}_{-2.7-0.8}; 2.6\sigma$$

$$\mathcal{B}(B \to (\rho,\omega)\gamma) = (1.34^{+0.34\,+0.14}_{-0.31\,-0.10}) \times 10^{-6}$$

$$\mathcal{B}(B^- \to \rho^- \gamma) = (0.55^{+0.43\,+0.12}_{-0.37\,-0.11}) \times 10^{-6}$$

$$\mathcal{B}(\overline{B}^0 \to \rho^0 \gamma) = (1.17^{+0.35\,+0.09}_{-0.31\,-0.08}) \times 10^{-6}$$

$$\mathcal{B}(\overline{B}^0 \to \omega \gamma) = (0.58^{+0.35\,+0.07}_{-0.27\,-0.08}) \times 10^{-6}$$

$$\mathcal{B}(\overline{B} \to (\rho,\omega)\gamma) \equiv \mathcal{B}(B^- \to \rho^- \gamma) = 2 \times \frac{\tau_{B^+}}{\tau_{B^0}} \mathcal{B}(\overline{B}^0 \to \rho^0 \gamma) = 2 \times \frac{\tau_{B^+}}{\tau_{B^0}} \mathcal{B}(\overline{B}^0 \to \omega \gamma)$$

using $\frac{\tau_{B^+}}{\tau_{B^0}} = 1.076 \pm 0.008$

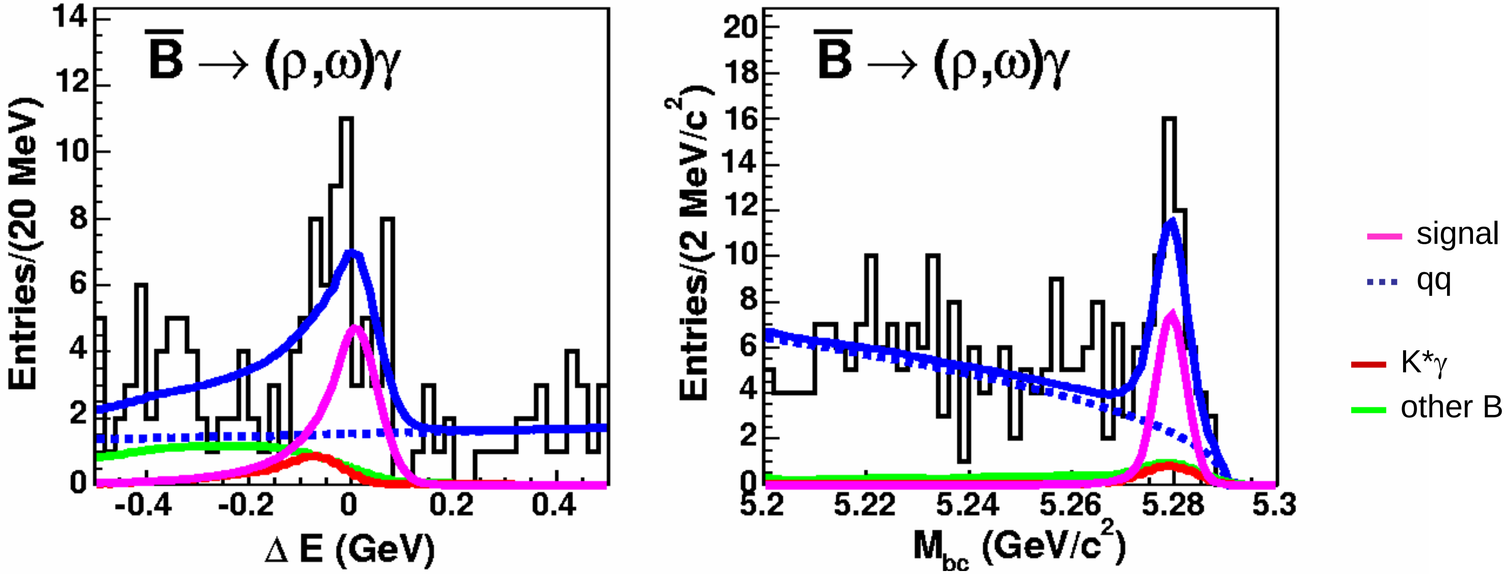
First Observation of b→d γ

hep-ex/0506079

The measured branching fraction, $\mathcal{B}(B \to (\rho\omega)\gamma) = (1.34^{+0.34}_{-0.31}\ ^{+0.14}_{-0.10}) \times 10^{-6}$, translates to

$$|V_{td}/V_{ts}| = 0.200^{+0.026}_{-0.025}(\text{exp.})^{+0.038}_{-0.029}(\text{theo.}),$$

which is compatible with SM constraints based on fits using measurements of other CKM parameters.



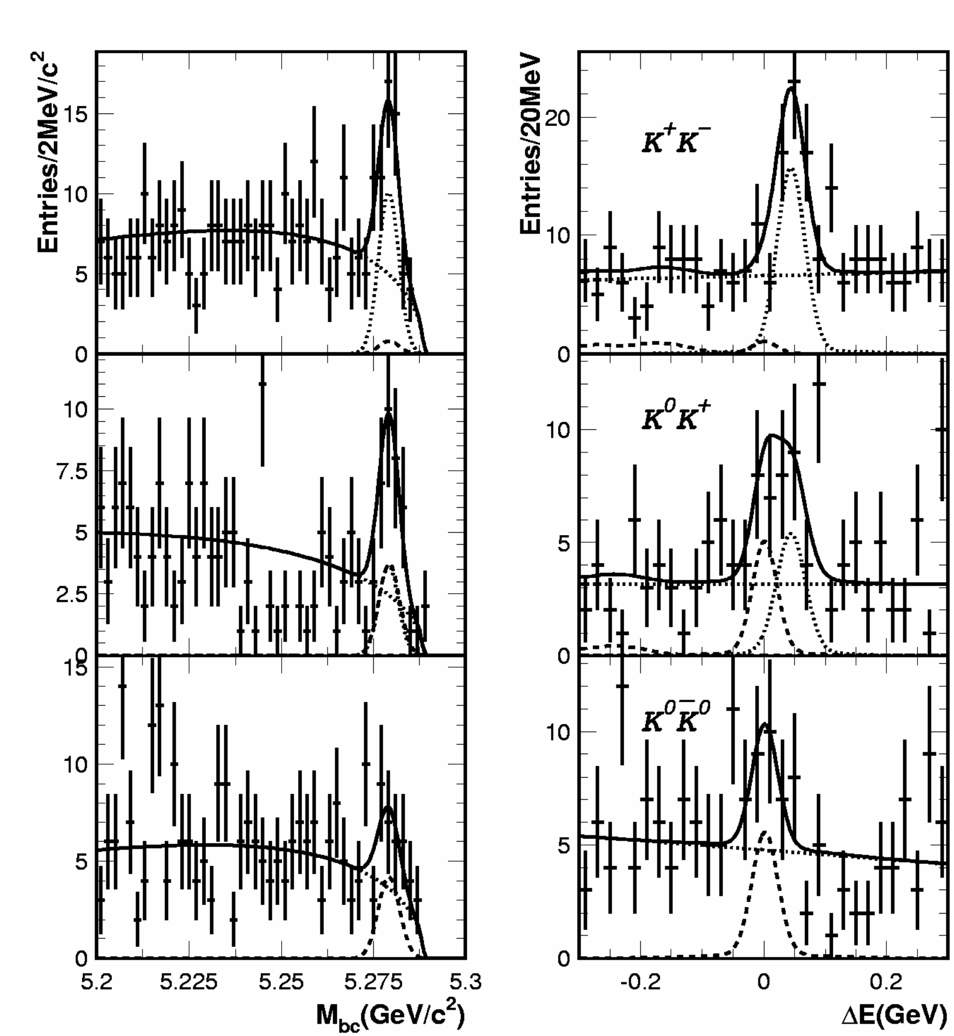
$$B(\overline{B}\to(\rho,\omega)\gamma) \equiv B(B^-\to\rho^-\gamma) = 2\times\frac{\tau_{B^+}}{\tau_{B^0}}B(\overline{B^0}\to\rho^0\gamma) = 2\times\frac{\tau_{B^+}}{\tau_{B^0}}B(\overline{B^0}\to\omega\gamma)$$

using $\frac{\tau_{B^+}}{\tau_{B^0}} = 1.076 \pm 0.008$

Addresses the same physics issue as B_s- B_s mixing (future Tevatron RunII +LHCb goal).

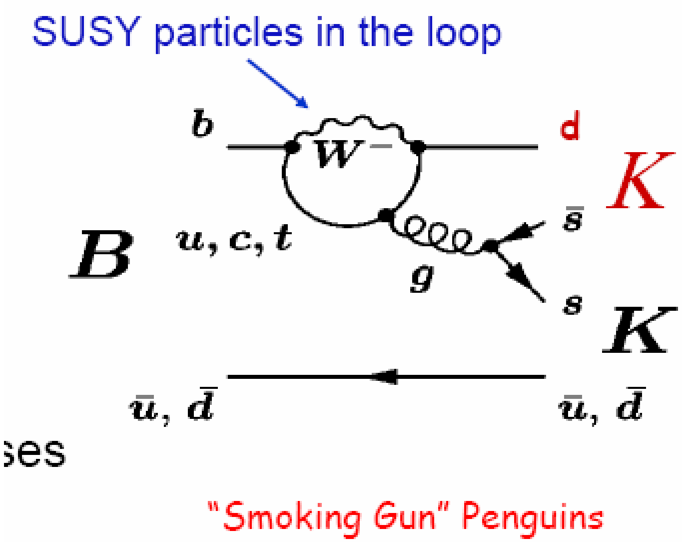
Evidence for B→$\bar{K}^0$ K (hadronic b→d s $\bar{s}$ processes)

hep-ex/0506080, PRL 95, 231802(2005)



Belle@250 fb^{-1}

Mode	Yield	Eff.(%)	Eff.×$\mathcal{B}_s$ (%)	$\mathcal{B}(10^{-6})$	Sig.
K^+K^-	$2.5^{+5.1+1.1}_{-4.1-0.6}$	15.5	15.5	< 0.37	0.5
K^0K^+	13.3 ± 5.6	14.5	5.0	$1.0 \pm 0.4 \pm 0.1$	3.0
$K^0\bar{K}^0$	15.6 ± 5.8	28.7	6.8	$0.8 \pm 0.3 \pm 0.1$	3.5



ses

Measurements of B→ K⁰ K⁰ CPV at Super B will be possible.

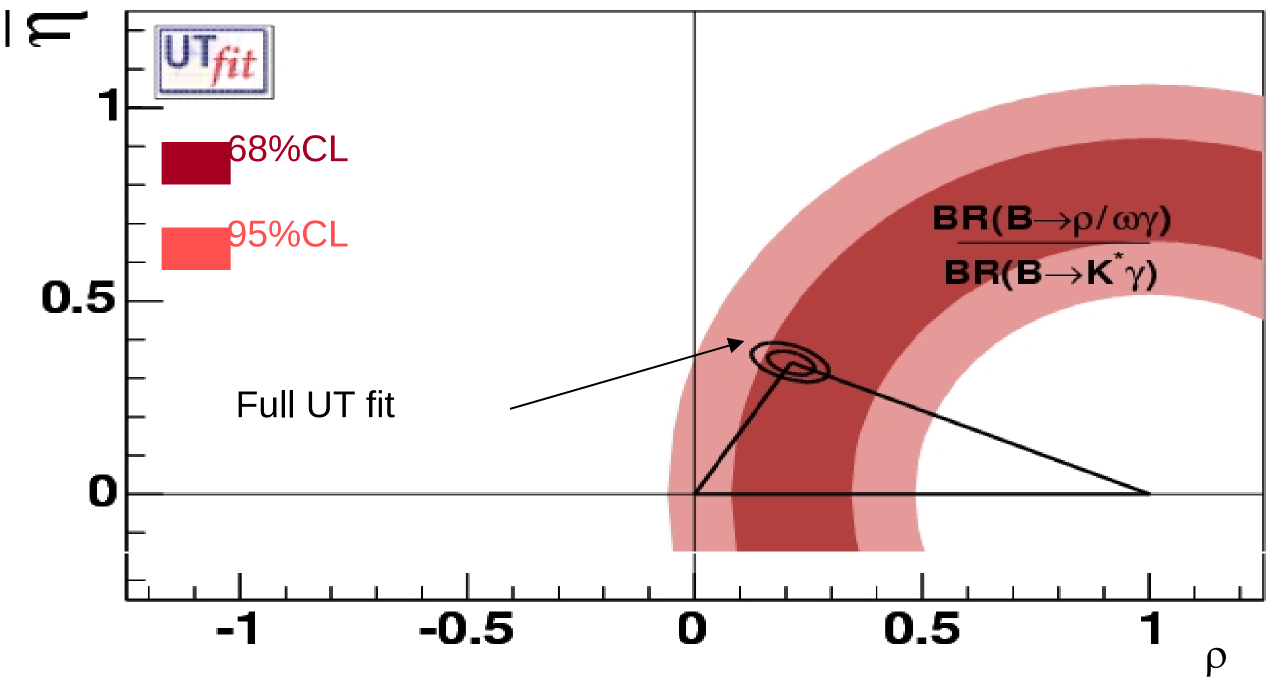
Implications of Belle's observation of b→d γ

Together with the evidence of $B \to \bar{K}^0 K$ modes, ***Belle has demonstrated the existence of a new quark level transition:*** *b→d*

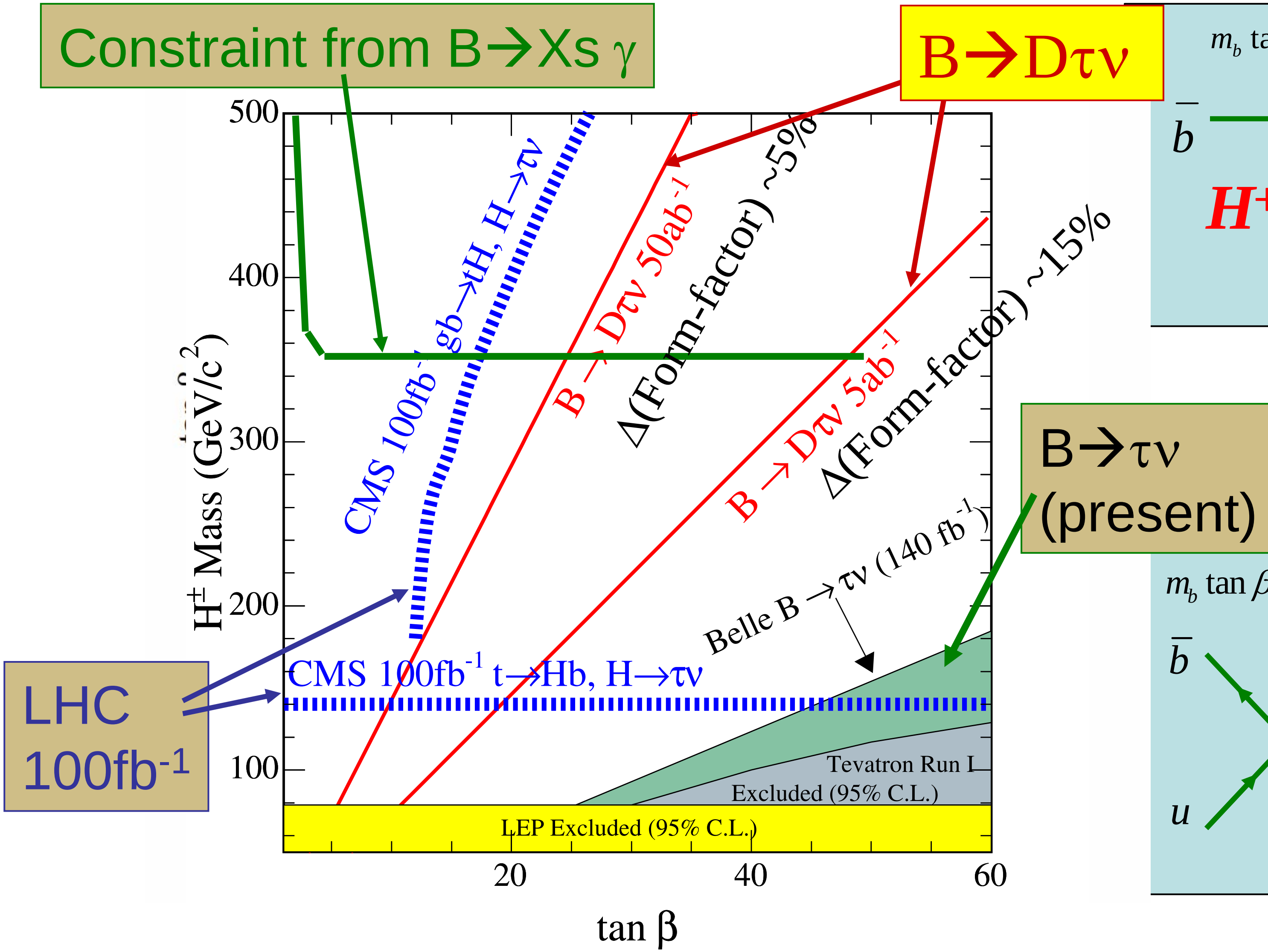
$$\frac{\mathrm{BR}(B \to (\rho/\omega)\gamma)}{\mathrm{BR}(B \to K^*\gamma)} \propto \left|\frac{V_{td}}{V_{ts}}\right|^2$$

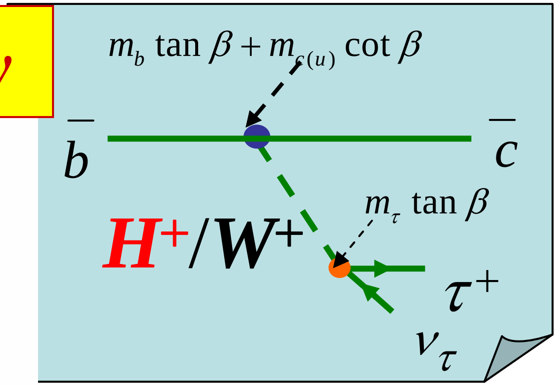
SU(3) breaking correction

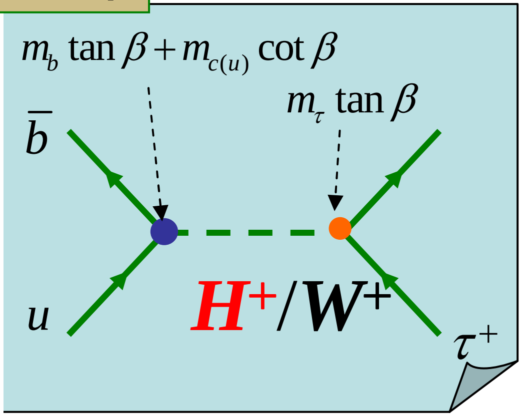
weak annihilation diagram for $BR(B \to \rho/\omega\,\gamma)$



Sensitivity for Charged Higgs

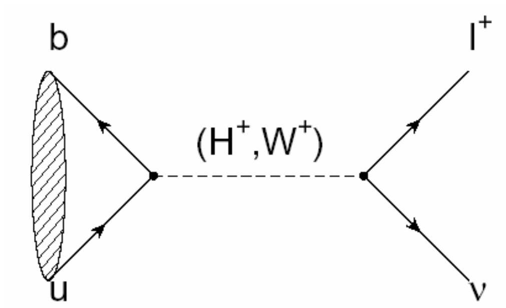




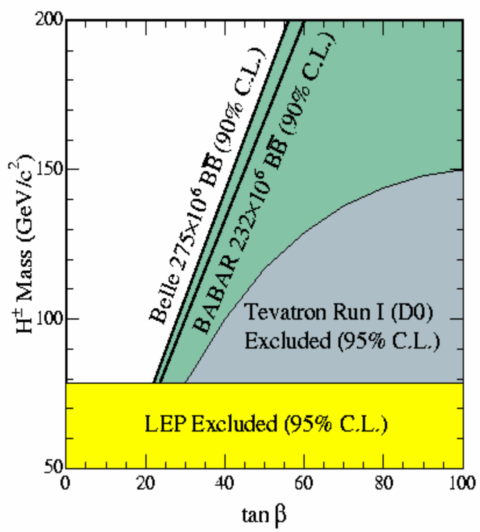


hep-ex/0507034

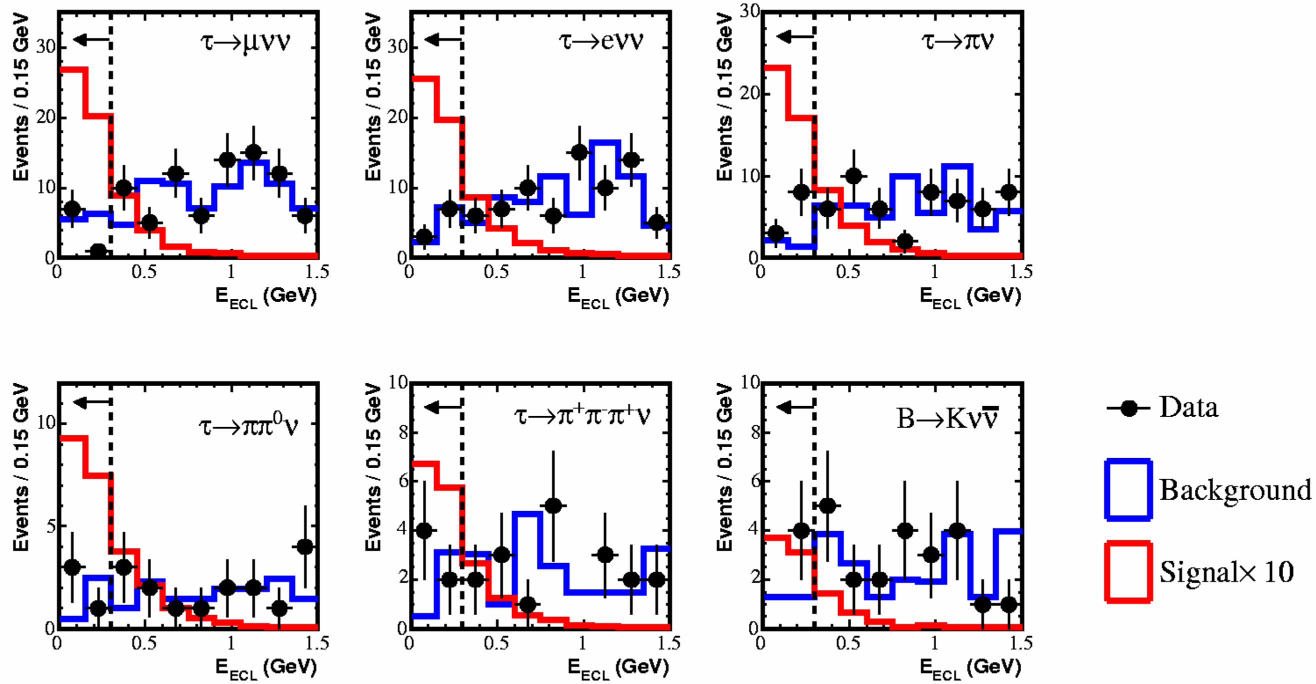
Search for $B \to \tau\nu$ and $B \to K\nu\bar{\nu}$ with 250 fb^{-1} of Belle data



Limits on 2-Higgs Models



Extra energy opposite a fully reconstructed B

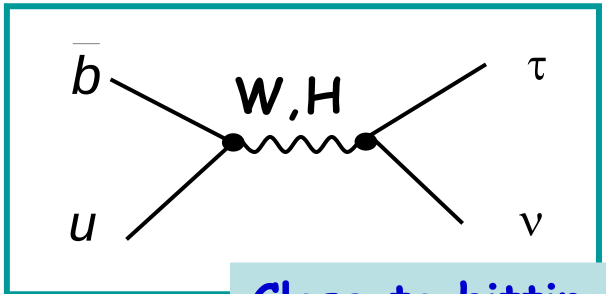


$$BF(B \to \tau\nu) < 1.8 \times 10^{-4}$$ (Expected level 0.9 x 10^{-4})

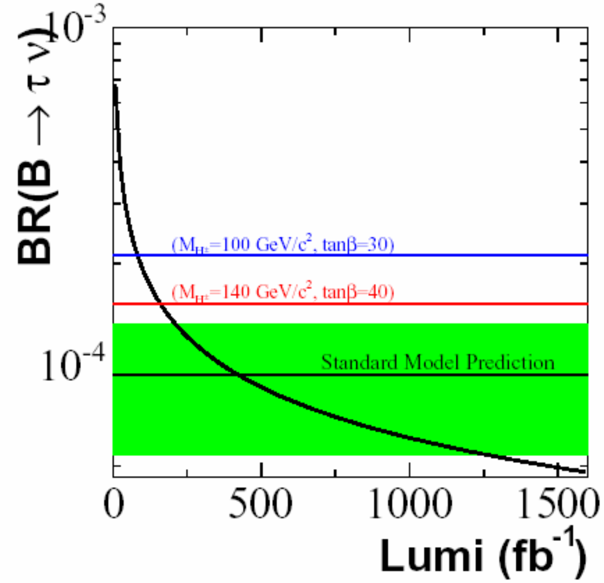
$$BF(B \to K\nu\nu) < 3.6 \times 10^{-4}$$ (SM expected ~3.8 x 10^{-6})

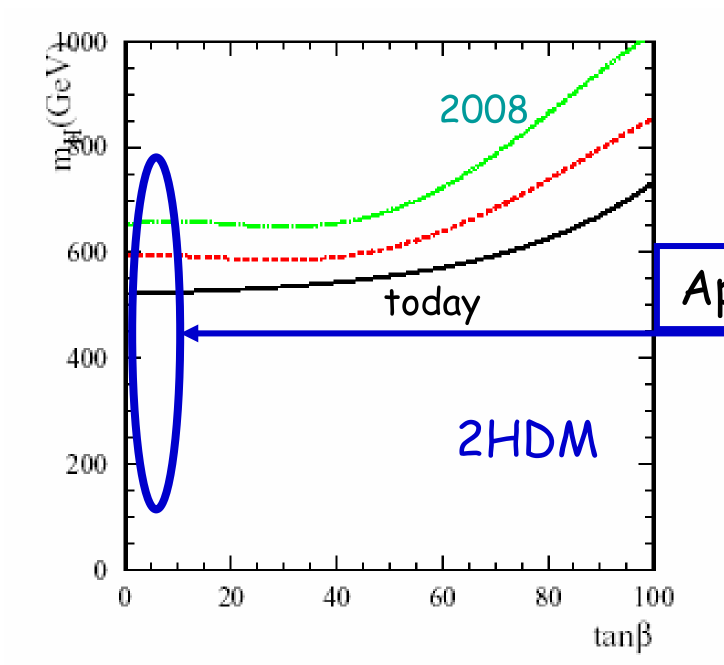
R.Faccini

B→τν

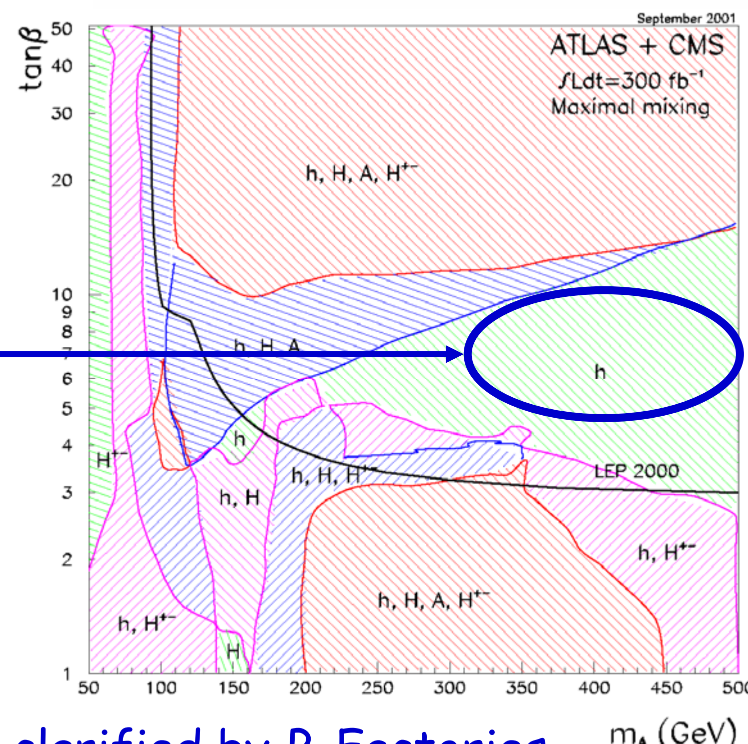


Close to hitting the SM prediction





Approx…



Uncertain regions could be clarified by B-Factories

- depends on all other SUSY parameters …