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# Recent results and future plans of the B factory Belle

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December 16, 2005

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Experimental apparatus: Belle at KEK-B

CP violation in the B system

Searching for New Physics: FCNC processes

- Observation of  $b \rightarrow d$  penguins:  $B \rightarrow \rho\gamma, \omega\gamma$  decays
- CP violation in  $b \rightarrow s$  decays
- $A_{fb}$  vs  $q^2$  in  $B \rightarrow K^* l^+ l^-$  decays

Plans for the future: a Super B factory

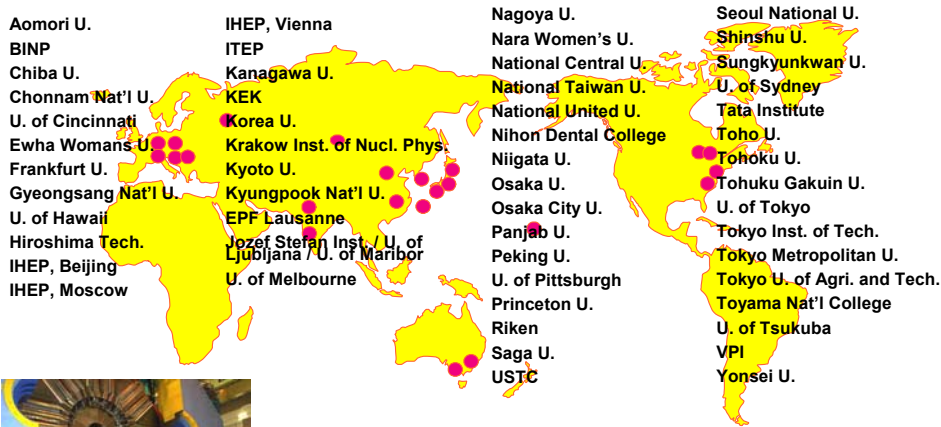
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# Belle Collaboration



13 countries, 55 institutes, ~400 collaborators

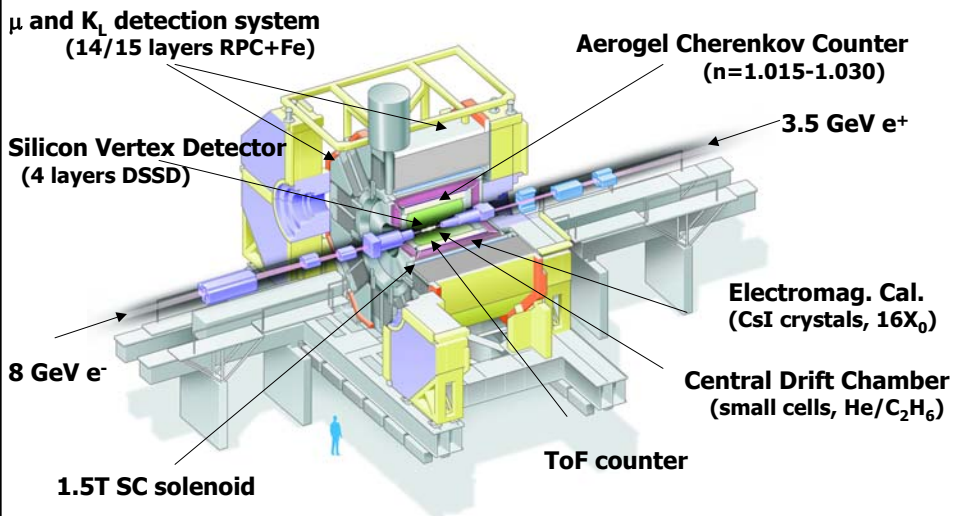
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# Belle spectrometer at KEK-B



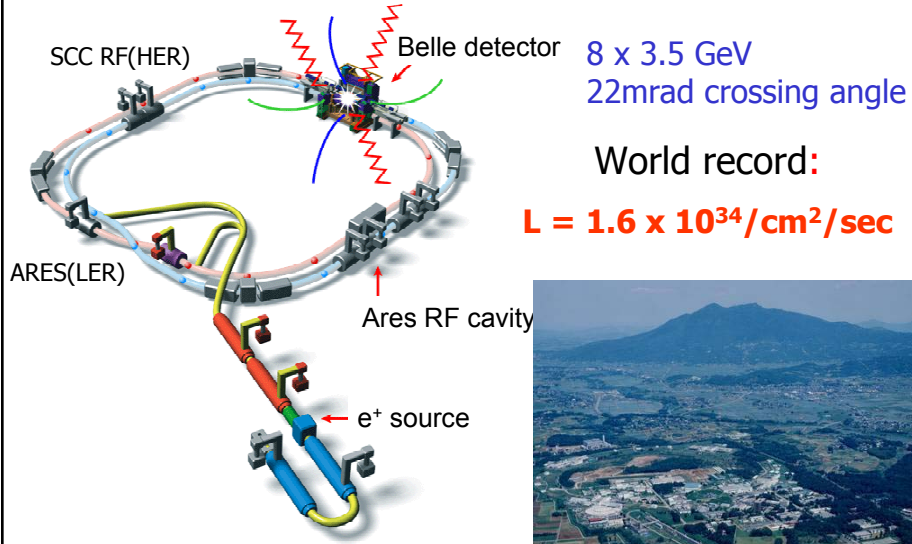
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# The KEKB Collider



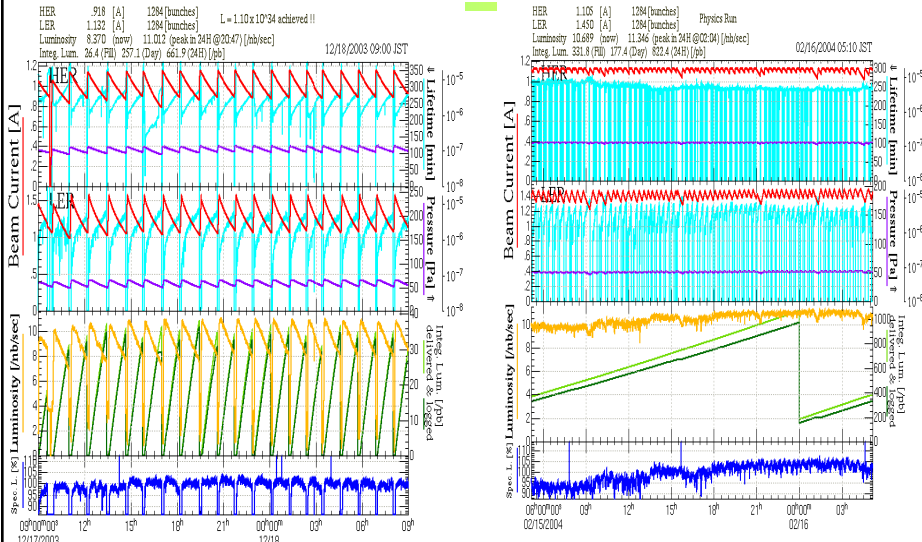
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## Normal injection

## Continuous injection



**661/pb/day**

**→ 1182/pb/day**

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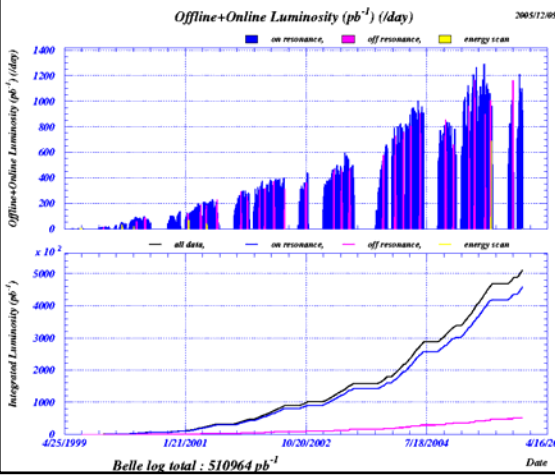
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# Belle/KEKB Luminosity Milestone: $500 \text{ fb}^{-1} = 0.5 \text{ ab}^{-1}$

Accumulated > 500 M BB-pairs



←  $1 \text{ fb}^{-1}/\text{day}$

**Total =  $512 \text{ fb}^{-1}$**

Today: some results with  $350 \text{ fb}^{-1}$   
( $386 \times 10^6$ ) B B pairs

as well as results based on  $253 \text{ fb}^{-1}$   
( $275 \times 10^6$ ) B B pairs

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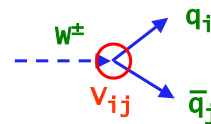
## B factory physics program

**B factory main task:** measure CP violation in the system of B mesons

specifically: various measurements of complex elements of  
Cabbibo-Kobayashi-Maskawa matrix

CKM matrix is unitary

deviations could signal processes not included in SM



$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\bar{\rho}-i\bar{\eta}) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\bar{\rho}-i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix}$$

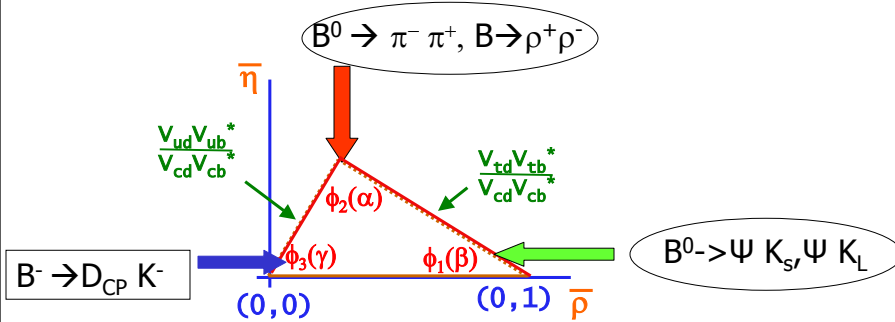
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## Three Angles: $(\phi_1, \phi_2, \phi_3)$ or $(\beta, \alpha, \gamma)$



Big Questions: *Are determinations of angles consistent with determinations of the sides of the triangle? Are angle determinations from loop and tree decays consistent?*

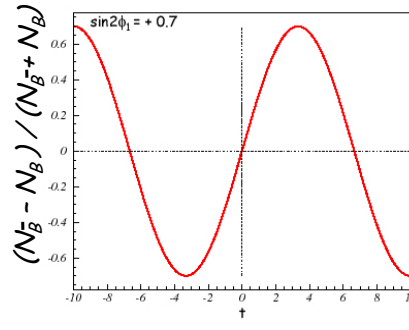
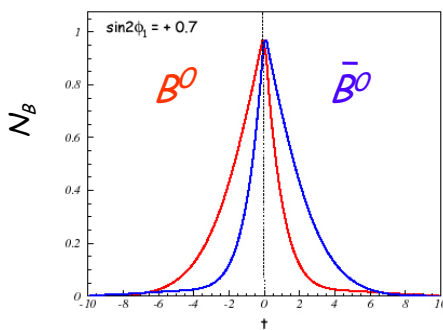
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## Mixing Induced CP Violation



$$\xrightarrow{\text{red arrow}} A_{CP}(t) = \frac{\Gamma(\bar{B}^0(t) \rightarrow f_{CP}) - \Gamma(B^0(t) \rightarrow f_{CP})}{\Gamma(\bar{B}^0(t) \rightarrow f_{CP}) + \Gamma(B^0(t) \rightarrow f_{CP})} = \xi_f \sin 2\phi \sin \Delta m_B t$$

$\xi_f = \pm 1$  for  $CP = \pm 1$

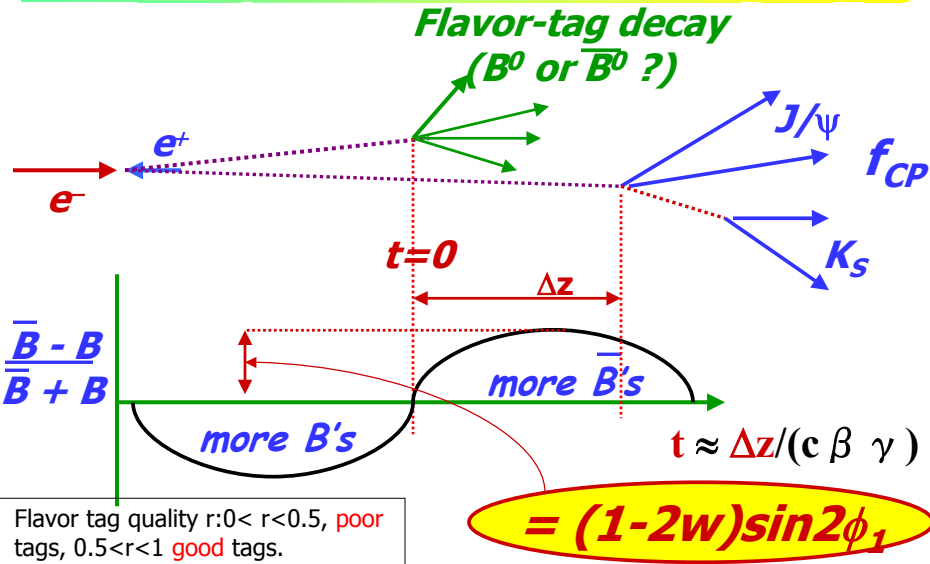
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# Principle of CPV Measurement



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If there is **more than one diagram** and additional weak phases, there is the possibility of **direct CPV** and a new term with a  $\cos(\Delta m \Delta t)$  time dependence.

$$P(B \rightarrow f_{CP}; \Delta t) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B} [1 + q \cdot \{A \cos(\Delta m \Delta t) + S \sin(\Delta m \Delta t)\}]$$

with  $q = \pm 1$

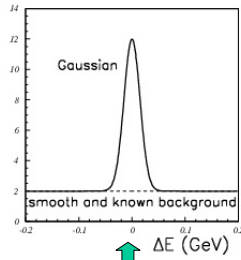
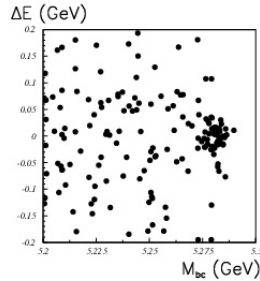
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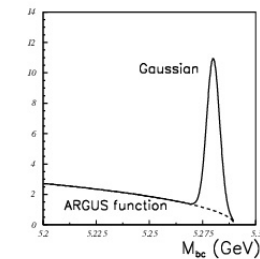
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# Reconstruction of B meson decays



Reconstructing rare B meson decays at Y(4s): use two variables, **beam constrained mass  $M_{bc}$**  and **energy difference  $\Delta E$**



$$\Delta E \equiv \sum E_i - E_{CM}/2$$

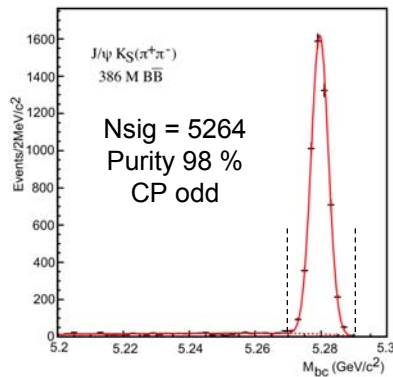
$$M_{bc} = \sqrt{(E_{CM}/2)^2 - (\sum \vec{p}_i)^2}$$

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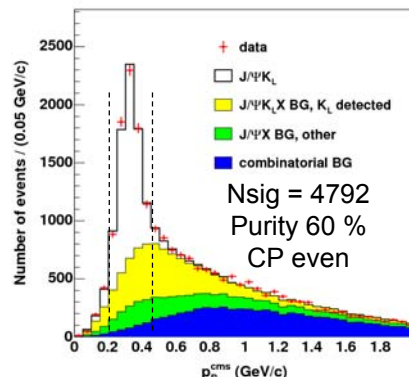
# 2005: $B^0 \rightarrow J/\psi \bar{K}^0$ with 386 M $B\bar{B}$ pairs

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



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

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

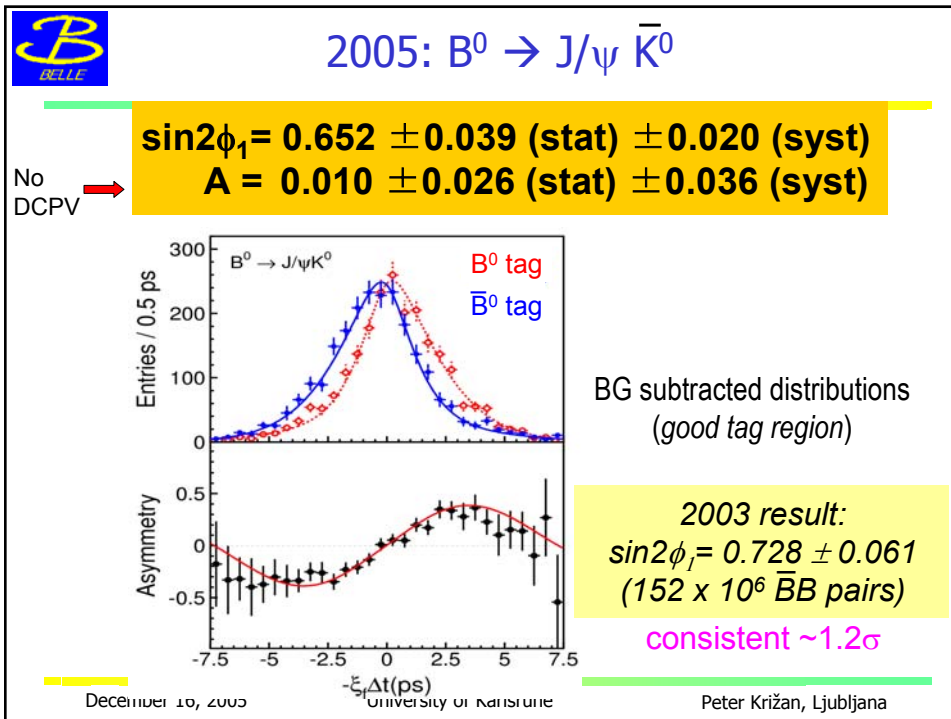
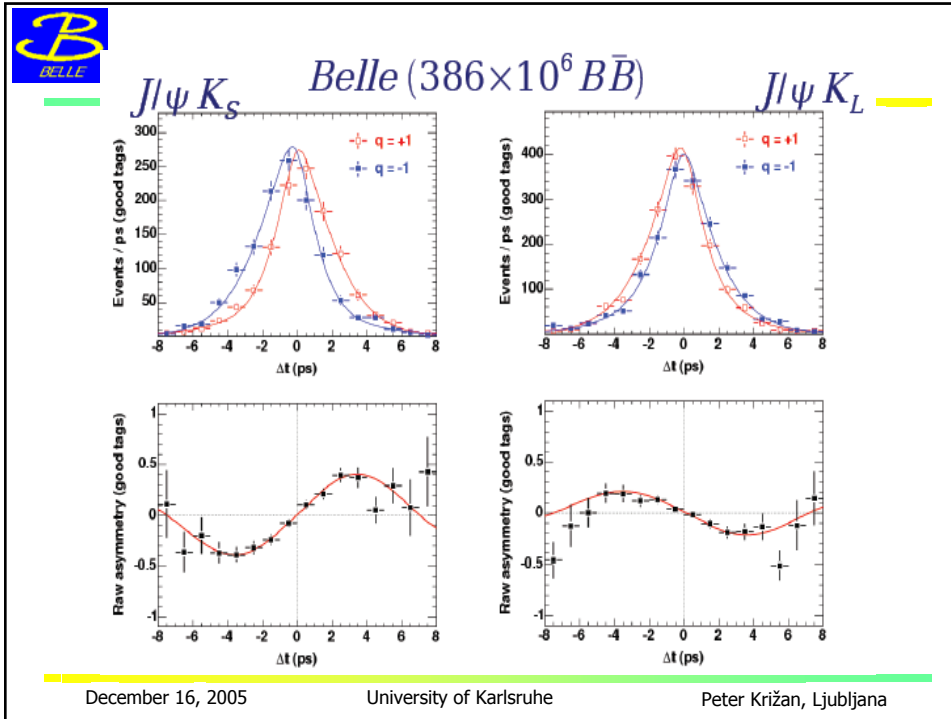


$p_B^*$  (momentum in CM)

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## Evidence and Observation of Direct CP Violation in B Decays

DCPV in  $B^0 \rightarrow \pi^+ \pi^-$  and  $B^0 \rightarrow K^- \pi^+$ ,

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

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

*hep-ex/0509001*

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## Importance of direct CPV in B decays

*"The final, completely definitive death of any superweak theory will come from the observation of direct CP violation in the B system....."*

Evidence for such direct CP violation would be given by the difference between the asymmetry parameters in a decay such as  $B \rightarrow \pi^+ \pi^-$  from that of  $B \rightarrow J/\psi K_S$ . This can be considered the  $\epsilon'$  experiment for the B system."

*Lincoln Wolfenstein, 1999*

[All CPV in the B system is due to a new superweak interaction. Expect no CPV in  $\Delta B=1$  transitions. ]

[e.g. J.M. Soares +L.Wolfenstein, PRD 47,421 1993.]

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# Direct CPV asymmetry in B Decays

## Asymmetry in B decay rates

$$A_{dir} \equiv \frac{\Gamma(\bar{B} \rightarrow \bar{f}) - \Gamma(B \rightarrow f)}{\Gamma(\bar{B} \rightarrow \bar{f}) + \Gamma(B \rightarrow f)}$$

$$= \frac{2r \sin \phi \sin \delta}{1 + r^2 + 2r \cos \phi \cos \delta}$$

$r = |P|/|T|$ ,  $\phi = \text{weak phase diff}$   
 $\delta = \text{strong phase diff}$

The direct CP asymmetry ( $A_{dir}$ ) can be large if two amplitudes have comparable sizes, **different weak phases as well as a strong phase difference**. This can happen in certain B decays due to the interference of penguin (P) and tree (T) decays.

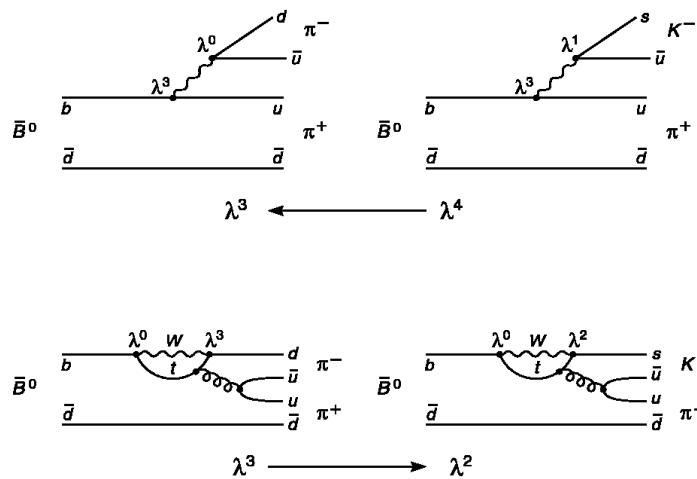
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## Hierarchy of diagrams for $B \rightarrow K\pi, \pi\pi$ decays



**Possibility of tree-penguin interference.**

**N.B. in  $B \rightarrow \pi\pi$  the two diagrams are the same order in  $\lambda$**

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# Experimental Situation for $B \rightarrow \pi^+ \pi^-$ in 2004



**Belle** 152 M  $\bar{B}B$

with  $372 \pm 32$   $B^0 \rightarrow \pi^+ \pi^-$  events

$$S_{\pi\pi} = -1.00 \pm 0.21 \pm 0.07$$

$$A_{\pi\pi} = +0.58 \pm 0.15 \pm 0.07$$

PRL 93, 021601 (2004)

**5.2 $\sigma$  CPV,**

**First evidence for DCPV (3.2 $\sigma$ )**



**BABAR** 227M  $\bar{B}B$

with  $467 \pm 33$   $B^0 \rightarrow \pi^+ \pi^-$  events

$$S_{\pi\pi} = -0.30 \pm 0.17 \pm 0.03$$

$$A_{\pi\pi} = +0.09 \pm 0.15 \pm 0.04$$

hep-ex/0501071, to appear in PRL

Also  $\sim 3.2s$  discrepancy between Belle and BaBar

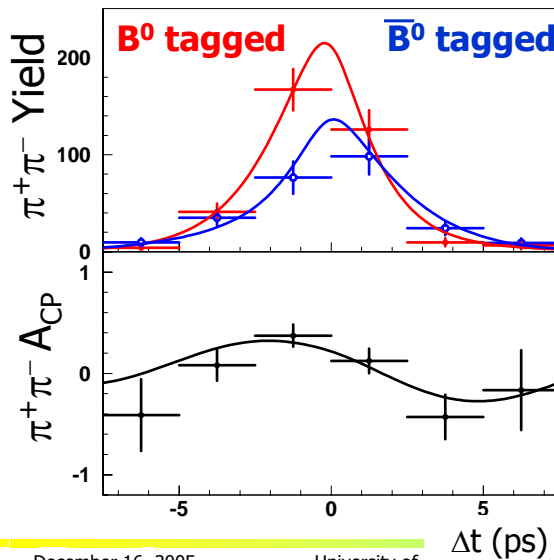
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# $B \rightarrow \pi^+ \pi^-$ time evolution



$666 \pm 43$   $B \rightarrow \pi^+ \pi^-$  signal events

$\Delta E$ -Mbc 2D fits to individual time intervals

**Bkg subtracted fit** projections for  $B \rightarrow \pi^+ \pi^-$

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## Summary of Belle $B^0 \rightarrow \pi^+ \pi^-$ CPV results

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

1st error statistical,  
2nd systematic

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

- Compelling evidence for direct CP violation in  $B \rightarrow \pi^+ \pi^-$  with  $4.0\sigma$  significance
- Confirms previous Belle results.
- Isospin analysis for this mode alone gives (95.4% C.L)  $0^\circ < \phi_2 < 19^\circ$  &  $71^\circ < \phi_2 < 180^\circ$

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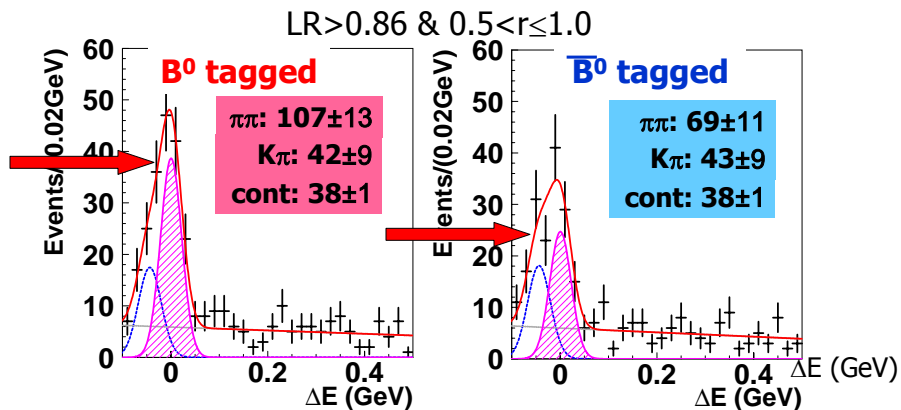
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## Consistency Checks with time-integrated fits

$$A_{\pi\pi} = +0.52 \pm 0.14$$

Counting experiment consistent with unbinned time-dependent fits.

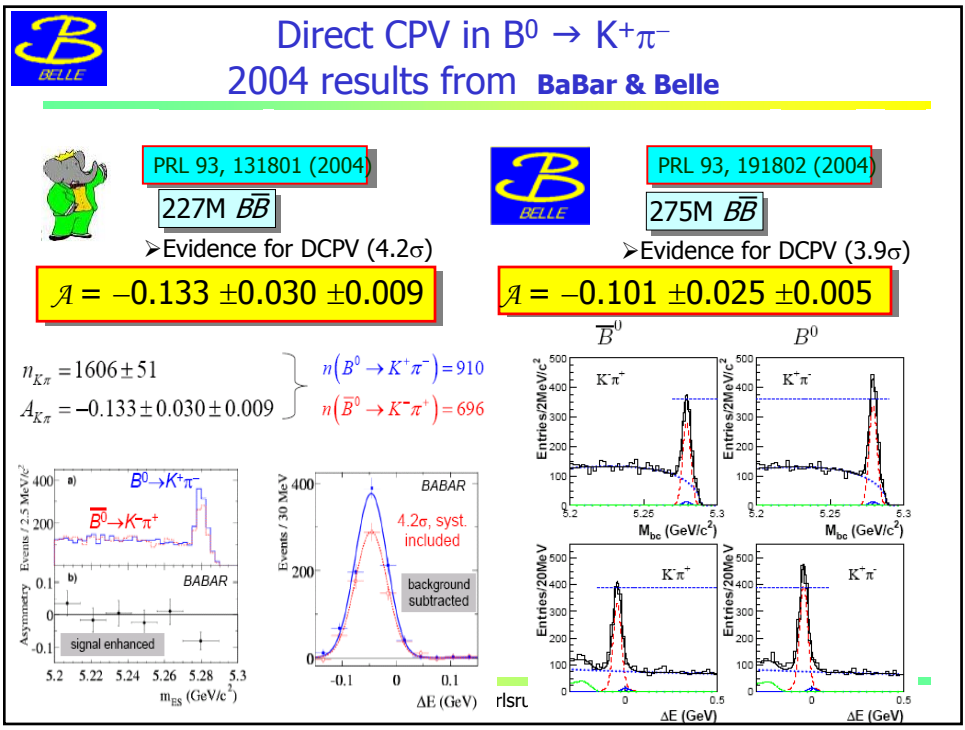
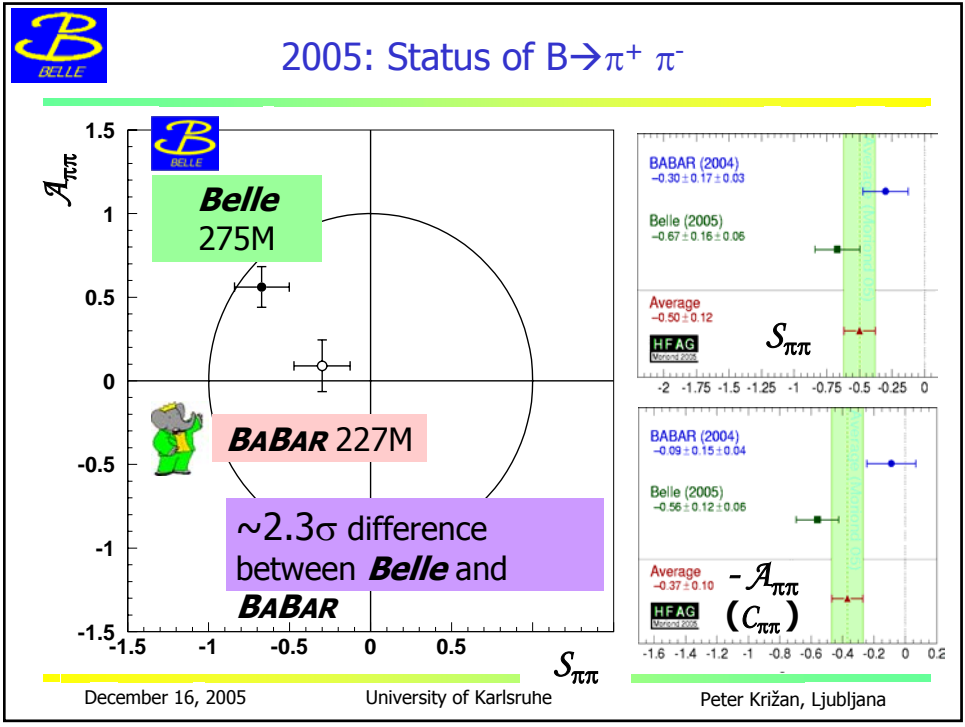


Visible indication of direct CP violation.

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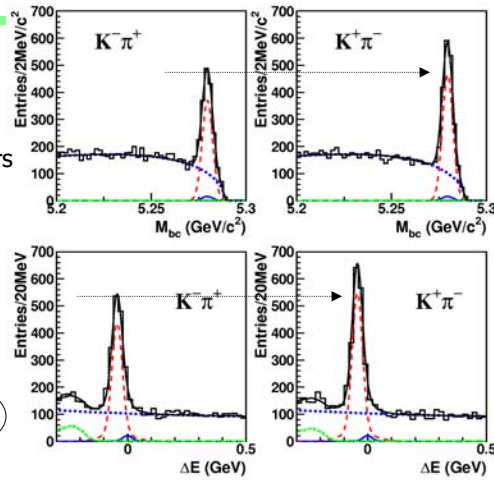
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## 2005: "Observation" of Direct CPV in $B \rightarrow K\pi$

Belle update with  
 $386 \times 10^6$  B Bbar pairs  
 (hep-ex/0507045)



Significance  
 $5.0 \sigma$

One more nail in the  
 Superweak coffin.

$$A_{CP}(K^+\pi^-) \equiv \frac{N(\bar{B} \rightarrow K^-\pi^+) - N(B \rightarrow K^+\pi^-)}{N(\bar{B} \rightarrow K^-\pi^+) + N(B \rightarrow K^+\pi^-)} = 0.113 \pm 0.022 \pm 0.008.$$

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## 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

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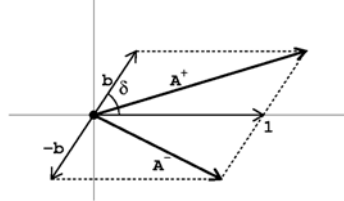
## A new approach to direct CPV using the Dalitz plot in $B^\pm \rightarrow K^\pm \pi^+ \pi^-$ (hep-ex/0509001)

Sample used for  $B^\pm \rightarrow K^\pm \pi^+ \pi^-$  study:

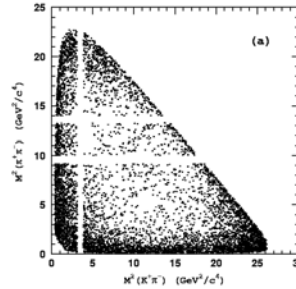
contains  $2248 \pm 79 B^-$ ,  $2038 \pm 76 B^+$

Fix the resonant substructure, then allow both the phase and amplitude to be different for  $B^+$  and  $B^-$  decays.

For each resonant amplitude replace  $ae^{i\delta}$  with  $ae^{i\delta}(1 \pm b e^{i\phi})$



Combined Dalitz plot, signal region



De FIG. 9: Illustration of the amplitude parametrization with Eq. 7.

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## Evidence for CP Violation in the Decay $B^\pm \rightarrow \rho^0 K^\pm$

TABLE I: Results of the best fit to  $K^\pm \pi^\pm \pi^\mp$  events in the  $B$  signal region. The first quoted error is statistical and the second is the model dependent uncertainty. The quoted  $A_{CP}$  significance is statistical only.

Channel	Fraction (%)	$\delta$ ( $^\circ$ )	$b$	$\varphi$ ( $^\circ$ )	$A_{CP}$ significance ( $\sigma$ )
$K^*(892)\pi^\pm$	$13.0 \pm 0.8^{+0.5}_{-0.7}$	0 (fixed)	$0.078 \pm 0.033^{+0.012}_{-0.003}$	$-18 \pm 44^{+5}_{-12}$	2.6
$K_0^*(1430)\pi^\pm$	$65.5 \pm 1.5^{+2.2}_{-3.9}$	$55 \pm 4^{+1}_{-5}$	$0.069 \pm 0.031^{+0.010}_{-0.008}$	$-123 \pm 16^{+4}_{-5}$	2.7
$\rho(770)^0 K^\pm$	$7.85 \pm 0.93^{+0.64}_{-0.59}$	$-21 \pm 14^{+14}_{-19}$	$0.28 \pm 0.11^{+0.07}_{-0.09}$	$-125 \pm 32^{+10}_{-85}$	3.9
$\omega(782)K^\pm$	$0.15 \pm 0.12^{+0.03}_{-0.02}$	$100 \pm 31^{+38}_{-21}$	0 (fixed)	-	-
$f_0(980)K^\pm$	$17.7 \pm 1.6^{+1.1}_{-3.3}$	$67 \pm 11^{+10}_{-11}$	$0.30 \pm 0.19^{+0.05}_{-0.10}$	$-82 \pm 8^{+2}_{-4}$	1.6
$f_2(1270)K^\pm$	$1.52 \pm 0.35^{+0.22}_{-0.37}$	$140 \pm 11^{+18}_{-7}$	$0.37 \pm 0.17^{+0.11}_{-0.04}$	$-24 \pm 29^{+14}_{-20}$	2.7
$f_X(1300)K^\pm$	$4.14 \pm 0.81^{+0.31}_{-0.30}$	$-141 \pm 10^{+8}_{-9}$	$0.12 \pm 0.17^{+0.04}_{-0.07}$	$-77 \pm 56^{+88}_{-43}$	1.0
Non-Res.	$34.0 \pm 2.2^{+2.1}_{-1.8}$	$\delta_1^{nr} = -11 \pm 5^{+3}_{-3}$ $\delta_2^{nr} = 185 \pm 20^{+62}_{-19}$	0 (fixed)	-	-
$\chi_{c0} K^\pm$	$1.12 \pm 0.12^{+0.24}_{-0.08}$	$-118 \pm 24^{+37}_{-38}$	$0.15 \pm 0.35^{+0.08}_{-0.07}$	$-77 \pm 94^{+154}_{-11}$	0.7

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

Significance varies from  $3.7\sigma$  to  $4.0\sigma$  depending on the model for the resonant substructure (add or remove modes, change nr model, cpv in  $b \rightarrow u$  background).

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## Evidence for CP Violation in the Decay $B^\pm \rightarrow \rho^0 K^\pm$

B- vs B+ in the  $\rho$  and  $f^0$  (980)  $m_{\pi\pi}$  region

- helicity hemisphere

+helicity hemisphere

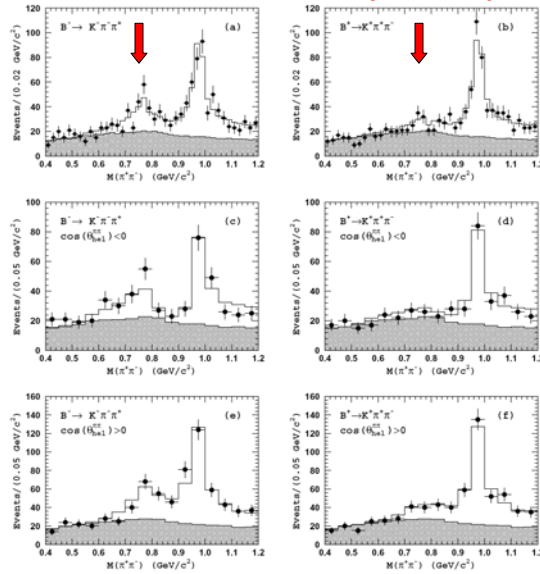


FIG. 7:  $M(\pi^+\pi^-)$  mass spectra for  $B^-$  (left column) and  $B^+$  (right column) for different helicity regions: (a,b) no helicity cuts; (c,d)  $\cos\theta_H^+ < 0$ ; (e,f)  $\cos\theta_H^+ > 0$ . Points with error bars are data, the open histogram is the fit result and the hatched histogram is the background component.

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## Comparison of result to predictions and BaBar

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



First evidence for DCPV in a charged meson decay

Cheng, Gronau, Luo, Rosner, Suprun; PRD 69, 034001 (2004)

$$A_{CP}(B^\pm \rightarrow \rho^0 K^\pm) = 0.21 \pm 0.10$$

M. Beneke and M. Neubert; Nucl. Phys. B675, 333 (2003)

$$A_{CP}(B^\pm \rightarrow \rho^0 K^\pm) = -13.6^{+4.5+6.9+3.7+62.7}_{-5.7-4.4-3.1-55.4} \%$$

Four representative scenarios (-27.3, -9.3, 26.6, 31.7)%

BaBar Data:  $A_{CP}(B^\pm \rightarrow \rho^0 K^\pm) = 0.32 \pm 0.13 \pm 0.06^{+0.08}_{-0.05} \quad (2.4\sigma)$

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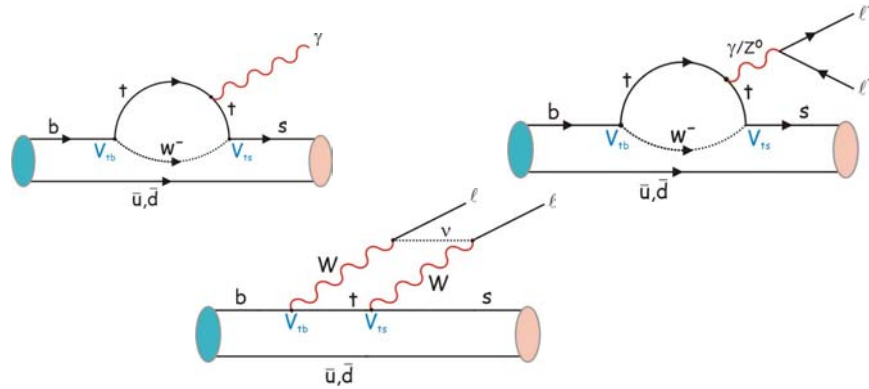
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## Why FCNC decays?

Flavour changing neutral current (FCNC) processes (like  $b \rightarrow s$ ,  $b \rightarrow d$ ) are forbidden at the tree level in the Standard Model. Proceed only at low rate via higher-order loop diagrams. Ideal place to search for new physics.



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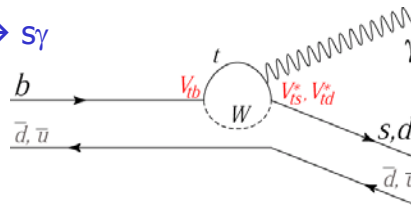
## A large number of $b \rightarrow s$ modes are known, where are the $b \rightarrow d$ penguins ?

Suppressed by  $|V_{td}/V_{ts}|^2$  vs  $b \rightarrow s\gamma$

Interesting:

Measurement of  $|V_{td}/V_{ts}|$

CP violation could be sizeable in SM (order 10%)



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

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

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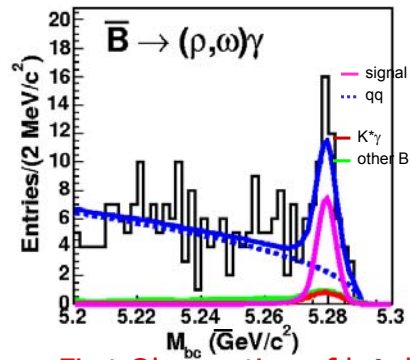
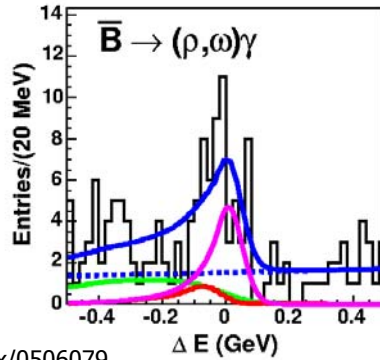


## $V_{td}/V_{ts}$ from $B \rightarrow \rho\gamma, \omega\gamma$

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



hep-ex/0506079

First Observation of  $b \rightarrow d \gamma$

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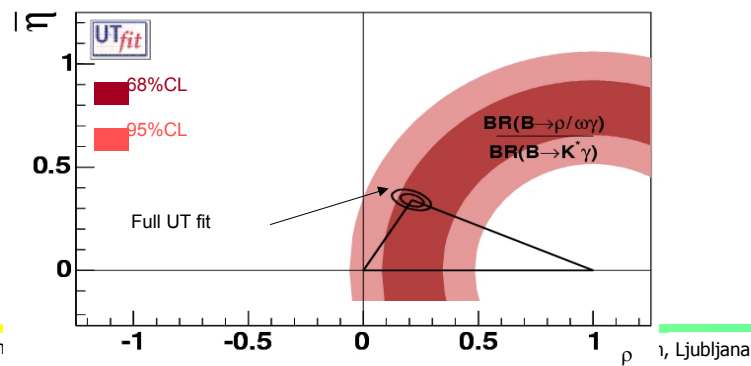
## Implications of Belle's observation of $b \rightarrow d \gamma$

Together with the evidence of  $B \rightarrow K^0 K$  modes, Belle has demonstrated the existence of a new quark level transition:  $b \rightarrow d$

+ measurement of  $|V_{td}/V_{ts}|$

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

SU(3) breaking correction  
weak annihilation diagram for  $\text{BR}(B \rightarrow \rho/\omega\gamma)$



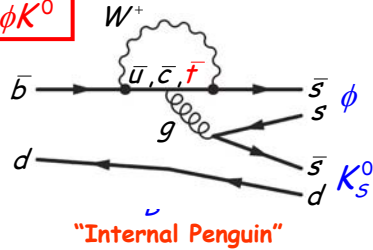
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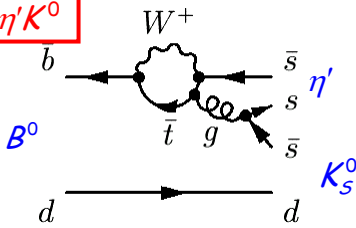


## How New Physics can contribute to $b \rightarrow s$

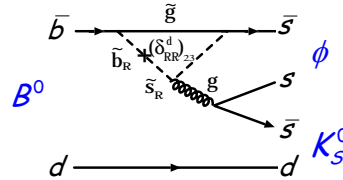
$B^0 \rightarrow \phi K^0$



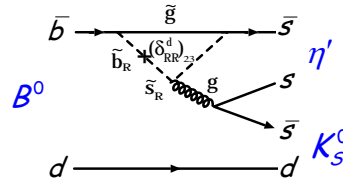
$B^0 \rightarrow \eta' K^0$



**New physics in loops?**



**Many new phases are possible in SUSY**



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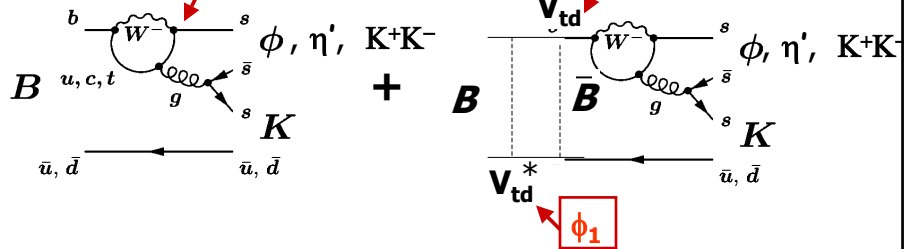
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## Searching for new physics phases in CP violation measurements in $b \rightarrow s$ decays

Example:

**no KM phase**



SM:  $\sin 2\phi_1^{\text{eff}} = \sin 2\phi_1$  from  $B \rightarrow J/\psi K^0$  ( $b \rightarrow c \bar{c} s$ )  
 unless there are other, non-SM particles in the loop

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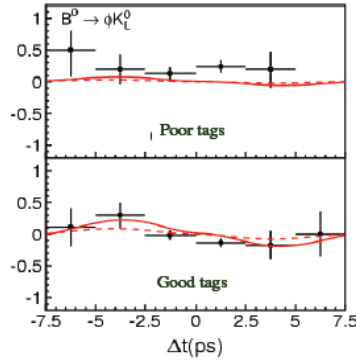
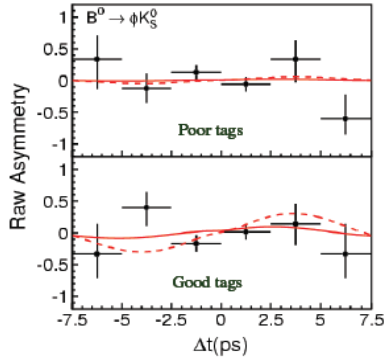
### Belle 2005 update:

hep-ex/0507037

$B \rightarrow \phi K^0 : K^0 \rightarrow K_S \text{ or } K_L$  ( $386 \times 10^6 B\bar{B}$  pairs)

$\phi K_S$

$\phi K_L$



$\sin 2\phi_1 = +0.19 \pm 0.32$

$\sin 2\phi_1 = +1.54 \pm 0.59$

$\sin(2\phi_1)(B \rightarrow \phi K^0) = 0.44 \pm 0.27 \pm 0.05$

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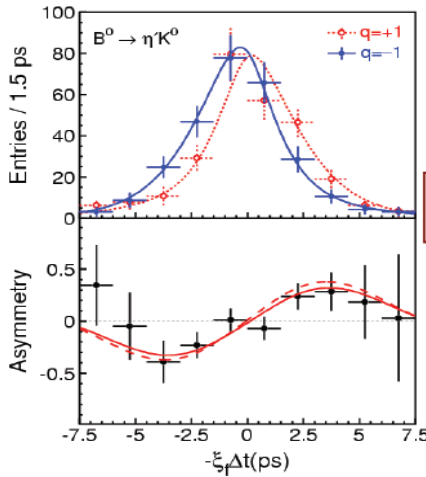
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### "Compelling Evidence" for CP Violation in a $b \rightarrow s$ mode

$\eta' K^0$  (background subtracted)



$\sin 2\phi_1 = +0.62 \pm 0.12 \pm 0.04$   
 $A = -0.04 \pm 0.08 \pm 0.06$

significance  $> 4\sigma$

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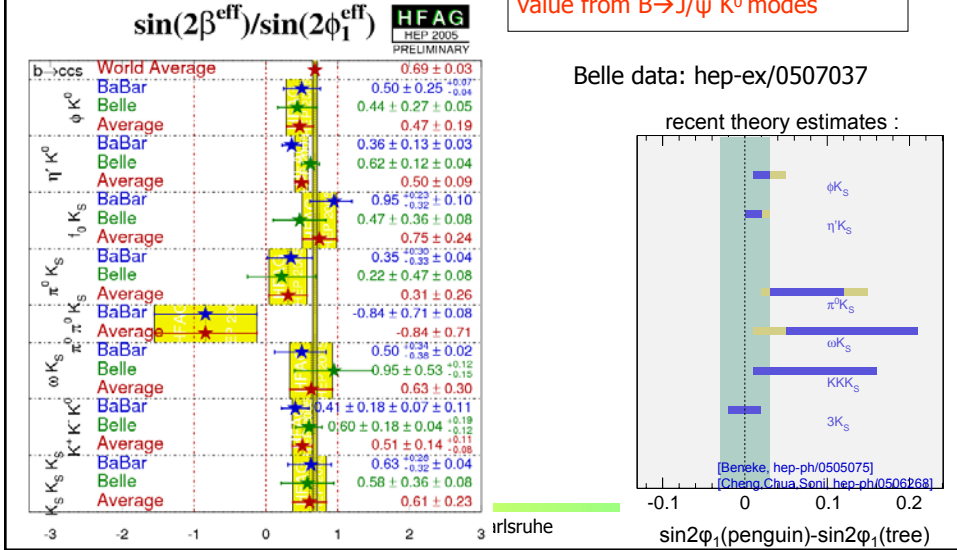
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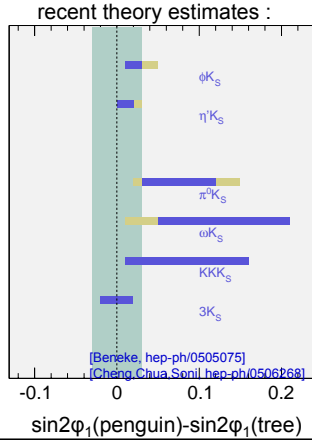


# Many b→s modes were studied:

~all are systematically below  $\sin(2\beta)$  value from  $B \rightarrow J/\psi K^0$  modes



Belle data: hep-ex/0507037

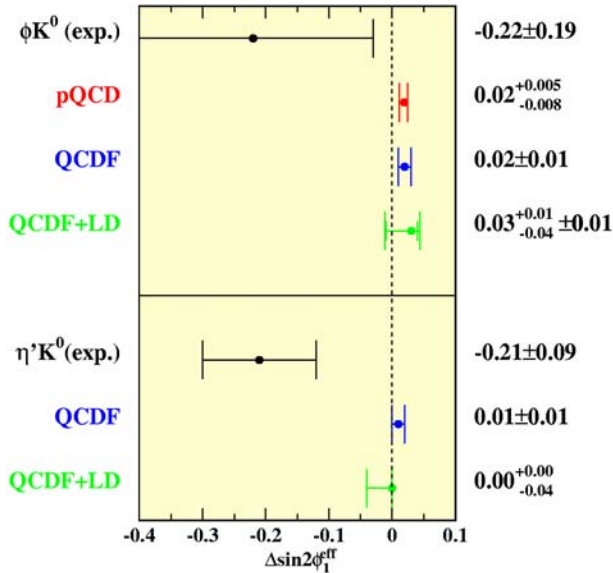


# New Physics ?

## $\Delta \sin 2\phi_1^{\text{eff}}$ in $b \rightarrow \bar{s}q\bar{q}$ golden modes (July 2005)

Very large effects of order unity,  $\Delta S=1$ , are now ruled out.

Theory corrections are small and opposite in sign to the measured deviations.



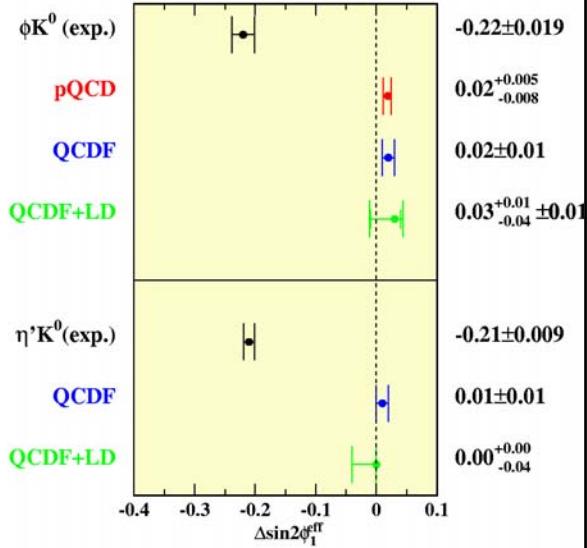
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### Projection for Super B Factory (50ab<sup>-1</sup>)

Are there New Physics effects of order 0.2 in b → s CPV ?

Super B Factory level statistics will allow us to answer this question.



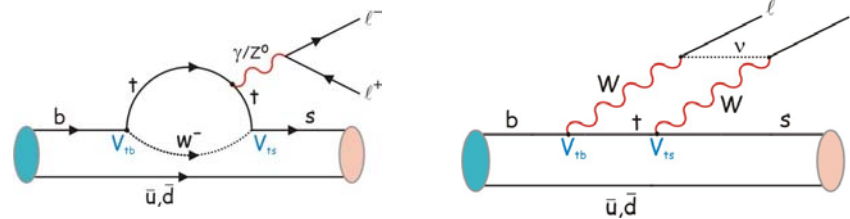
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### Another FCNC decay: $B \rightarrow K^* l^+ l^-$



$b \rightarrow s l^+ l^-$  was first measured in  $B \rightarrow K l^+ l^-$  by Belle (2001).

Important for further searches for the physics beyond SM

$$\frac{d\Gamma(b \rightarrow s l^+ l^-)}{d\hat{s}} = \left(\frac{\alpha_{em}}{4\pi}\right)^2 \frac{G_F^2 m_b^5 |V_{ts}^* V_{tb}|^2}{48\pi^3} (1-\hat{s})^2 \times \left[ (1+2\hat{s}) (|C_9^{eff}|^2 + |C_{10}^{eff}|^2) + 4 \left(1 + \frac{2}{\hat{s}}\right) |C_7^{eff}|^2 + 12 \text{Re}(C_7^{eff} C_9^{eff*}) \right]$$

Particularly sensitive: backward-forward asymmetry in  $K^* l^+ l^-$

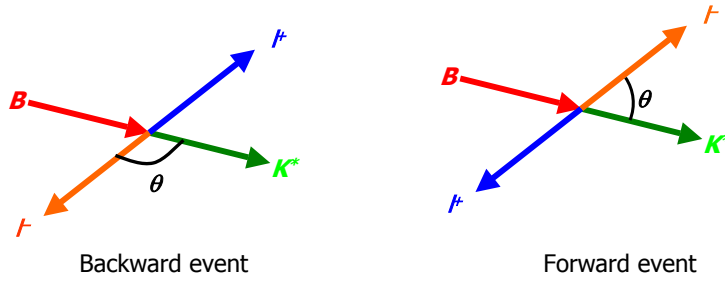
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$$A_{FB}(q^2) = \frac{\int_0^1 \frac{d^2\Gamma}{dq^2 d\cos\theta} d\cos\theta - \int_{-1}^0 \frac{d^2\Gamma}{dq^2 d\cos\theta} d\cos\theta}{\int_0^1 \frac{d^2\Gamma}{dq^2 d\cos\theta} d\cos\theta + \int_{-1}^0 \frac{d^2\Gamma}{dq^2 d\cos\theta} d\cos\theta}$$

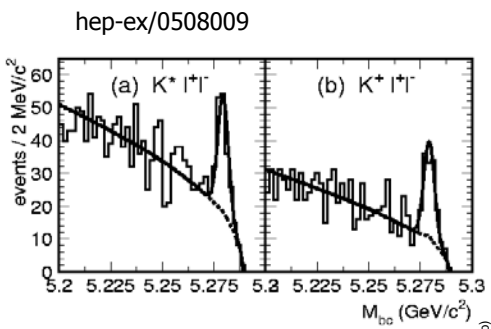


[ $\gamma^*$  and  $Z^*$  contributions in  $B \rightarrow K^* l l$  interfere and give rise to forward-backward asymmetries c.f.  $e^+e^- \rightarrow \mu^+ \mu^-$ ]

Unbinned fit to the variables  $q^2$  (di-lepton invariant mass) and  $\cos(\theta)$  for  $B \rightarrow K^* l l$  data



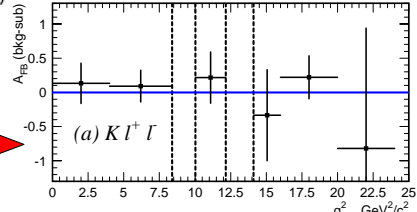
### 2005: Sample used for $A_{FB}(B \rightarrow K^* l l)(q^2)$



Sample for  $B \rightarrow K^* l l$  events  $113 \pm 13$   
 $B \rightarrow K^* l l$  control sample  $96 \pm 12$   
 Consistent with flat

$$P(q^2, \cos\theta; A_0/A_1, A_2/A_1) = f_{sig} \epsilon_{sig}(q^2, \cos\theta) \frac{d^2\Gamma}{dq^2 d\cos\theta}(q^2, \cos\theta) / N_{sig} + f_{ctct} \epsilon_{ctct}(q^2, \cos\theta) \frac{d^2\Gamma}{dq^2 d\cos\theta}(q^2, \cos\theta) / N_{ctct} + f_{fctct} \epsilon_{fctct}(q^2, \cos\theta) \frac{d^2\Gamma}{dq^2 d\cos\theta}(q^2, -\cos\theta) / N_{fctct} + f_{X, \ell} P_{X, \ell \ell}(q^2, \cos\theta) + f_{all} \{ (1 - f_{K^* l l}) P_{all}(q^2, \cos\theta) + f_{K^* l l} P_{K^* l l}(q^2, \cos\theta) \} + f_{K^* h h} P_{K^* h h}(q^2, \cos\theta) + f_{\psi} P_{\psi}(q^2, \cos\theta)$$

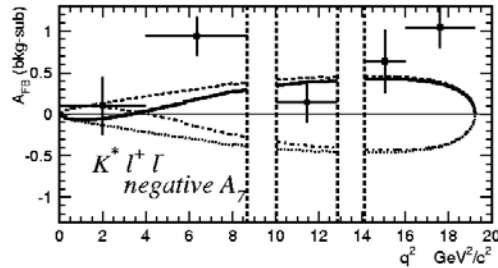
Treat  $q^2, \cos(\theta)$  dependence of bkg.





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

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



Integrated FB asymmetry

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

control sample:

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

Observed integrated  $A_{FB}$  rules out some radical New Physics Models with incorrect signs/magnitudes of  $C_9$  and  $C_{10}$

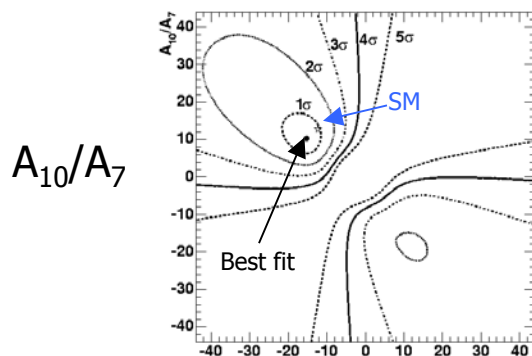
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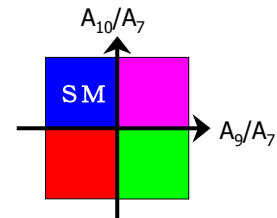


## Results of the unbinned fit to $q^2$ and $\cos(\theta)$ distributions for ratios of Wilson coefficients.



$|A_7|$  constrained from  $b \rightarrow s \gamma$  to be close to SM

$A_9/A_7$



Ref: hep-ex/0508009

$$-1401 < A_9 A_{10} / A_7^2 < -26.4 \text{ at } 95\% \text{ C.L.}$$

	negative $A_7$	positive $A_7$
$A_9/A_7$	$-15.3^{+3.4}_{-4.8} \pm 1.1$	$-16.3^{+3.7}_{-5.7} \pm 1.4$
$A_{10}/A_7$	$10.3^{+5.2}_{-3.5} \pm 1.8$	$11.1^{+6.0}_{-3.9} \pm 2.4$

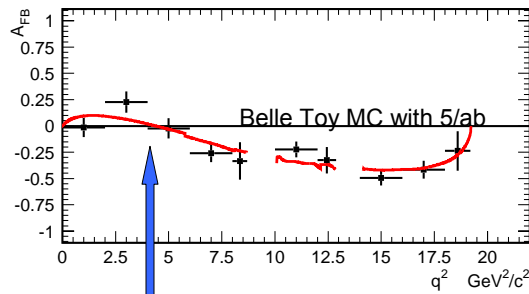
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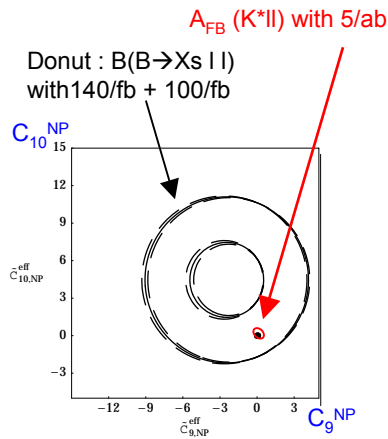


## $A_{FB}(B \rightarrow K^* l^+ l^-)[q^2]$ at Super B Factory

- Assume 1 year of running at  $5 \times 10^{35}$  nb/sec
- $\rightarrow$  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  $50 \text{ ab}^{-1}$



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## Fundamental Questions in Flavor Physics

Are there New Physics Phases and New sources of CP Violation Beyond the SM ?

Experiments:  $b \rightarrow s$  CPV, compare CPV angles from tree and loops

Are there new operators with quarks enhanced by New Physics ?

Experiments:  $A_{FB}(B \rightarrow K^* l^+ l^-)$ ,  $B \rightarrow K \pi$  rates and asymmetries

Are there right-handed currents ?

Experiments:  $b \rightarrow s \gamma$  CPV,  $B \rightarrow V V$  triple-product asymmetries

Are there new flavor changing neutral currents ?

Experiments:  $b \rightarrow s \nu \nu$ ,  $D$ - $\bar{D}$  mixing+CPV+rare,  $\tau \rightarrow \mu \gamma$

These questions can only be answered at a Super B Factory.

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## Super B Factory Motivation

- Physics beyond the Standard Model (SM) must exist.
  - finite  $m_\nu$
  - gravity
- If the LHC finds New Physics at the TeV scale,
  - its flavor structure must be examined experimentally. A super B factory is the best tool for this purpose.

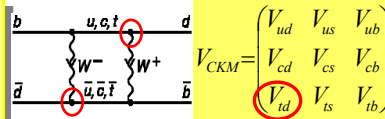


cf. Physics of top quark

First estimate of mass: BB mixing → ARGUS

Direct production, Mass, width etc. → CDF/D0

Off-diagonal couplings, phase → BaBar/Belle



- If the LHC finds nothing but a SM-like Higgs,
  - searching for deviations from the SM in flavor physics will be one of the best ways to find new physics.

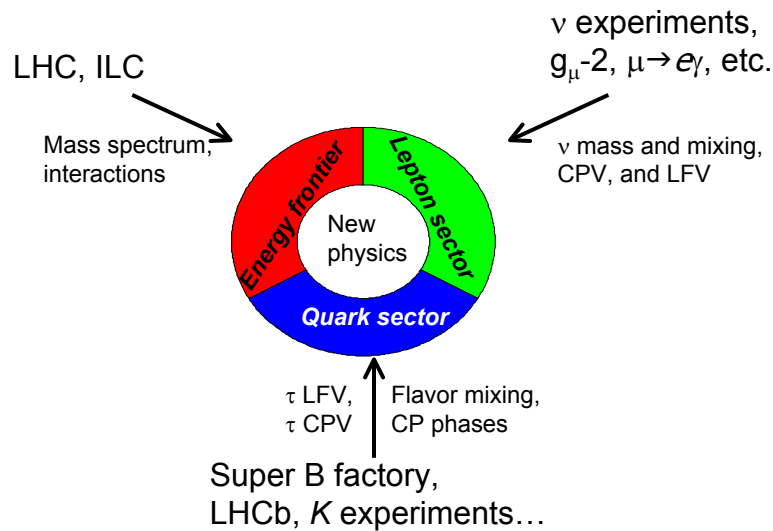
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## A Broad Unbiased Approach to New Physics



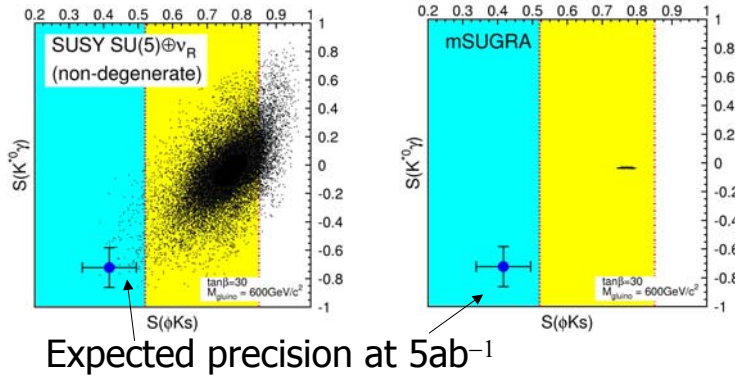
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## CPV in $b \rightarrow s$ and diagnosis of new physics



Many other examples of using correlations to distinguish new physics scenarios have been examined.

T.Goto, Y.Okada, Y.Shimizu, T.Shindou, M.Tanaka (2002, 2004) + SuperKEKB LoI

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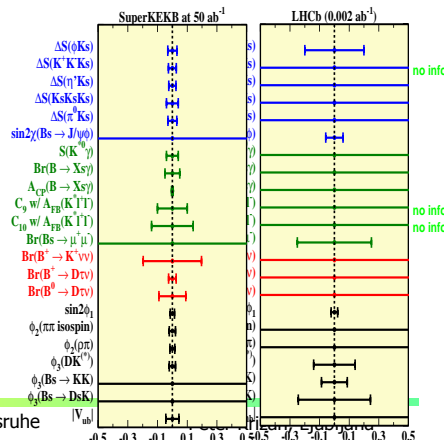
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## Comparison of Super-B and LHCb

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



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**Super KEKB**  
next for BSM

## Super B Factory at KEK

**New Beam pipe**

Ante-chamber & solenoid coils to reduce photo-electron clouds

**More RF power**

**Damping ring**

**Linac upgrade**  $L = 4 \times 10^{35} / \text{cm}^2 / \text{s}$

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**BELLE**

## Crab crossing in the near future

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

(Strong-weak simulation)      K. Ohmi

(a)

$y$

$I_+ \text{ (mA)}$

**Head-on (crab)**

crossing angle 22 mrad

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



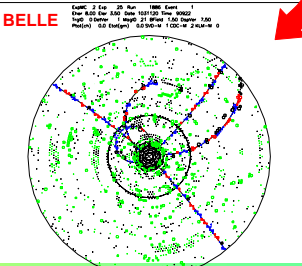
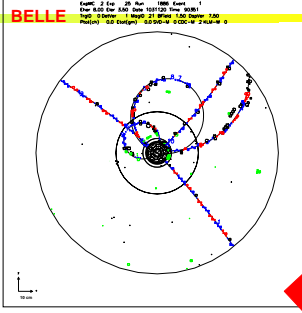
# Requirements for the Super B detector

Critical issues at  $L = 4 \times 10^{35}/\text{cm}^2/\text{sec}$

- ▶ **Higher background (x20)**
  - radiation damage and occupancy
  - fake hits and pile-up noise in the EM
- ▶ **Higher event rate (x10)**
  - higher rate trigger, DAQ and computing
- ▶ **Require special features**
  - low  $p \mu$  identification  $\leftarrow s\mu\mu$  recon. eff.
  - hermeticity  $\leftarrow \nu$  "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.



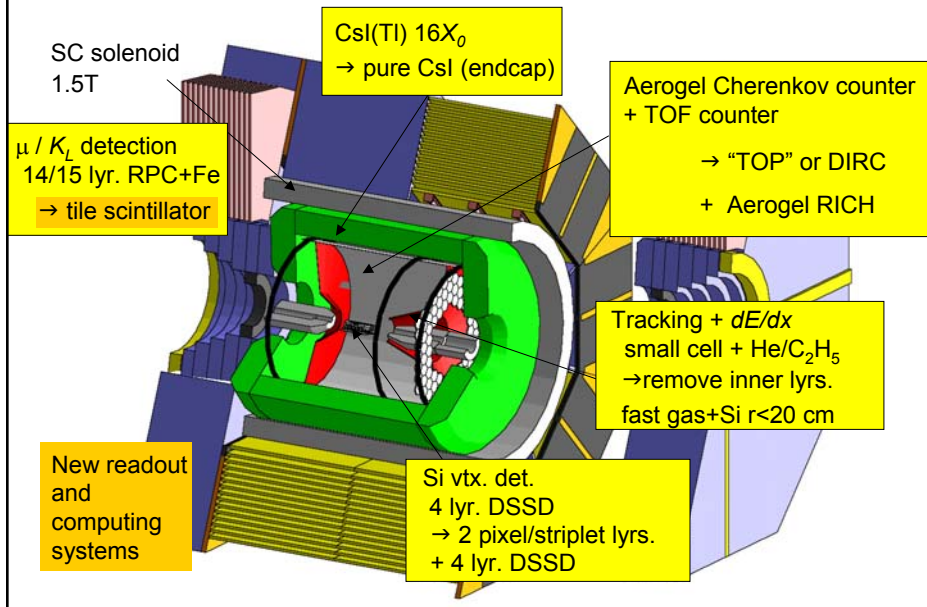
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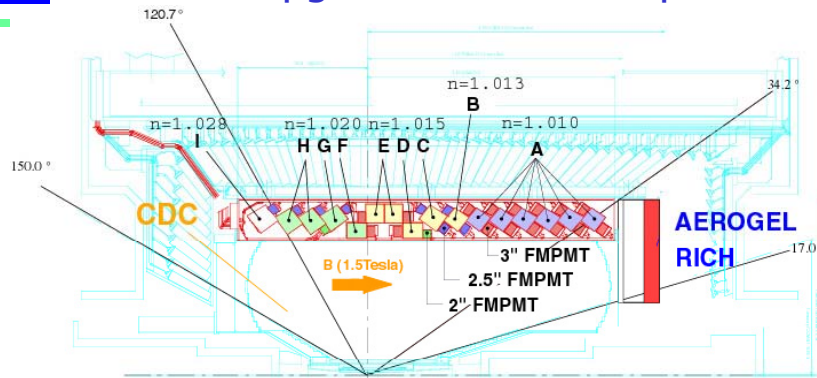


# Belle Upgrade for Super-B





## PID upgrade in the endcap



- improve  $K/\pi$  separation in the forward (high mom.) region for few-body decays of B's
- good  $K/\pi$  separation for  $b \rightarrow d\gamma$ ,  $b \rightarrow s\gamma$
- improve purity in fully reconstructed B decays
- low momentum ( $<1\text{GeV}/c$ )  $e/\mu/\pi$  separation (B  $\rightarrow$  KII)
- keep high the efficiency for tagging kaons

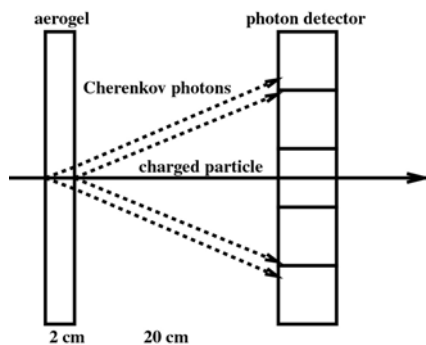
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## Proximity focusing RICH in the forward region



$K/\pi$  separation at 4 GeV/c  
 $\theta_c(\pi) \sim 308 \text{ mrad}$  ( $n = 1.05$ )  
 $\theta_c(\pi) - \theta_c(K) \sim 23 \text{ mrad}$

$d\theta_c(\text{meas.}) = \sigma_0 \sim 13 \text{ mrad}$   
 With 20mm thick aerogel and  
 6mm PMT pad size

$\rightarrow 6\sigma$  separation with  $N_{pe} \sim 10$

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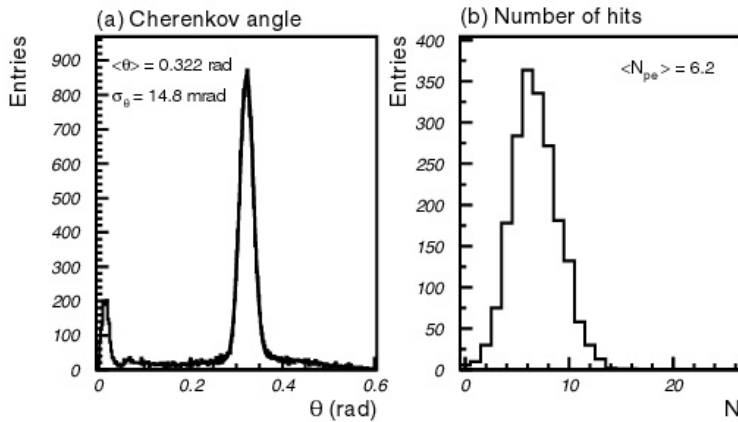
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## Beam test: Cherenkov angle resolution and number of photons

Beam test results with 2cm thick aerogel tiles:  
 $>4\sigma$  K/ $\pi$  separation



-> Number of photons has to be increased.

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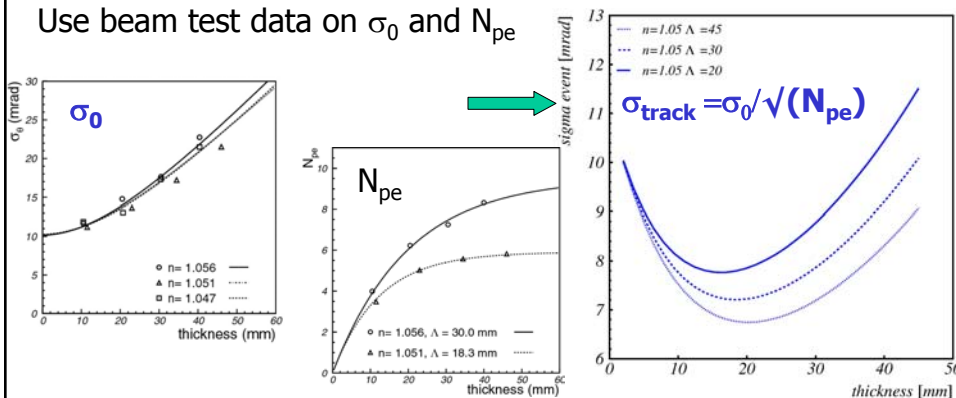
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## How to increase the number of photons?

What is the optimal radiator thickness?

Use beam test data on  $\sigma_0$  and  $N_{pe}$



Minimize the error per track:

$$\sigma_{track} = \sigma_0 / \sqrt{N_{pe}}$$

Optimum is close to 2 cm

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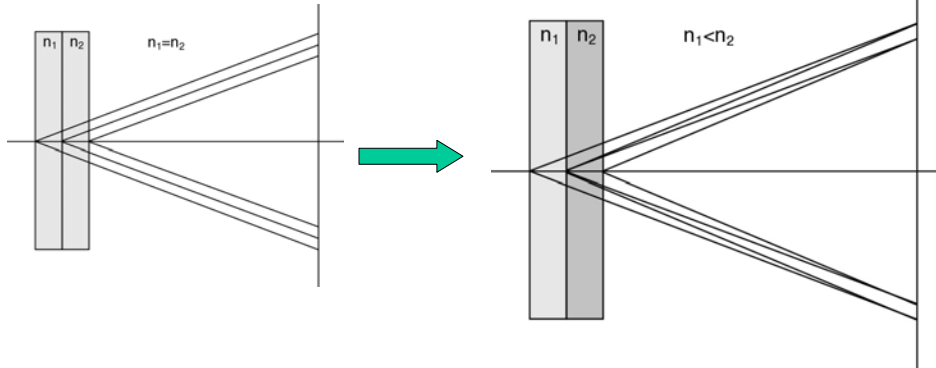


## Radiator with multiple refractive indices

How to increase the number of photons without degrading the resolution?

-> stack two tiles with different refractive indices: "focusing" configuration

normal



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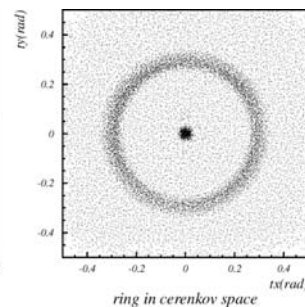
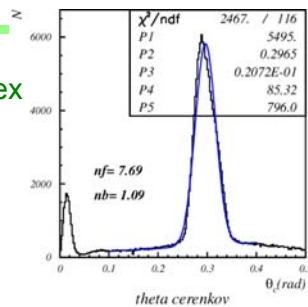
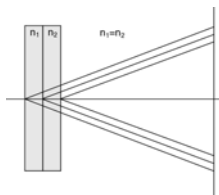
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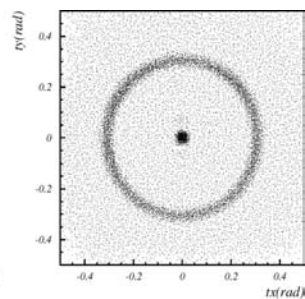
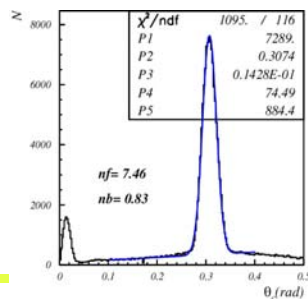
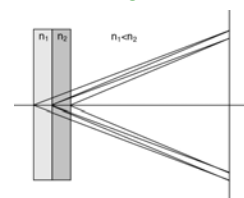


## Focusing configuration – data

4cm aerogel single index



2+2cm aerogel



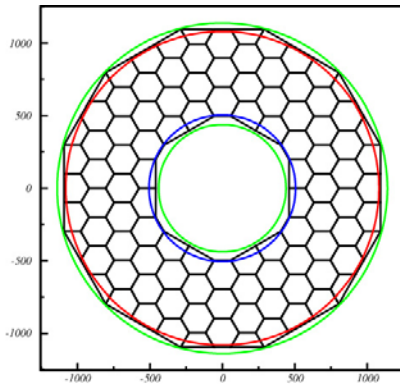
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## Tiling of the radiator

Minimize photon yield losses at the aerogel tile boundary: hexagonal tiling scheme



- Cut into hexagonal shape from a square block
- Machining device: use "water-jet" thanks to the hydrophobic nature

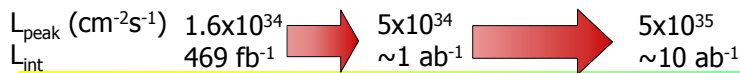
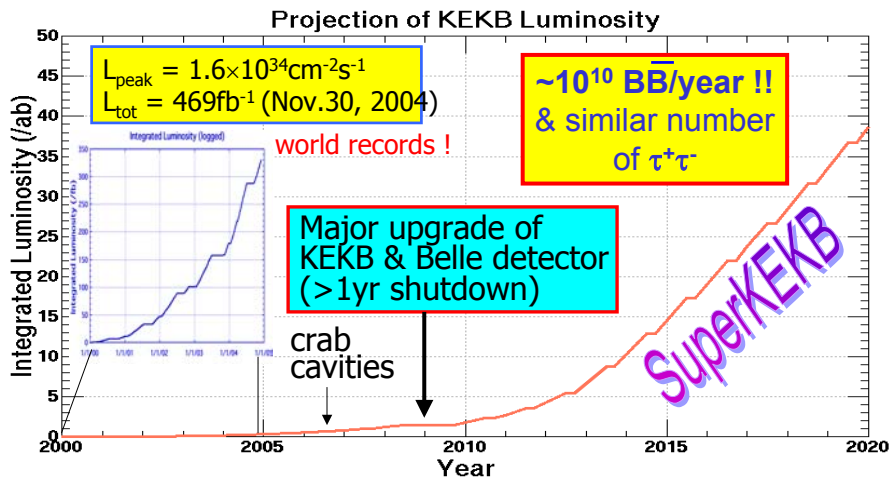
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## KEKB Collider Upgrade Scenario



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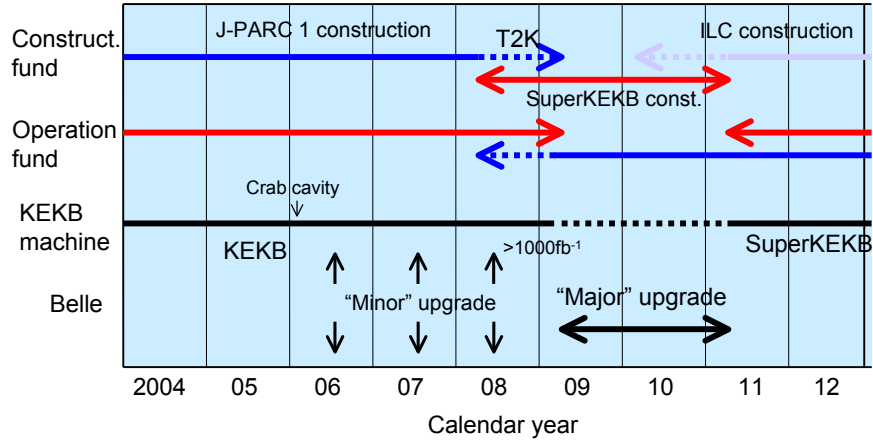
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## Yamauchi's Schedule for Super B

A Super B proposal was submitted to MEXT in August 2005.  
 KEB/Belle project receives a grade of S(i.e. A+) in gov. review  
 A search for a new KEK laboratory director is underway.



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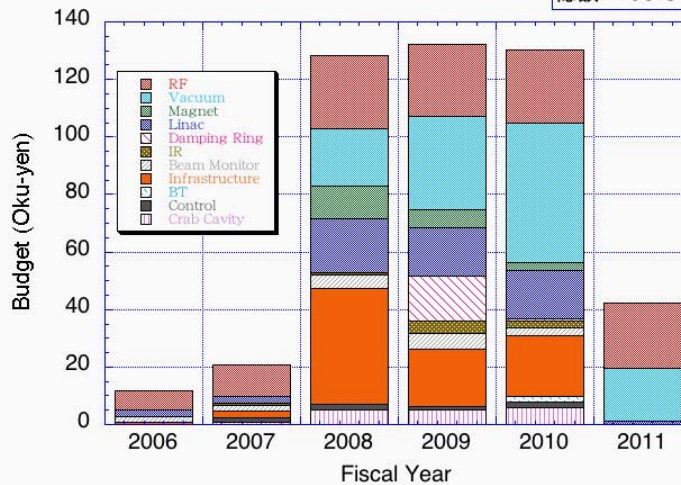
Peter Krizan, Ljubljana



## Yamauchi's budget for Super B

SuperKEKB 年次計画 (2005.1.11)

総額: 465.8 Oku-yen



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## Summary 1

- Observation of direct CP violation in  $B^0 \rightarrow \pi^+\pi^-$  and  $K^+\pi^-$  decays, evidence in  $B^- \rightarrow \rho^0 K^-$
- CP violation in  $b \rightarrow s$  transitions remains below SM expectation, but **statistically limited**.
- Forward-backward asymmetry ( $A_{FB}$ ) in  $b \rightarrow s l^+ l^-$  is becoming another powerful tool to search for physics beyond SM.
- We are entering an exciting phase of **precision measurements**.

.... and there are much more interesting results, but could not be covered in this talk!

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## Summary 2

- B factories have proven to be an excellent tool for flavour physics
- Reliable long term operation, constant improvement of the performance.
- Short term plan: increase luminosity **x3** by a crab cavity
- Major upgrade in 2009-10 -> Super B factory, **L x30**
- Essentially a new project, all components have to be replaced, plans exist (LoI), nothing is frozen...
- Expect a new, exciting era of discoveries, complementary to LHC
- **Do not miss the chance to be part of it...**

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