Univerza v Ljubljani

Belle: recent results and future plans

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Contents

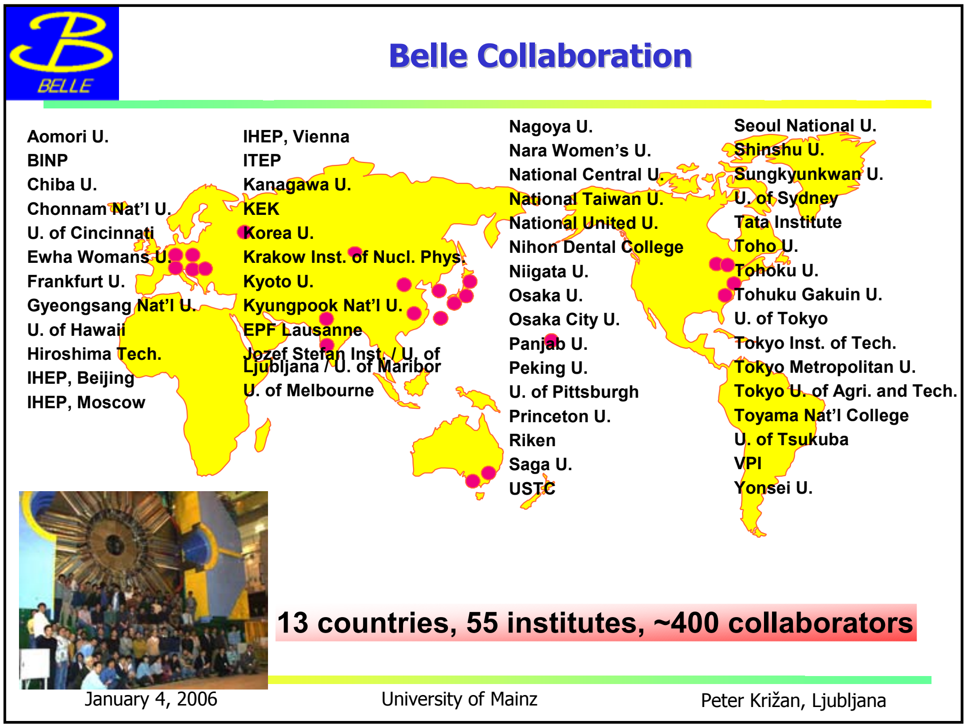
Experimental apparatus: Belle at KEK-B

CP violation in the B system

Searching for New Physics: FCNC processes

- Observation of b→d penguins: B → ργ, ωγ decays
- CP violation in b→s decays
- A_{fb} vs q^2 in B → $K^* l^+ l^-$ decays

Plans for the future: a Super B factory



Belle Collaboration

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

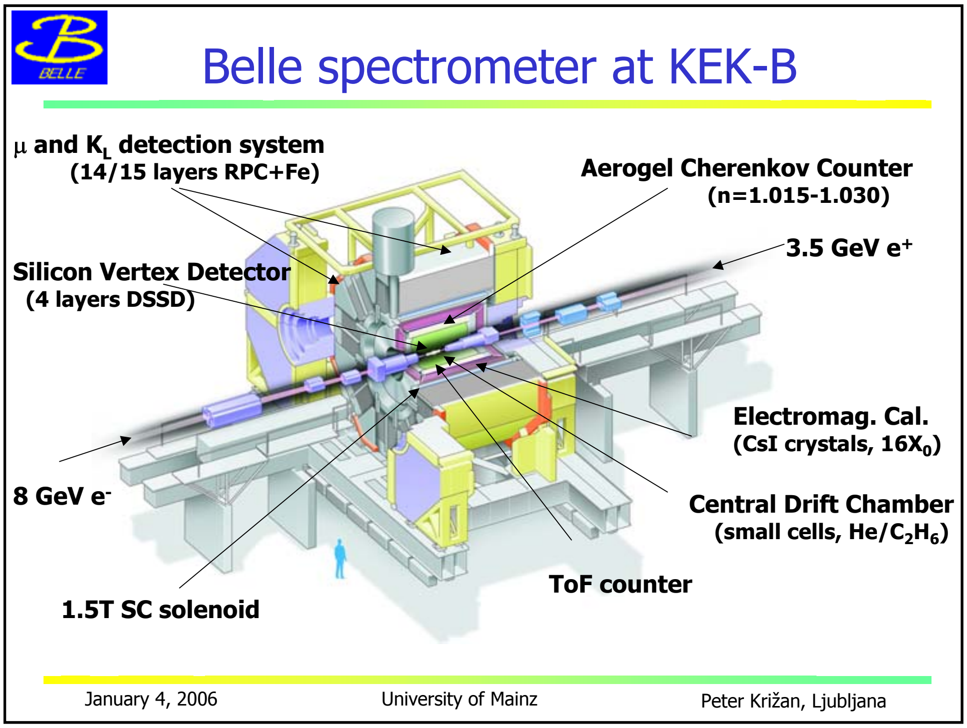
IHEP, Vienna
ITEP
Kanagawa U.
KEK
Korea U.
Krakow Inst. of Nucl. Phys.
Kyoto U.
Kyungpook Nat'l U.
EPF Lausanne
Jozef Stefan Inst. / U. of Ljubljana / U. of Maribor
U. of Melbourne

Nagoya U.
Nara Women's U.
National Central U.
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
VPI
Yonsei U.

13 countries, 55 institutes, ~400 collaborators

January 4, 2006 University of Mainz Peter Križan, Ljubljana



Belle spectrometer at KEK-B

μ and K_L detection system
(14/15 layers RPC+Fe)

Aerogel Cherenkov Counter
(n=1.015-1.030)

3.5 GeV e^+

Silicon Vertex Detector
(4 layers DSSD)

Electromag. Cal.
(CsI crystals, $16X_0$)

8 GeV e^-

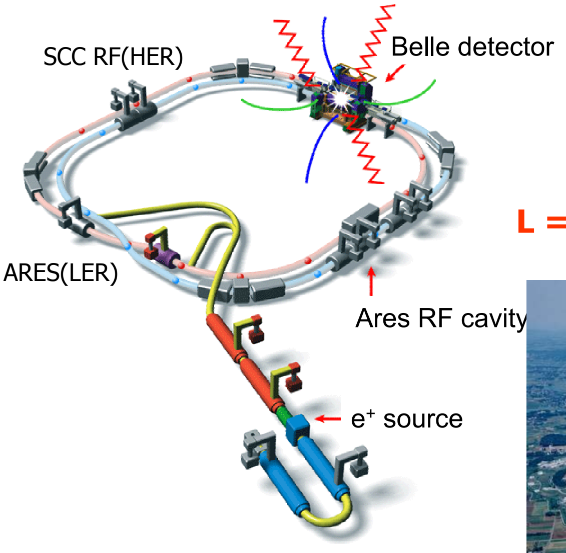
Central Drift Chamber
(small cells, He/C_2H_6)

ToF counter

1.5T SC solenoid

January 4, 2006 University of Mainz Peter Križan, Ljubljana

The KEKB Collider



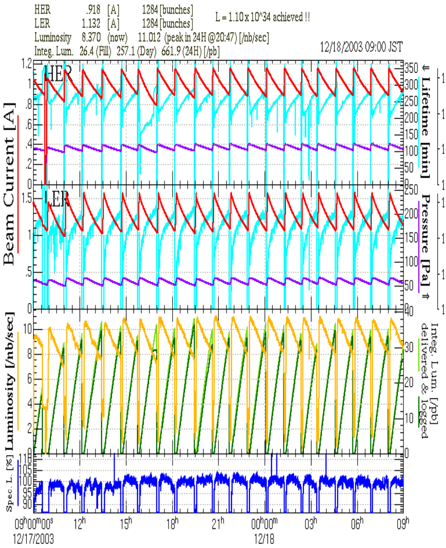
8 x 3.5 GeV
22mrad crossing angle

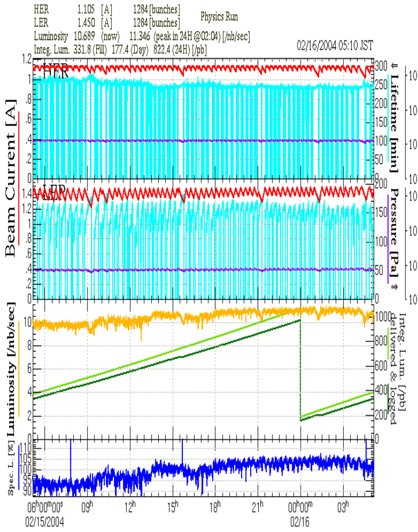
World record:

L = 1.6 x 10^{34}/cm^2/sec

Normal injection

Continuous injection

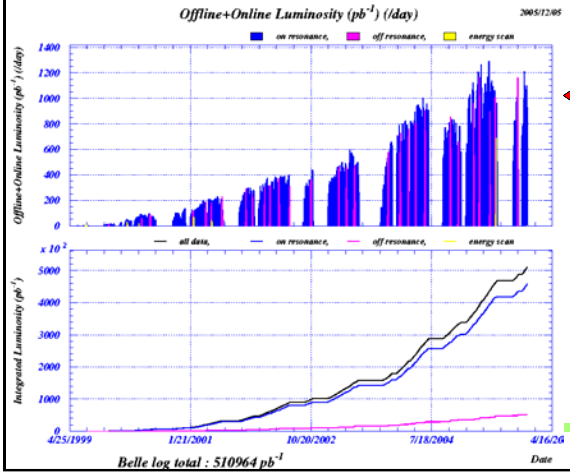




661/pb/day **→1182/pb/day**

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

Accumulated > 500 M BB-pairs



1 fb^{-1}/day

Total =512 fb^{-1}

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

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

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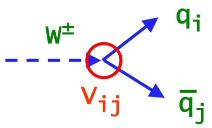
B factory physics program

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

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

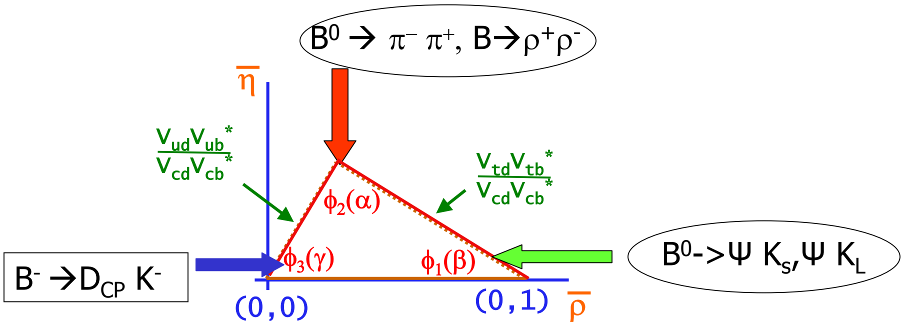
CKM matrix is unitary

deviations could signal processes not included in SM



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

Three Angles: (ϕ_1,ϕ_2,ϕ_3) or (β, α, γ)



$B^0 \to \pi^- \pi^+$, $B \to \rho^+\rho^-$

$\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$

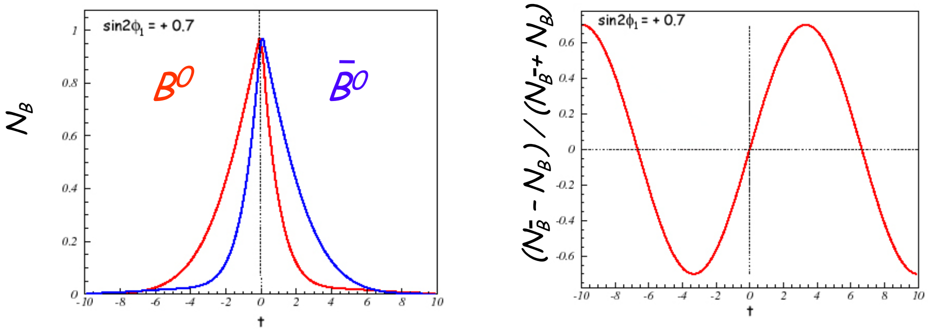
$\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}$

$B^- \to D_{CP} K^-$

$B^0 \to \Psi K_s, \Psi K_L$

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

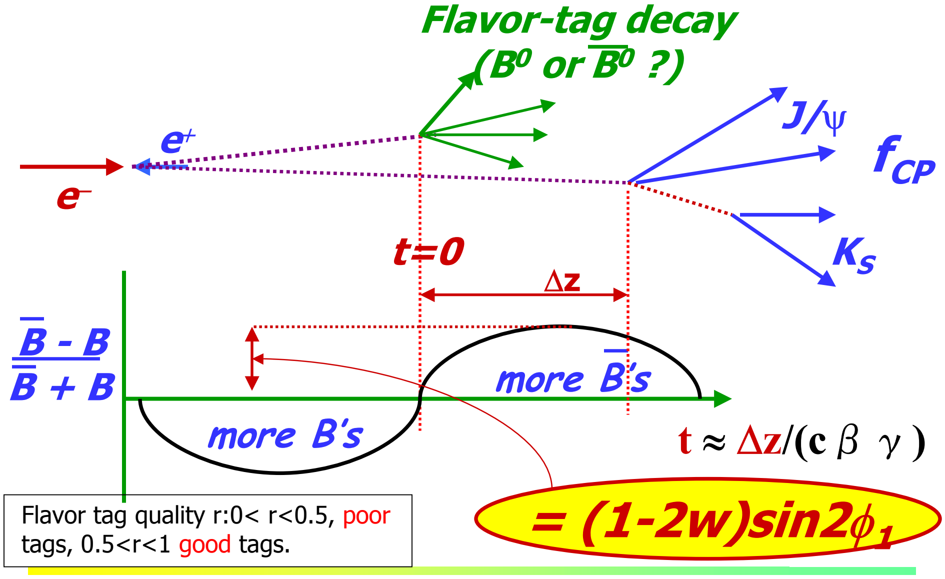
Mixing Induced CP Violation



$$A_{CP}(t)=\frac{\Gamma(\overline{B}^0(t)\to f_{CP})-\Gamma(B^0(t)\to f_{CP})}{\Gamma(\overline{B}^0(t)\to f_{CP})+\Gamma(B^0(t)\to f_{CP})}=-\xi_f \sin 2\phi_1 \sin \Delta m_B t$$

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

Principle of CPV Measurement



Flavor tag quality r:0< r<0.5, poor tags, 0.5<r<1 good tags.

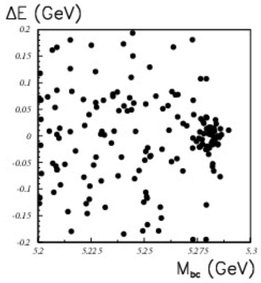
If there is more than one diagram and additional weak phases, there is the possibility of direct CPV and a new term with a cos(Δmt) time dependence.

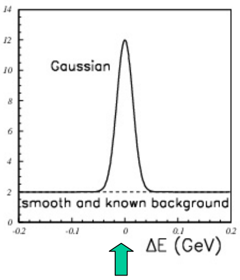
$$P(B \to f_{CP};t) = \frac{e^{-|t|/\tau_B}}{4\tau_B}[1 + q \cdot \{A\ \cos(\Delta m t) + S\ \sin(\Delta m t)\}]$$

with q=±1

If integrated over all times (-inf,+inf), the asymmetry with the sin(Δmt) term vanishes, while the term with cos(Δmt) remains.

Reconstruction of B meson decays





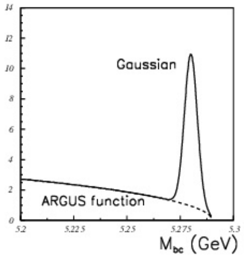
Reconstructing rare B meson decays at Υ(4s): use two variables,

beam constrained mass M_{bc}

and

energy diference ΔE

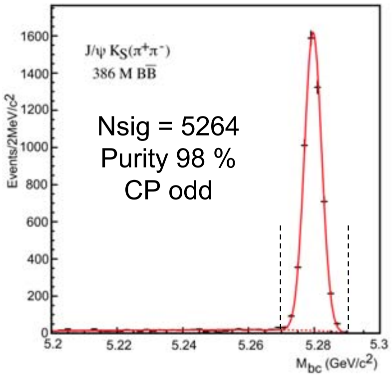
$$\Delta E \equiv \sum E_i - E_{CM}/2$$



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

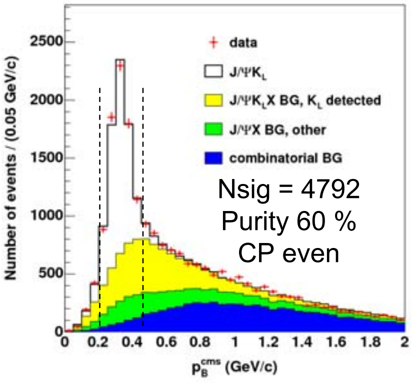
2005: $B^0 \to J/\psi\ \overline{K}^0$ with 386 M $B\overline{B}$ pairs

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



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

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

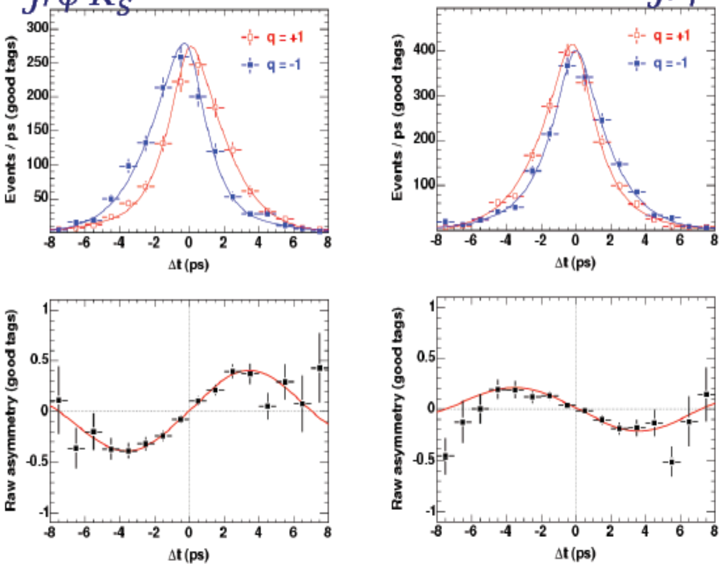


p_B^* (momentum in CM)

Belle $(386\times10^6 B\bar{B})$

$J/\psi K_S$

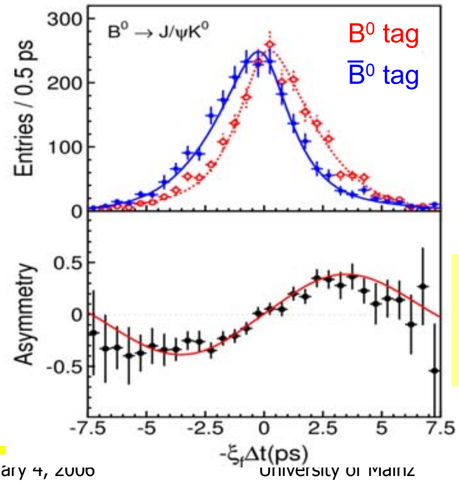
$J/\psi K_L$



2005: $B^0 \rightarrow J/\psi\ \bar{K}^0$

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

No DCPV →



BG subtracted distributions
(*good tag region*)

2003 result:
$\sin 2\phi_1$= 0.728 ± 0.061
(152 x 10^6 $\bar{B}B$ pairs)

consistent ~1.2σ

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

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 ε' experiment for the B system."

Lincoln Wolfenstein, 1999

Direct CPV asymmetry in B Decays

Asymmetry in B decay rates

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

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

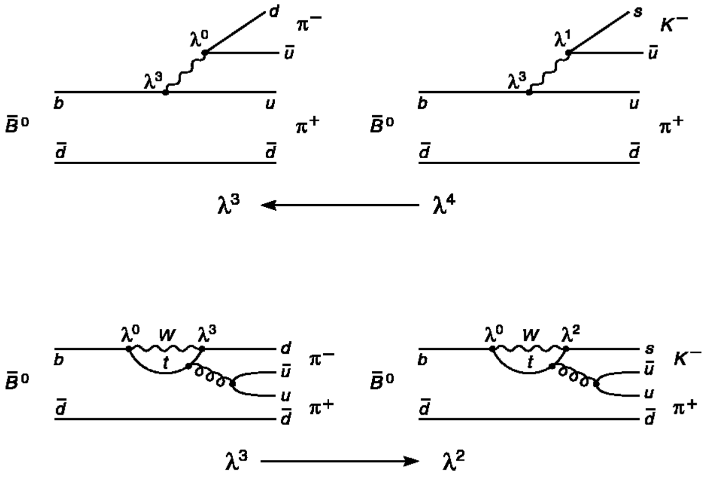
$$\boxed{r = |P|/|T|}, \phi = weak\ \ phase\ diff$$

$$\delta = strong\ \ phase\ diff$$

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 be happen in certain B decays due to the interference of penguin (P) and tree (T) decays.

Hierarchy of diagrams for B→ ππ, Kπ decays

ππ



Kπ

Possibility of tree-penguin interference.

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

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

Belle 152 M $B\bar{B}$
with 372±32 $B^0 \to \pi^+\pi^-$ 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)

5.2σ CPV,

First evidence for DCPV (3.2σ)

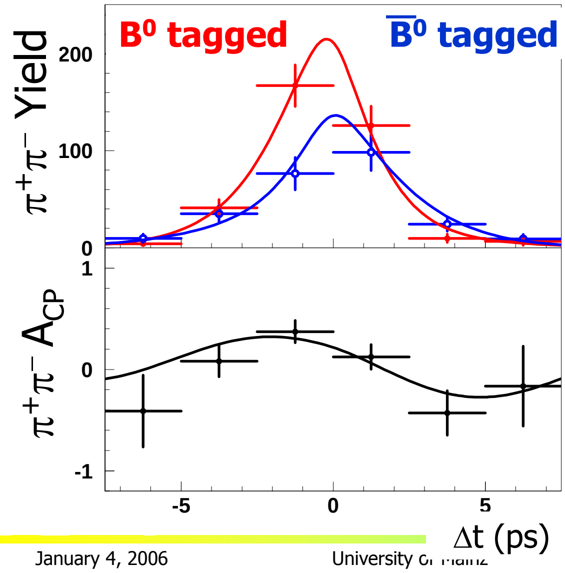
BABAR 227M $B\bar{B}$
with 467±33 $B^0 \to \pi^+\pi^-$ events

$$S_{\pi\pi} = -0.30 \pm 0.17 \pm 0.03$$
$$A_{\pi\pi} = +0.09 \pm 0.15 \pm 0.04$$

hep-ex/0501071, to
appear in PRL

Also ~3.2s discrepancy between Belle and BaBar

B→$\pi^+ \pi^-$ time evolution



666±43 B→$\pi^+ \pi^-$ signal events

ΔE-Mbc 2D fits
to individual
time intervals

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

2005 sample

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

$$A_{\pi\pi} = +0.56 \pm 0.12 \pm 0.06$$
$$S_{\pi\pi} = -0.67 \pm 0.16 \pm 0.06$$

1st error statistical,
2nd systematic

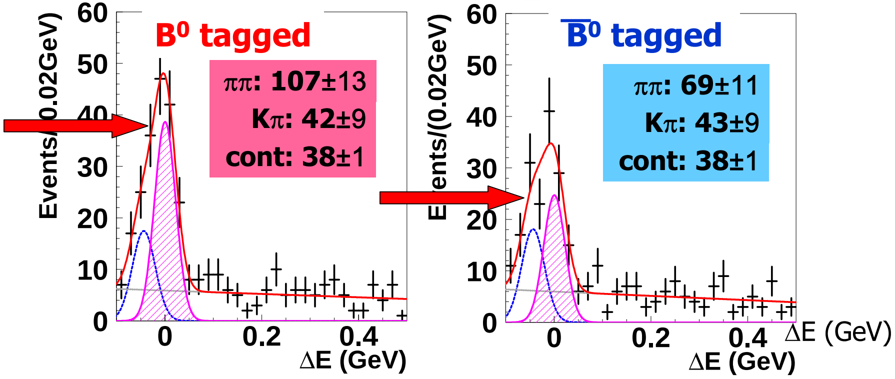
- Compelling evidence for direct CP violation in $B \rightarrow \pi^+\pi^-$ with 4.0σ significance
- Confirms previous Belle results.
- Isospin analysis for this mode alone gives (95.4% C.L) $0^\circ < \phi_2 < 19^\circ$ & $71^\circ < \phi_2 < 180^\circ$

Consistency Checks with time-integrated fits

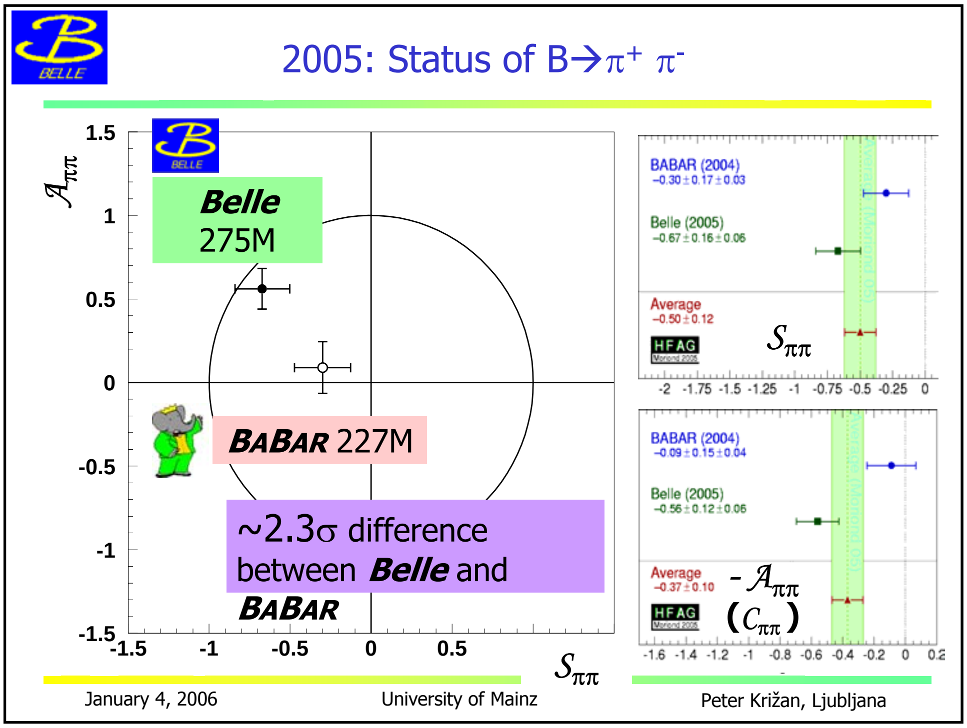
$$A_{\pi\pi} = +0.52 \pm 0.14$$

Counting experiment consistent
with unbinned time-dependent fits.

LR>0.86 & 0.5<r≤1.0



Visible indication of direct CP violation.

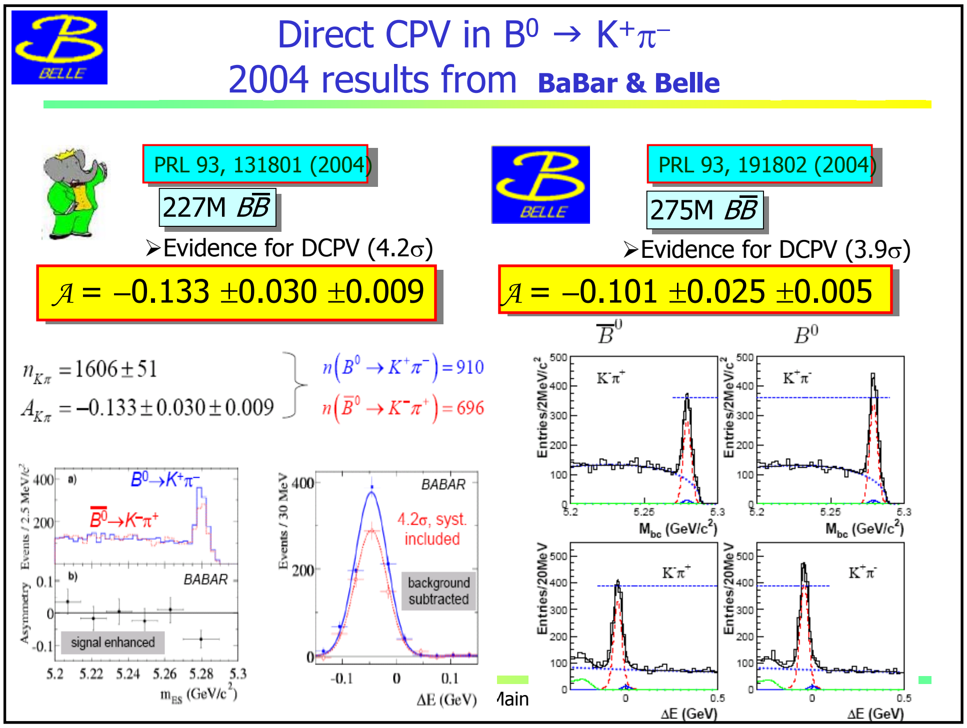


2005: Status of B→$\pi^+ \pi^-$

Belle 275M

BABAR 227M

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



Direct CPV in $B^0 \to K^+\pi^-$
2004 results from **BaBar & Belle**

PRL 93, 131801 (2004)

227M $B\overline{B}$

- ➢Evidence for DCPV (4.2σ)

$\mathcal{A}$ = −0.133 ±0.030 ±0.009

PRL 93, 191802 (2004)

275M $B\overline{B}$

- ➢Evidence for DCPV (3.9σ)

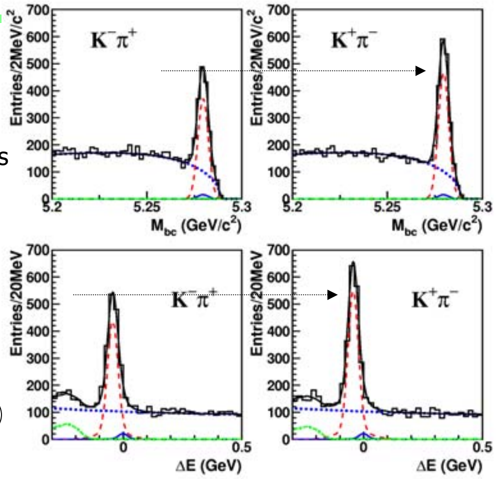
$\mathcal{A}$ = −0.101 ±0.025 ±0.005

$$n_{K\pi} = 1606 \pm 51$$
$$A_{K\pi} = -0.133 \pm 0.030 \pm 0.009$$
$$n(B^0 \to K^+\pi^-) = 910$$
$$n(\overline{B}^0 \to K^-\pi^+) = 696$$

2005: "Observation" of Direct CPV in B→$K^-\pi^+$

Belle update with
386 x 10^6 B Bbar pairs

(hep-ex/0507045)



Significance
5.0 σ

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

A new approach to direct CPV using the Dalitz plot in $B^\pm \rightarrow K^\pm \pi^+ \pi^-$

(hep-ex/0509001)

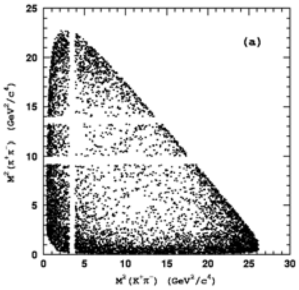
Sample used for $B^\pm \rightarrow K^\pm \pi^+\pi^-$ study:

contains 2248±79 B^- , 2038±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 $ae^{i\delta}\,(1 \pm b\, e^{i\varphi})$

Combined Dalitz plot, signal region



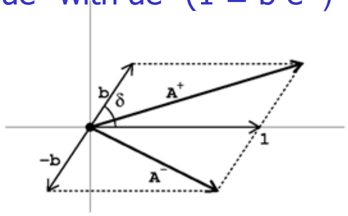


FIG. 9: Illustartion of the amplitude parametrization with Eq. 7.

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 (%)	δ (°)	b	φ (°)	A_{CP} significance (σ)
$K^*(892)\pi^\pm$	$13.0 \pm 0.8^{+0.5}_{-0.7}$	0 (fixed)	$0.078 \pm 0.033^{+0.012}_{-0.003}$	$-18 \pm 44^{+5}_{-13}$	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
$\rho(770)^0K^\pm$	$7.85 \pm 0.93^{+0.64}_{-0.59}$	$-21 \pm 14^{+14}_{-19}$	$0.28 \pm 0.11^{+0.07}_{-0.09}$	$-125 \pm 32^{+10}_{-85}$	3.9
$\omega(782)K^\pm$	$0.15 \pm 0.12^{+0.03}_{-0.02}$	$100 \pm 31^{+38}_{-21}$	0 (fixed)	–	–
$f_0(980)K^\pm$	$17.7 \pm 1.6^{+1.1}_{-3.3}$	$67 \pm 11^{+10}_{-11}$	$0.30 \pm 0.19^{+0.05}_{-0.10}$	$-82 \pm 8^{+2}_{-2}$	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

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

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

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

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

- helicity hemisphere

+helicity hemisphere

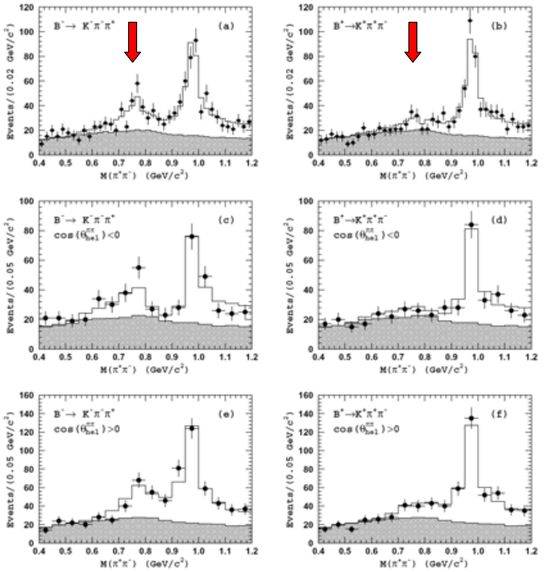


FIG. 7: $M(\pi^+\pi^-)$ mass spectra for B^- (left column) and B^+ (right column) for different helicity regions: (a,b) no helicity cuts; (c,d) $\cos\theta_H^{\pi\pi} < 0$; (e,f) $\cos\theta_H^{\pi\pi} > 0$; Points with error bars are data, the open histogram is the fit result and the hatched histogram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

Comparison of result to predictions and BaBar

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

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)

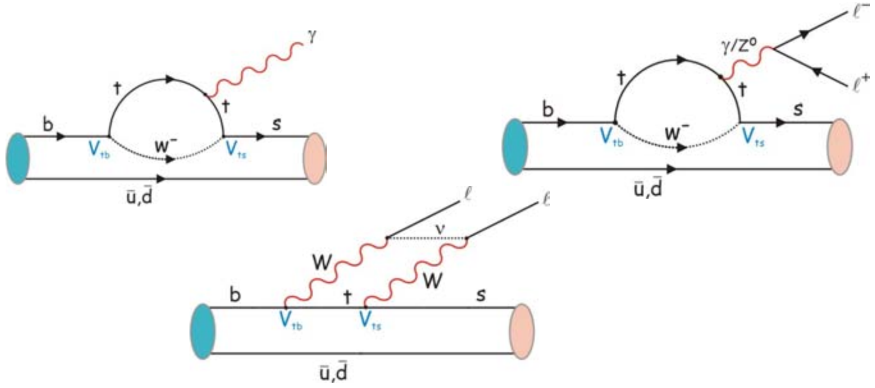
$$A_{CP}(B^{\pm} \rightarrow \rho^0 K^{\pm}) = -13.6^{+4.5+6.9+3.7+62.7}_{-5.7-4.4-3.1-55.4}\%$$

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

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

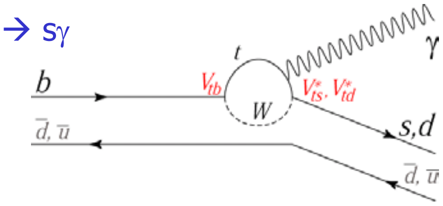
Why FCNC decays?

Flavour changing neutral current (FCNC) processes (like b→s, b→d) are fobidden 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.



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

Supressed by $|V_{td}/V_{ts}|^2$ vs b → sγ



Interesting:

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

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

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

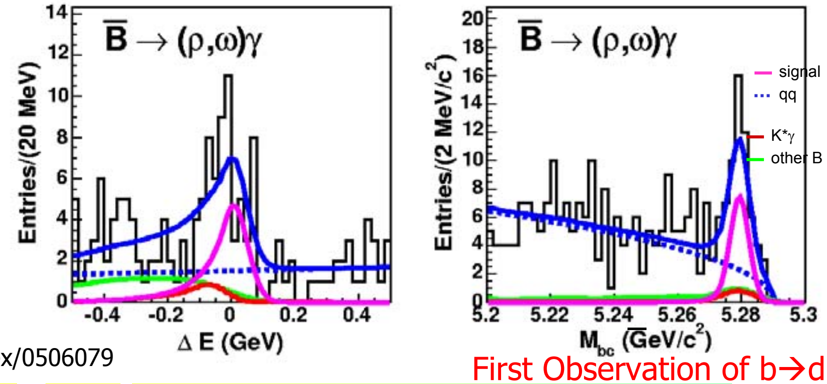
Addresses the same physics issue as B_s- B_s mixing (future Tevatron RunII +LHCb goal).

V_{td}/V_{ts} from B → ργ, ωγ

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.



hep-ex/0506079

First Observation of b→d γ

Implications of Belle's observation of b→d γ

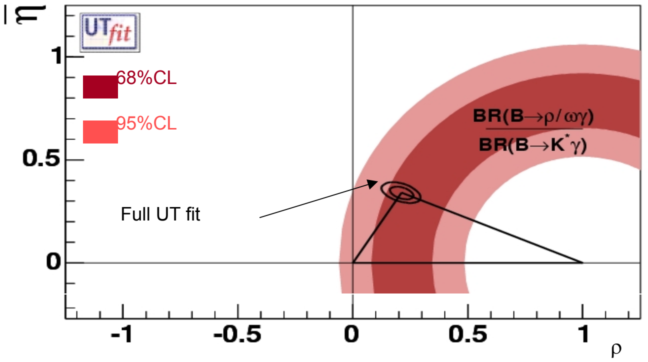
Together with the evidence of B→K^0 K modes, Belle has demonstrated the existence of a new quark level transition: b→d

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

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

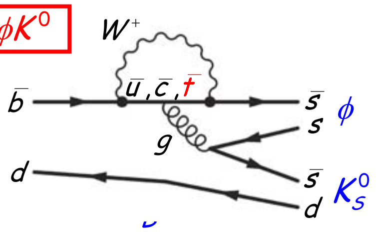
SU(3) breaking correction

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



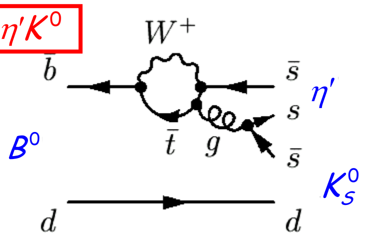
How can New Physics contribute to b→s?

$B^0 \to \phi K^0$

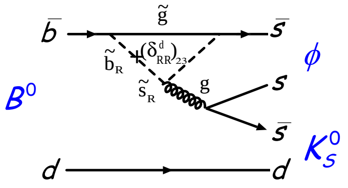


"Internal Penguin"

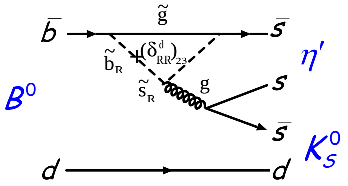
$B^0 \to \eta' K^0$



New physics in loops?



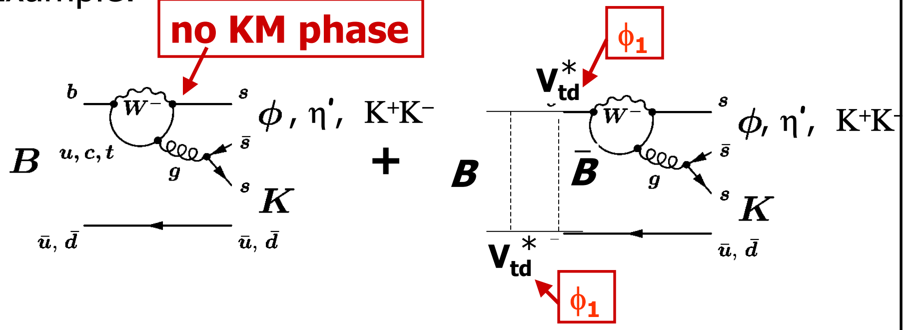
Many new phases are possible in SUSY



Searching for new physics phases in CP violation measurements in b→s decays

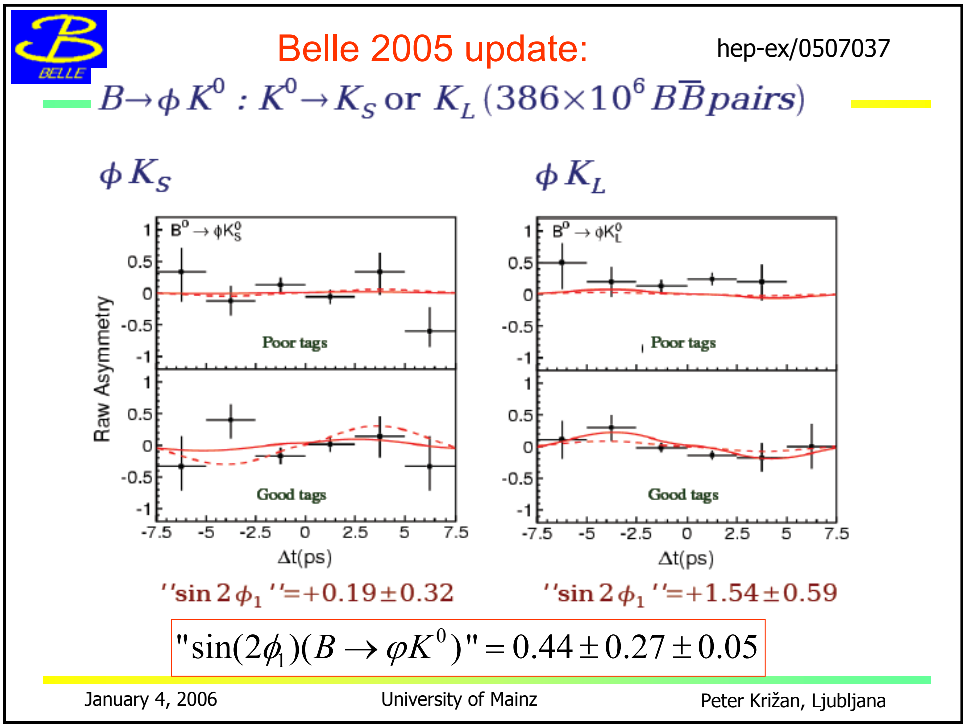
Example:

no KM phase



SM: $\sin 2\phi_1^{\text{eff}} = \sin 2\phi_1$ from B→J/ψ K^0 ($b \to c\bar{c}s$)

unless there are other, non-SM particles in the loop



Belle 2005 update:

hep-ex/0507037

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

ϕK_S

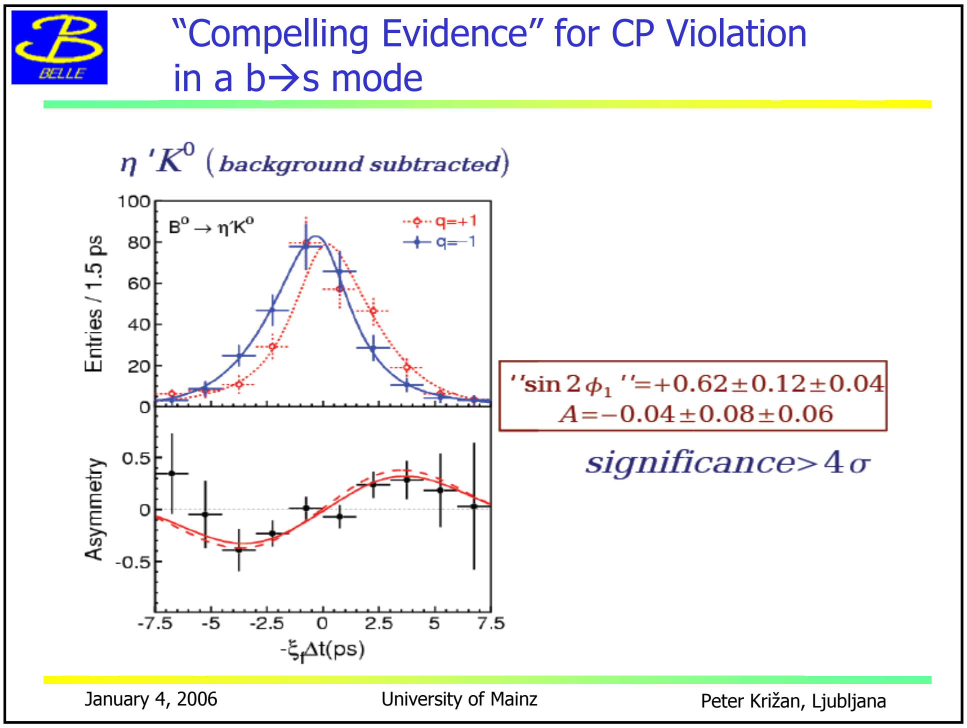
ϕK_L

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

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

$$\boxed{"\sin(2\phi_1)(B \to \varphi K^0)" = 0.44 \pm 0.27 \pm 0.05}$$

January 4, 2006 University of Mainz Peter Križan, Ljubljana



“Compelling Evidence” for CP Violation in a b→s mode

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

$$\boxed{\begin{array}{c} ''\sin 2\phi_1'' = +0.62 \pm 0.12 \pm 0.04 \\ A = -0.04 \pm 0.08 \pm 0.06 \end{array}}$$

$significance > 4\sigma$

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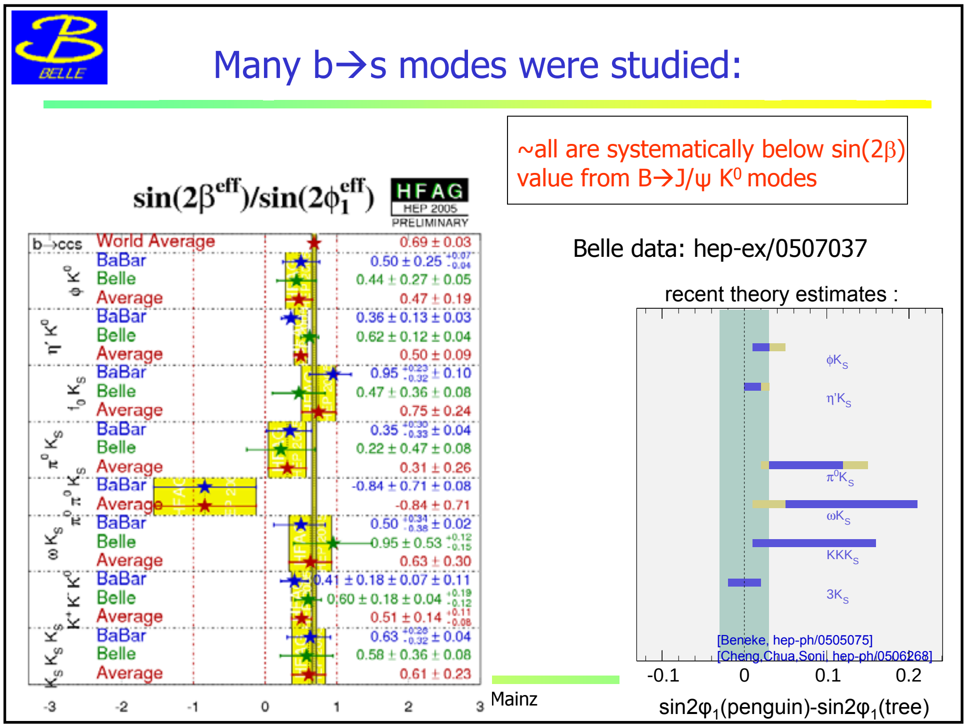


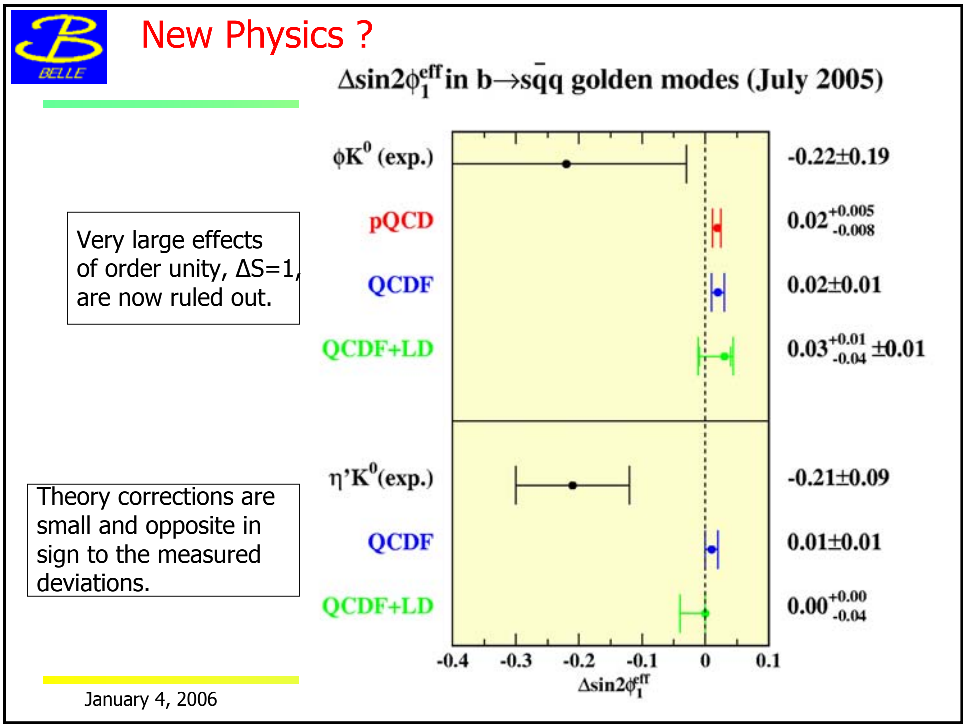
Many b→s modes were studied:

~all are systematically below sin(2β) value from B→J/ψ K^0 modes

Belle data: hep-ex/0507037

recent theory estimates :

Mainz



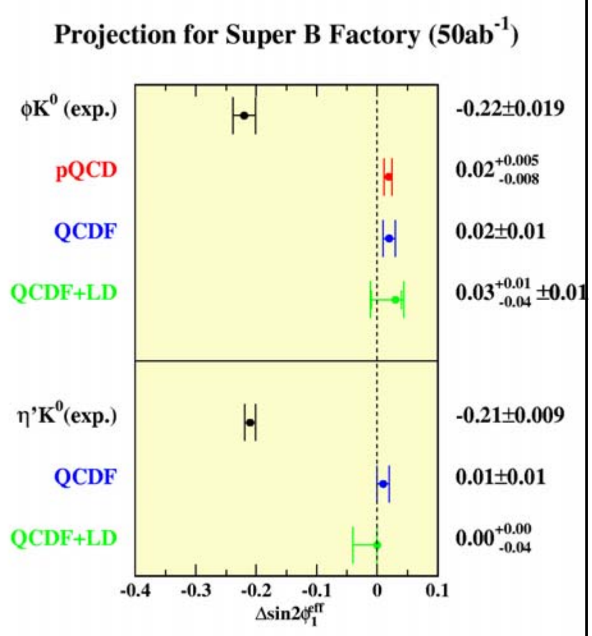
New Physics ?

Very large effects of order unity, ΔS=1, are now ruled out.

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

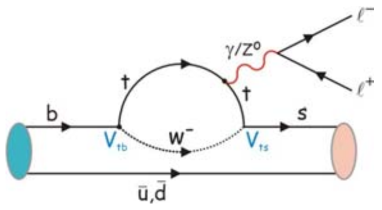
January 4, 2006

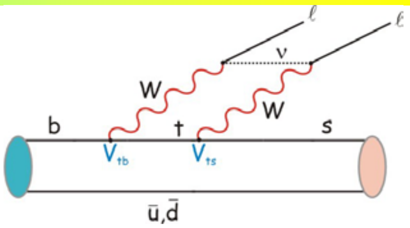
Are there New Physics effects of order 0.2 in b→s CPV ?



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

Another FCNC decay: B → K* l+ l-





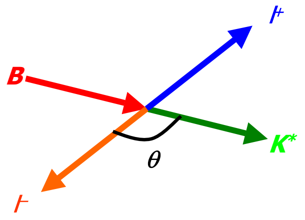
b → s l$^+$l$^-$ was first measured in B → K l$^+$l$^-$ by Belle (2001).

Important for further searches for the physics beyond SM

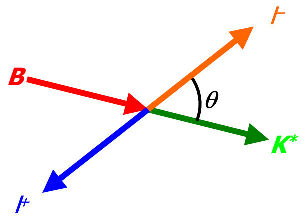
$$\frac{d\Gamma\left(b\to s\ell^+\ell^-\right)}{d\hat{s}}=\left(\frac{\alpha_{em}}{4\pi}\right)^2\frac{G_F^2 m_b^5\left|V_{ts}^*V_{tb}\right|^2}{48\pi^3}(1-\hat{s})^2$$
$$\times\left[(1+2\hat{s})\left(\left|C_9^{\rm eff}\right|^2+\left|C_{10}^{\rm eff}\right|^2\right)+4\left(1+\frac{2}{\hat{s}}\right)\left|C_7^{\rm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

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

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



Backward event



Forward event

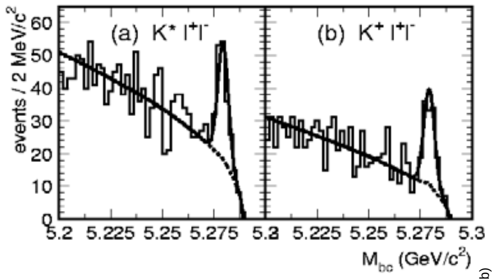
[γ* and Z* contributions in B→K* l l interfere and give rise to forward-backward asymmetries c.f. $e^+e^- \to \mu^+ \mu^-$]

Unbinned fit to the variables q^2 (di-lepton invariant mass) and cos(θ) for B→K* l l data

---

2005: Sample used for $A_{FB}(B \to K^*ll)(q^2)$

hep-ex/0508009



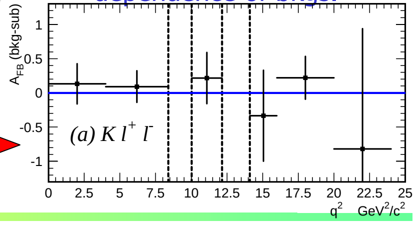
$$\begin{aligned}
&P(q^2,\cos\theta;A_9/A_7,A_{10}/A_7)\\
=\;& f_{\mathrm{sig}}\epsilon_{\mathrm{sig}}(q^2,\cos\theta)\frac{d^2\Gamma}{dq^2\,d\cos\theta}(q^2,\cos\theta)/N_{\mathrm{sig}}\\
+\;& f_{\mathrm{cfcf}}\epsilon_{\mathrm{cfcf}}(q^2,\cos\theta)\frac{d^2\Gamma}{dq^2\,d\cos\theta}(q^2,\cos\theta)/N_{\mathrm{cfcf}}\\
+\;& f_{\mathrm{ifcf}}\epsilon_{\mathrm{ifcf}}(q^2,\cos\theta)\frac{d^2\Gamma}{dq^2\,d\cos\theta}(q^2,-\cos\theta)/N_{\mathrm{ifcf}}\\
+\;& f_{X_s\ell\ell}\mathcal{P}_{X_s\ell\ell}(q^2,\cos\theta)\\
+\;& f_{\mathrm{dilep}}\Big\{(1-f_{K^*\ell h})\mathcal{P}_{\mathrm{dilep}}(q^2,\cos\theta)\\
& +f_{K^*\ell h}\mathcal{P}_{K^*\ell h}(q^2,\cos\theta)\Big\}\\
+\;& f_{K^*hh}\mathcal{P}_{K^*hh}(q^2,\cos\theta)+f_\psi\mathcal{P}_\psi(q^2,\cos\theta), \qquad (
\end{aligned}$$

Treat q^2, cos(θ) dependence of bkgs.

Sample for B→K* l l events 113±13

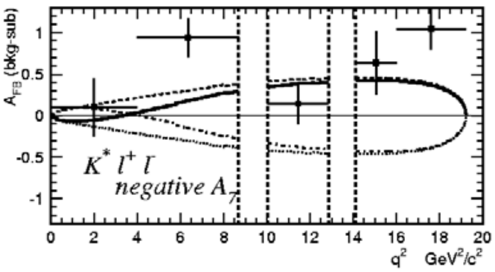
B→K l l control sample 96±12

Consistent with flat



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

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



Integrated FB asymmetry

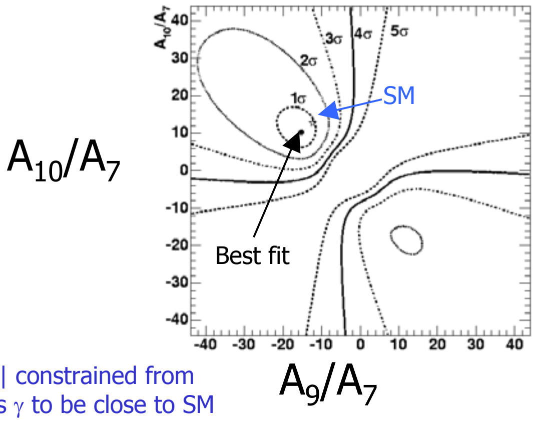
$$A_{FB}(B \to K^* l^- l^+) =$$
$$0.50 \pm 0.12 \pm 0.02; (3.4\sigma)$$

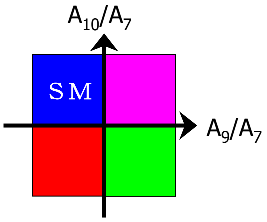
control sample:

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

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

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





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

Ref: hep-ex/0508009

	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	$10.3^{+5.2}_{-3.5} \pm 1.8$	$11.1^{+6.0}_{-3.9} \pm 2.4$

$$-1401 < A_9 A_{10}/A_7^2 < -26.4.$$

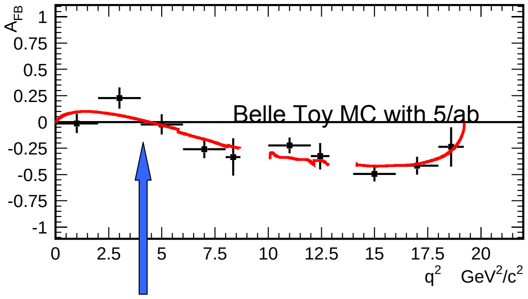
at 95% C.L.

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

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

  $\Delta A_9/A_9$~11%, $\Delta A_{10}/A_{10}$~13%

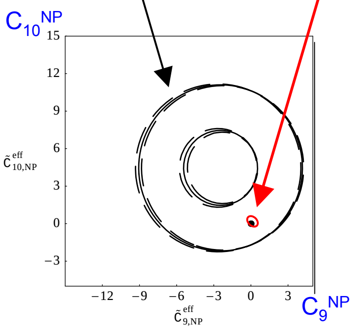
  - A_7 fixed to SM value



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

A_{FB} (K*ll) with 5/ab

Donut : B(B→Xs l l)
with140/fb + 100/fb



Fundamental Questions in Flavor Physics

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

Experiments: b→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→K π rates and asymmetries

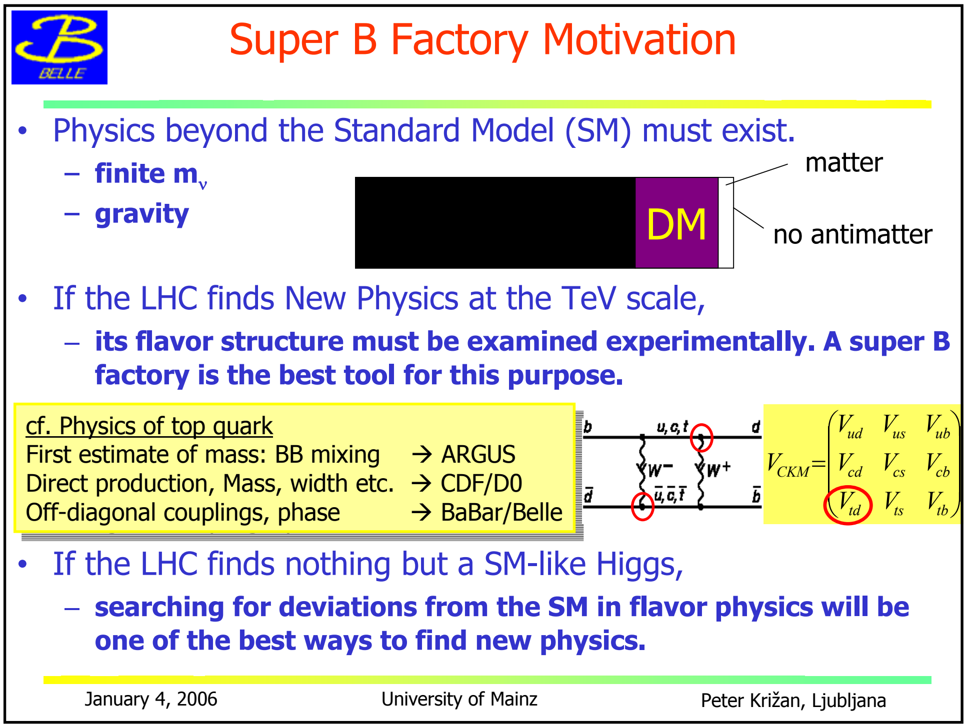
Are there right-handed currents ?

Experiments: b→s γ CPV, B→V V triple-product asymmetries

Are there new flavor changing neutral currents ?

Experiments: b→s ν ν bar, D-Dbar mixing+CPV+rare, $\tau\rightarrow\mu\gamma$

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



Super B Factory Motivation

- Physics beyond the Standard Model (SM) must exist.
  - **finite m_ν**
  - **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

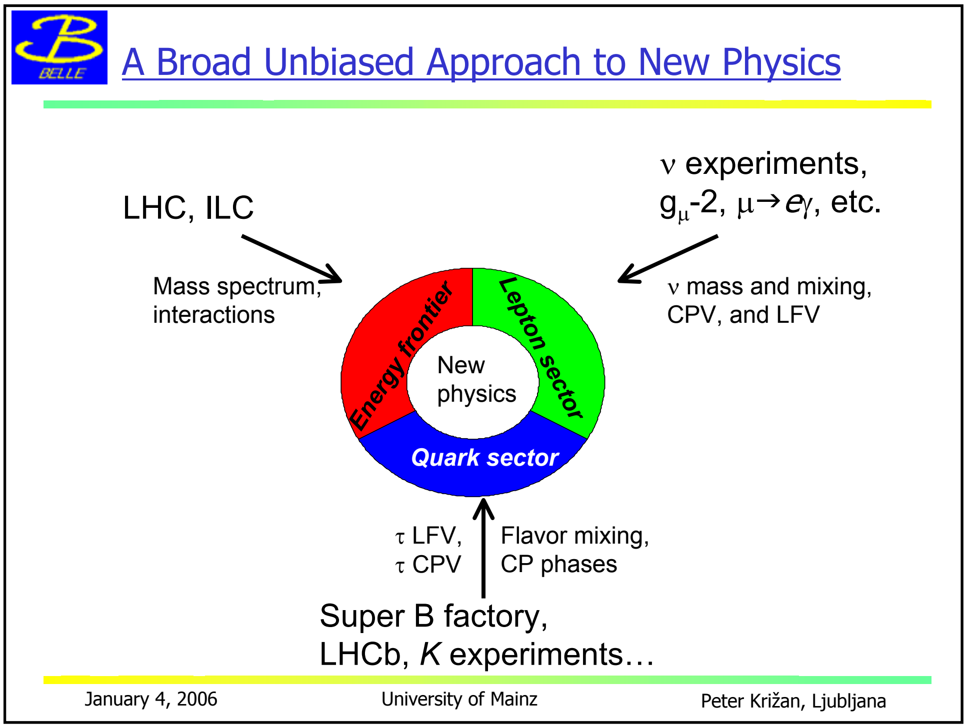
First estimate of mass: BB mixing → ARGUS

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

Off-diagonal couplings, phase → BaBar/Belle

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- 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.**



A Broad Unbiased Approach to New Physics

LHC, ILC

Mass spectrum, interactions

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

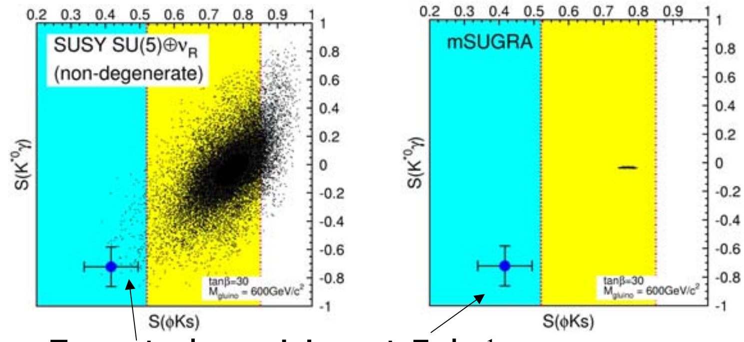
ν mass and mixing, CPV, and LFV

τ LFV, τ CPV

Flavor mixing, CP phases

Super B factory, LHCb, *K* experiments…

CPV in b → s and diagnosis of new physics



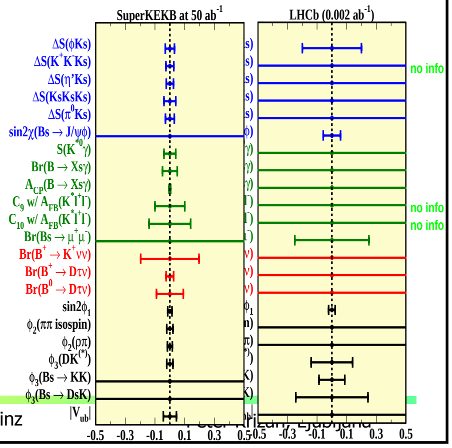
Expected precision at 5ab^{-1}

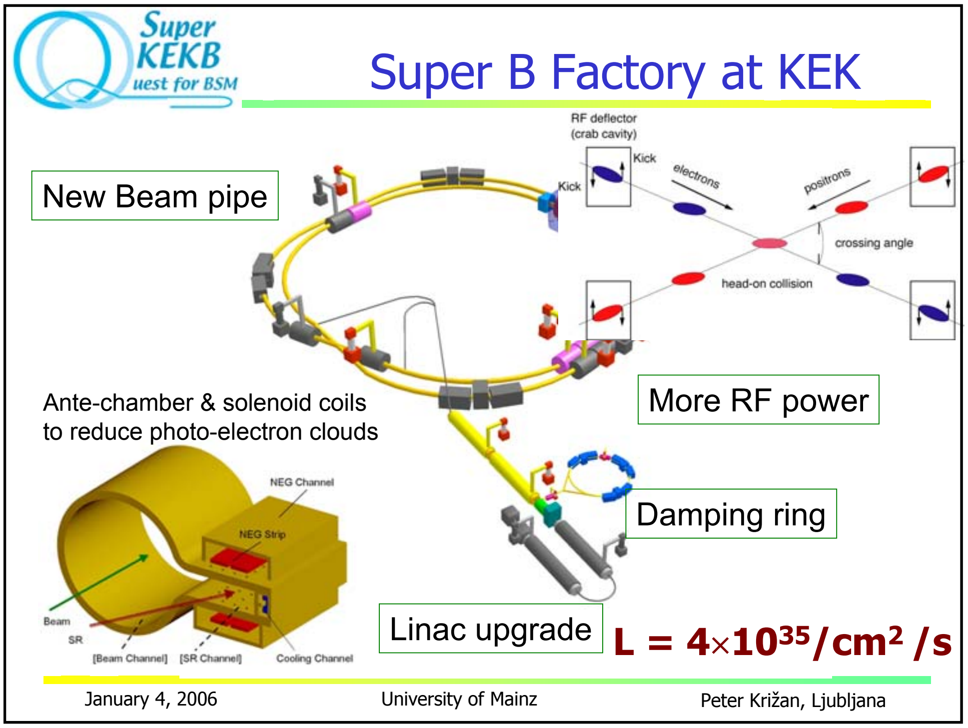
Many other examples of using correlations to distinguish new physics scenarios have been examined.

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

Comparison of Super-B and LHCb

- Clean environment → measurements that no other experiment can perform. Examples: CPV in ***B*** → φ***K⁰***, ***B*** → η'***K⁰*** for new phases, ***B*** → $K_S\pi^0\gamma$ for right-handed currents.
- "*B*-meson beam" technique → access to new decay modes. Example: discover *B* → *Kνν*.
- Measure new types of asymmetries Example: forward-backward asymmetry in ***b*** → ***s***μμ, ***see***
- Rich, broad physics program including *B*, τ and charm physics Examples: searches for *τ* → *μγ* and *D*-*D* mixing with unprecedented sensitivity.
- **No other experiment can compete for New Physics reach in the quark sector.**





Super B Factory at KEK

New Beam pipe

More RF power

Damping ring

Linac upgrade

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

$L = 4\times10^{35}/cm^2/s$

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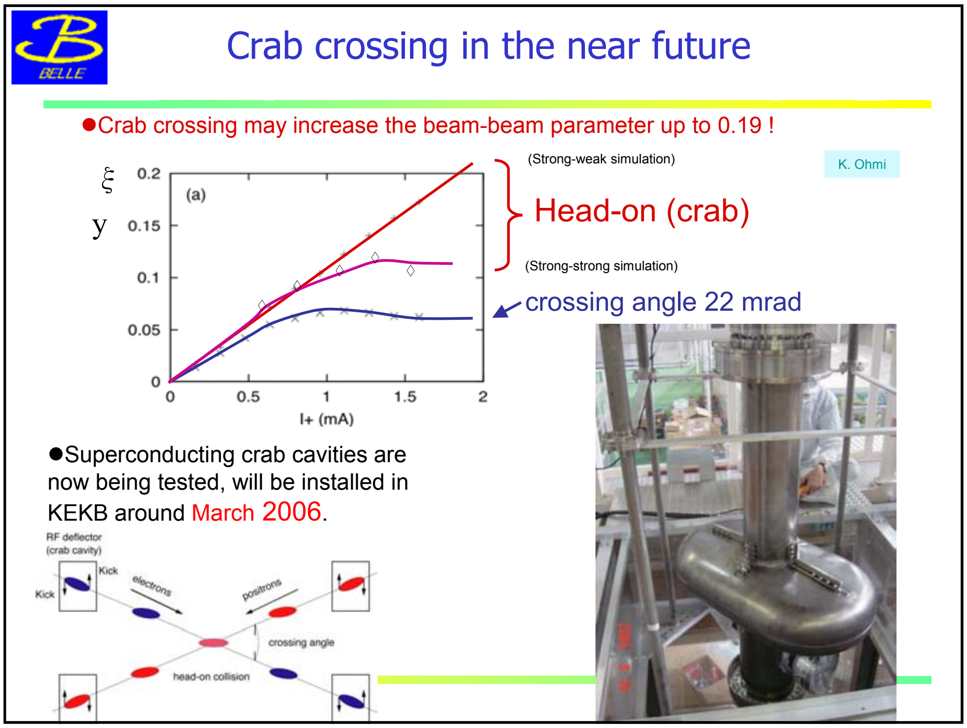


Crab crossing in the near future

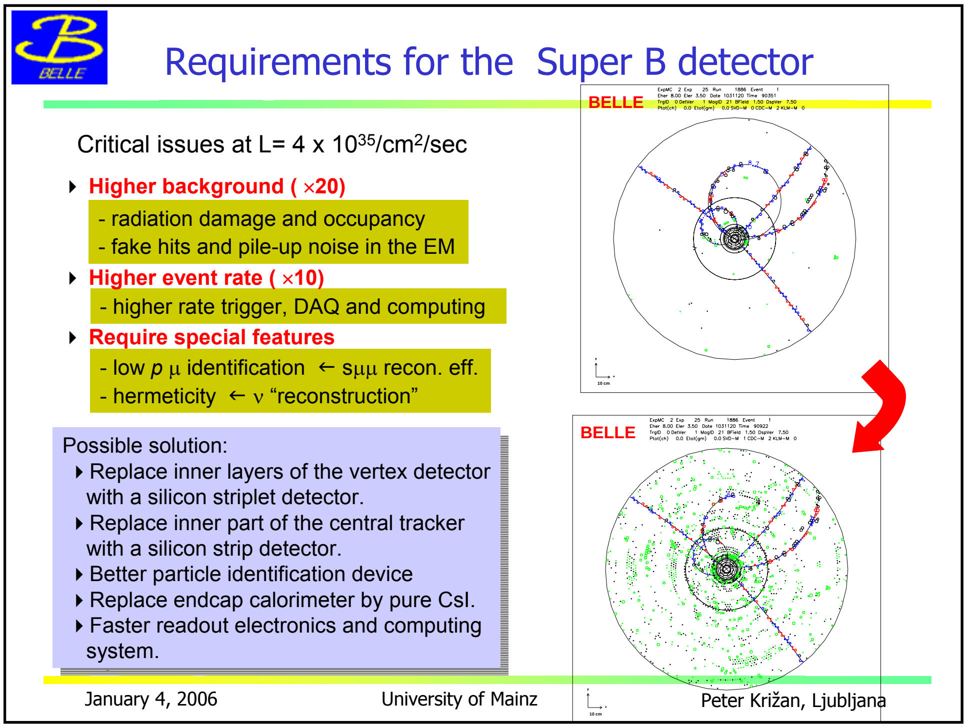
- Crab crossing may increase the beam-beam parameter up to 0.19 !

K. Ohmi

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 x 10^{35}/cm^2/sec

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

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

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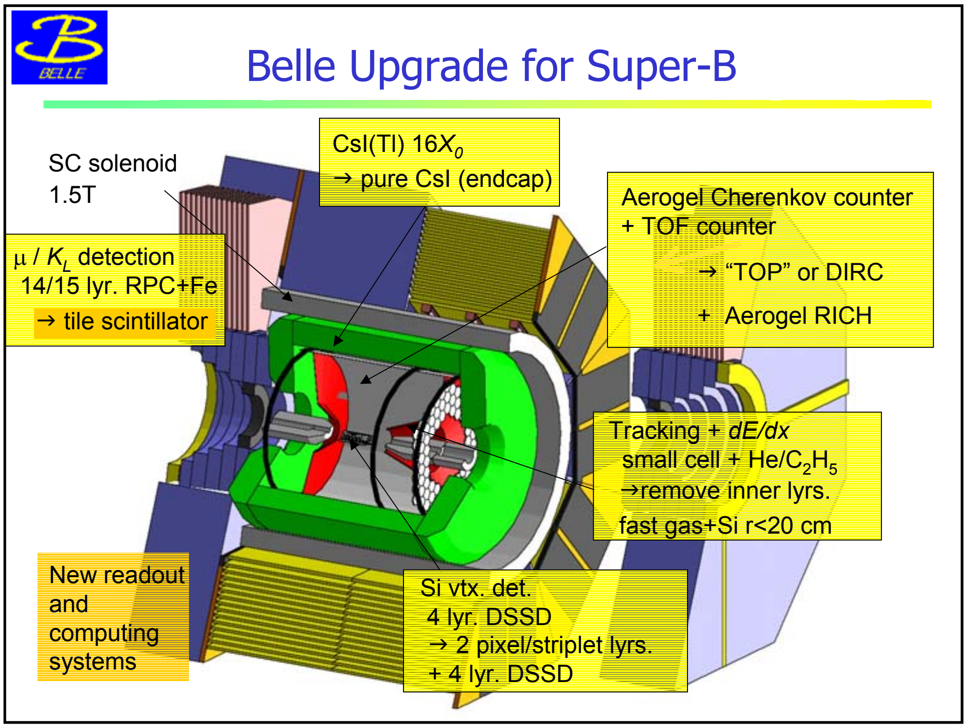


Belle Upgrade for Super-B

SC solenoid
1.5T

CsI(Tl) $16X_0$
→ pure CsI (endcap)

Aerogel Cherenkov counter
+ TOF counter
→ "TOP" or DIRC
+ Aerogel RICH

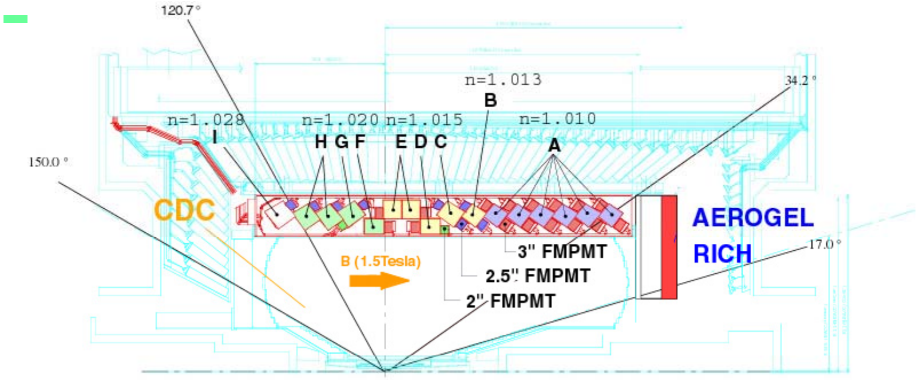
μ / K_L detection
14/15 lyr. RPC+Fe
→ tile scintillator

Tracking + dE/dx
small cell + He/C_2H_5
→remove inner lyrs.
fast gas+Si r<20 cm

New readout and computing systems

Si vtx. det.
4 lyr. DSSD
→ 2 pixel/striplet lyrs.
+ 4 lyr. DSSD

PID upgrade in the endcap



improve K/π separation in the forward (high mom.) region for few-body decays of B's

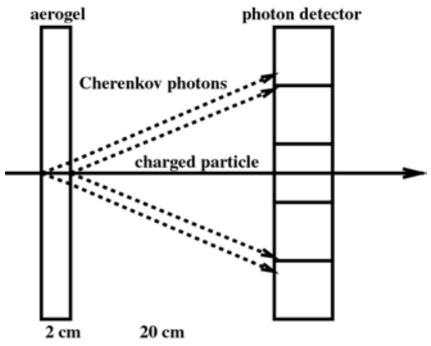
good K/π separation for b -> dγ , b -> sγ

improve purity in fully reconstructed B decays

low momentum (<1GeV/c) e/μ/π separation (B ->Kll)

keep high the efficiency for tagging kaons

Proximity focusing RICH in the forward region



K/π separation at 4 GeV/c
$\theta_c(\pi)$ ~ 308 mrad (n = 1.05)
$\theta_c(\pi)-\theta_c(K)$ ~ 23 mrad

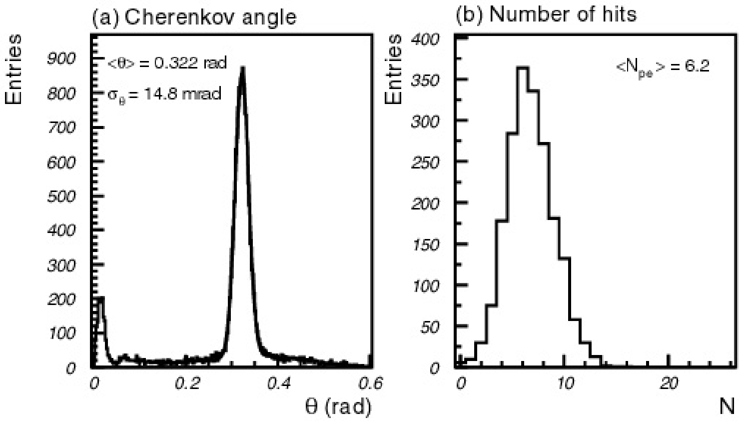
$d\theta_c$(meas.) = σ_0 ~ 13 mrad
With 20mm thick aerogel and 6mm PMT pad size

→ 6σ separation with N_{pe}~10

Beam test: Cherenkov angle resolution and number of photons

Beam test results with 2cm thick aerogel tiles:

>4σ K/π separation

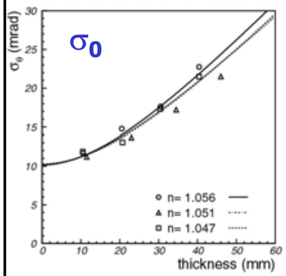


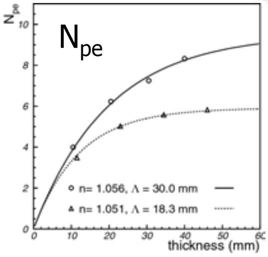
-> Number of photons has to be increased.

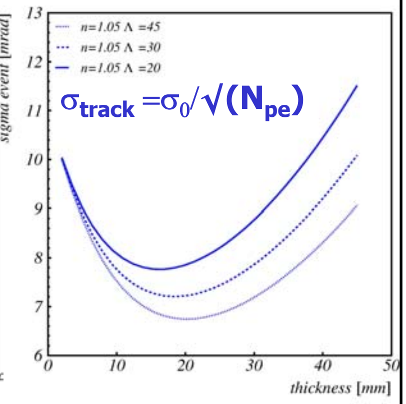
How to increase the number of photons?

What is the optimal radiator thickness?

Use beam test data on σ_0 and N_{pe}







Minimize the error per track: $\sigma_{track}=\sigma_0/\sqrt{(N_{pe})}$

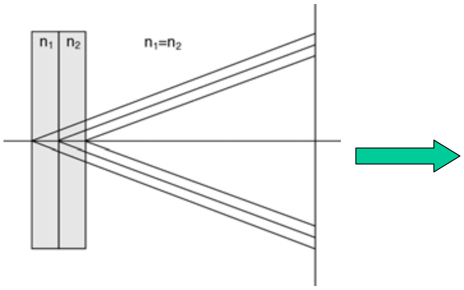
→ Optimum is close to 2 cm

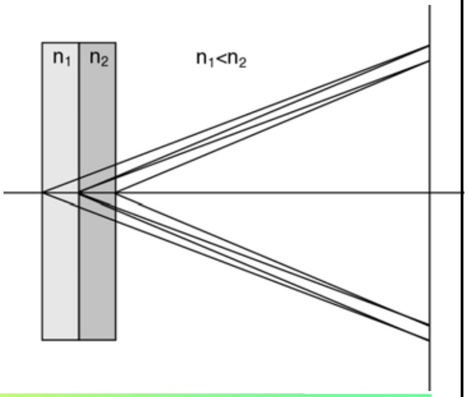
Radiator with multiple refractive indices

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

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

normal

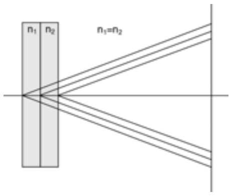


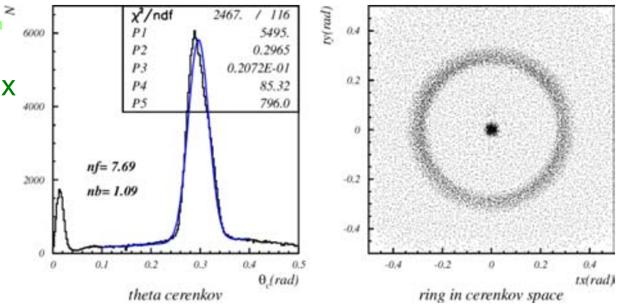


NIM A548 (2005) 383

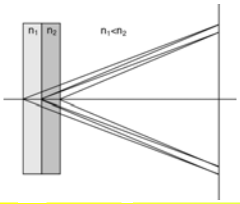
Focusing configuration – data

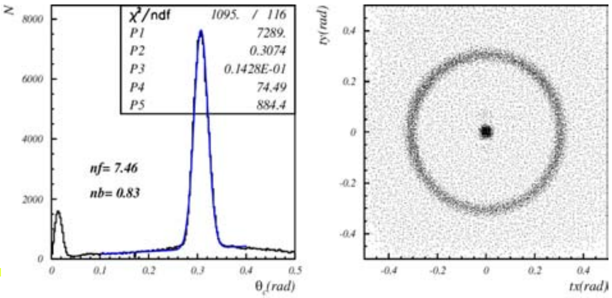
4cm aerogel single index





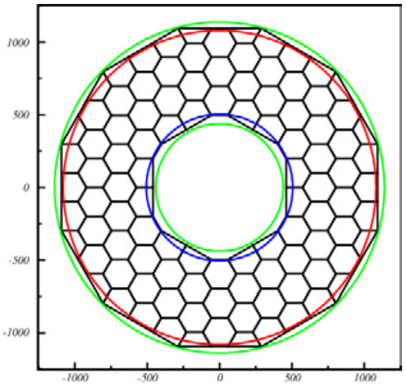
2+2cm aerogel





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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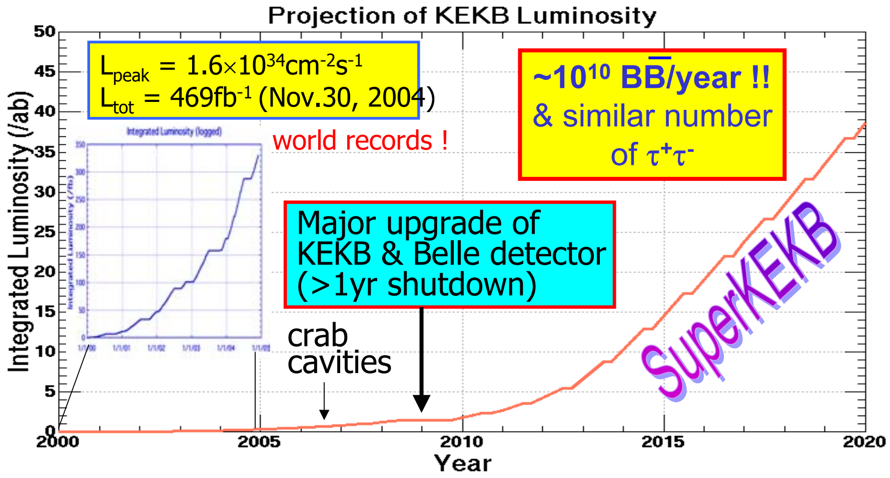
KEKB Collider Upgrade Scenario



L_{peak} = 1.6×10^{34}cm^{-2}s^{-1}
L_{tot} = 469fb^{-1} (Nov.30, 2004)

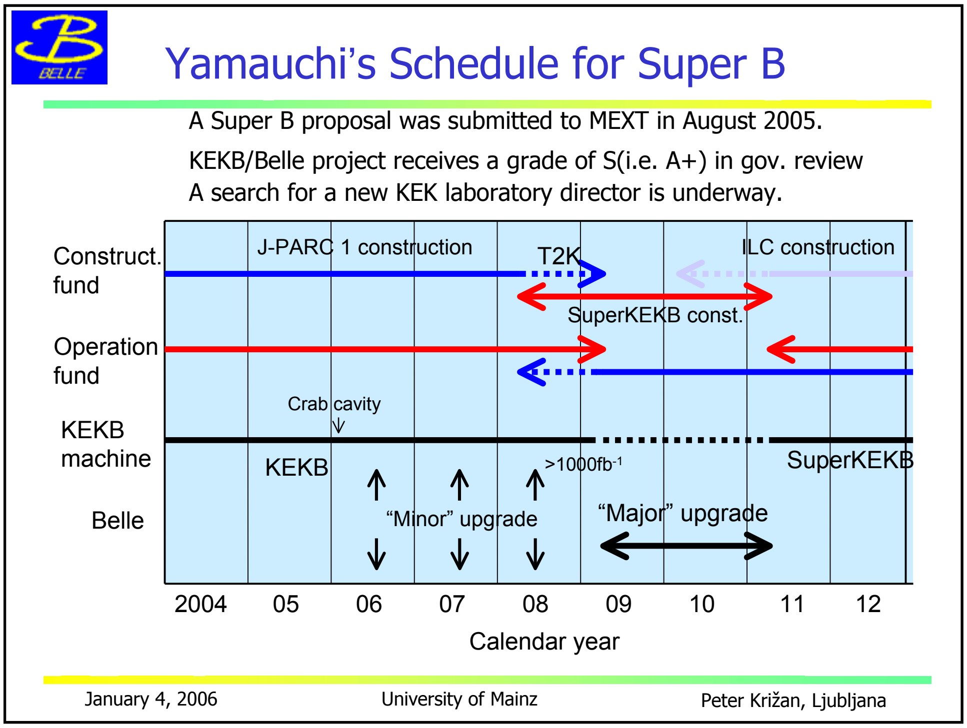
world records !

~10^{10} $B\overline{B}$/year !!
& similar number of $\tau^+\tau^-$

Major upgrade of KEKB & Belle detector (>1yr shutdown)

crab cavities

L_{peak} (cm^{-2}s^{-1}) 1.6x10^{34} → 5x10^{34} → 5x10^{35}
L_{int} 469 fb^{-1} → ~1 ab^{-1} → ~10 ab^{-1}

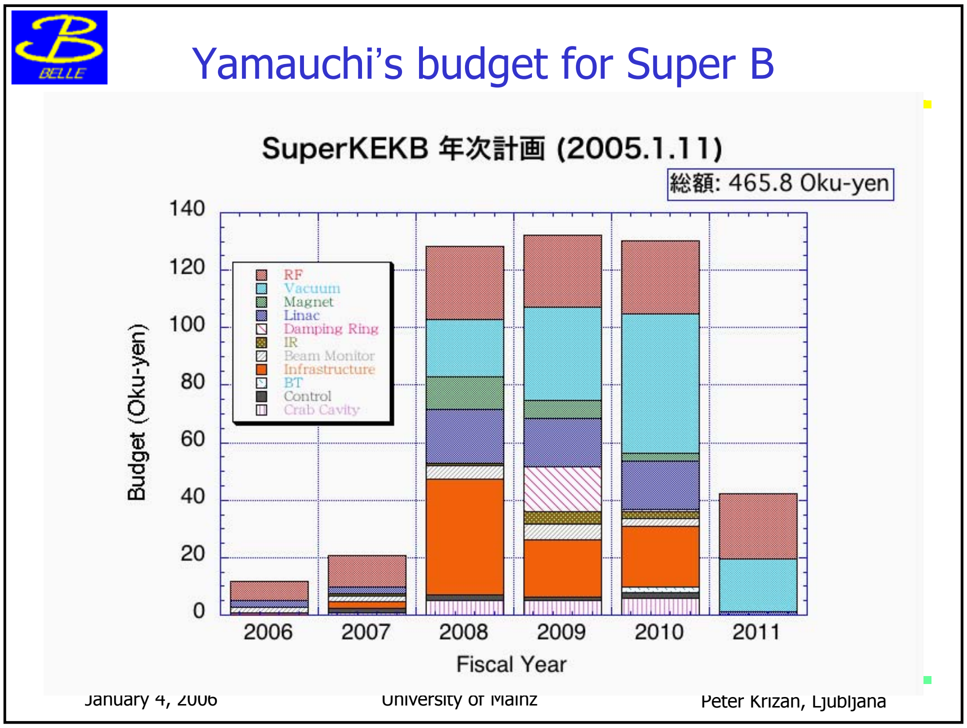


Yamauchi’s Schedule for Super B

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

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

A search for a new KEK laboratory director is underway.



Yamauchi’s budget for Super B

Summary 1

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

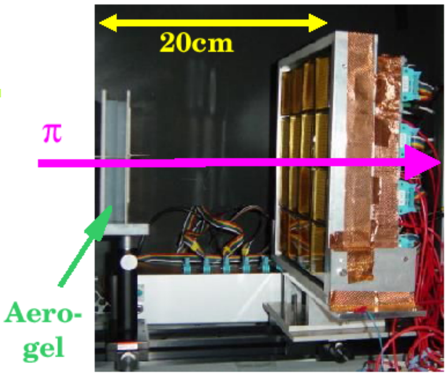
.... and there are much more interesting results, but could not be covered in this talk!

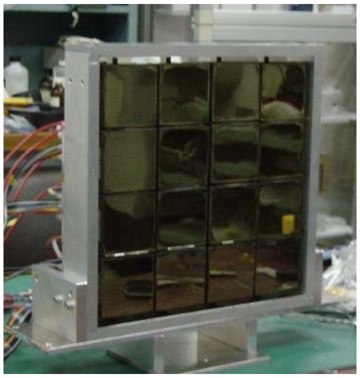
Summary 2

- 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...

Backup slides

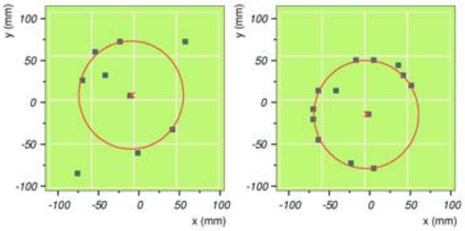
Beam tests



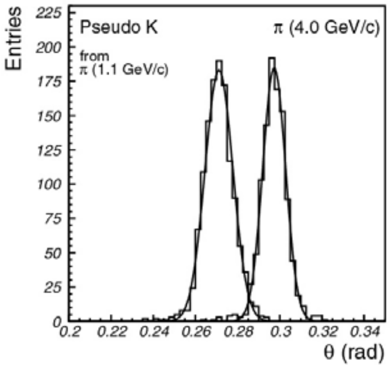


Photon detector: array of 16 H8500 PMTs

Clear rings, little background



PID capability on test beam data



From typical values (single photon resolution 13mrad and 6 detected photons) we can estimate the Cherenkov resolution per track: 5.3mrad;

-> 4.3sigma p/K separation a 4GeV/c.

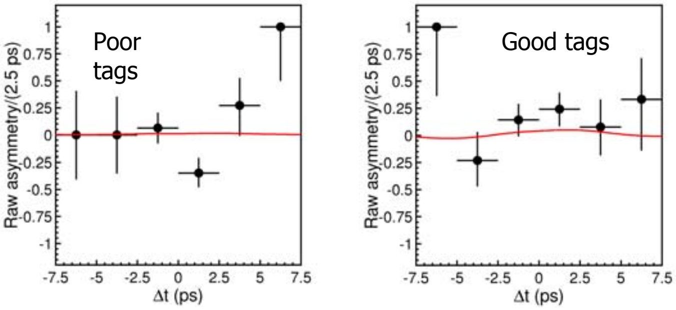
Illustration of PID performance: Cherenkov angle distribution for pions at 4GeV/c and 'kaons' (pions at 1.1GeV/c with the same Cherenkov angle as kaons at 4GeV/c).

Details: NIM paper

Photon detector: array of 16 H8500 PMTs

Search for Right-Handed Currents in B→$K_S\pi^0$ γ

Belle Update 2005 (386 x 10^6 B pairs):



Use the K_S to determine the vertex.

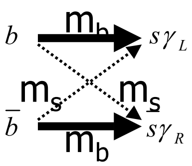
hep-ex/0507059

$$S(B\to K_S\pi^0\gamma)=0.08\pm0.41\pm0.10$$ (M_X<1.8 GeV)

In the SM, S should be close to zero (<0.10).

SM: γ is polarized, the final state almost flavor-specific.

$$S(B\to K_S\pi^0\gamma)=-2m_s/m_b\sin(2\phi_1)$$



Right-handed currents in b → sγ

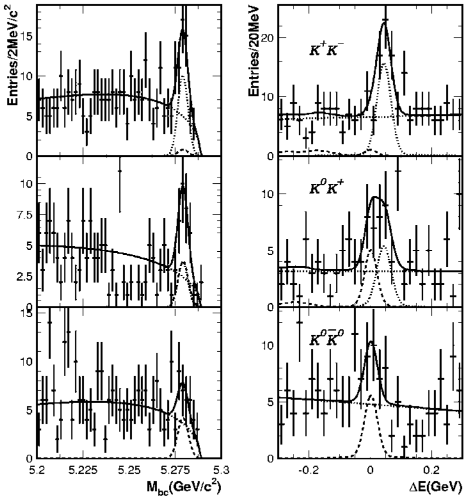
D.Atwood, M.Gronau, A.Soni (1997)
D.Atwood, T.Gershon, M.Hazumi A.Soni (2004)

- tCPV in $B^0 \to K_S\, \pi^0\gamma$
  - m_{heavy}/m_b enhancement for right-handed currents in many new physics models
    - LRSM, SUSY, Randall-Sundrum (warped extra dimension) model
  - LRSM: $SU(2)_L \times SU(2)_R \times U(1)$
    - Right-handed amplitude $\propto \zeta m_t/m_b$: ζ is W_L -W_R mixing parameter
    - for present exp. bounds ($\zeta < 0.003$, W_R mass > 1.4TeV) $|S(Ks\pi^0\gamma)| \sim 0.5$ is allowed.
  - *Here an asymmetry does not require a new CPV phase*

	Present Belle (stat.)	$5ab^{-1}$	$50ab^{-1}$
$S(B \to K^*\gamma, K^* \to Ks\pi^0)$	0.52	0.14	0.04

Evidence for B→K^0 K

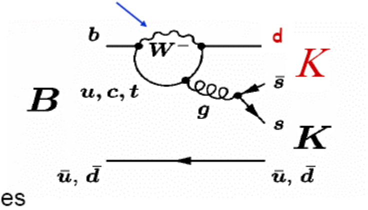
(hadronic b→d s $\bar{s}$ processes)



Belle@250 fb^{-1} hep-ex/0506080

Mode	Yield	Eff.(%)	Eff.$\times\mathcal{B}_s$ (%)	$\mathcal{B}(10^{-6})$	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
$K^0\overline{K}^0$	15.6 ± 5.8	28.7	6.8	$0.8 \pm 0.3 \pm 0.1$	3.5

SUSY particles in the loop



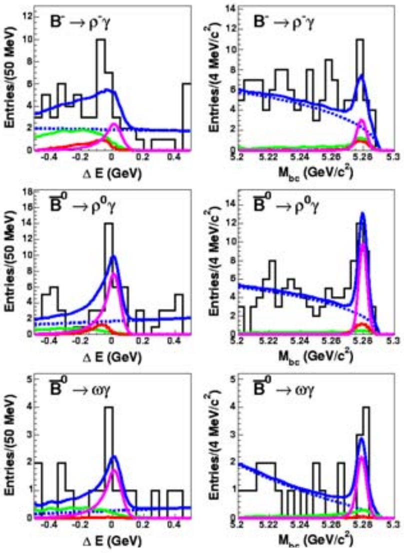
ses

"Smoking Gun" Penguins

Measurements of B→ K^0 K^0 CPV at Super B will be possible.

First Observation of b→d γ

hep-ex/0506079



Yields and significances

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

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

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

$$\begin{aligned} B(B\to(\rho,\omega)\gamma) &= (1.34^{+0.34\,+0.14}_{-0.31\,-0.10})\times 10^{-6} \\ B(B^-\to\rho^-\gamma) &= (0.55^{+0.43\,+0.12}_{-0.37\,-0.11})\times 10^{-6} \\ B(\overline{B^0}\to\rho^0\gamma) &= (1.17^{+0.35\,+0.09}_{-0.31\,-0.08})\times 10^{-6} \\ B(\overline{B^0}\to\omega\gamma) &= (0.58^{+0.35\,+0.07}_{-0.27\,-0.08})\times 10^{-6} \end{aligned}$$

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

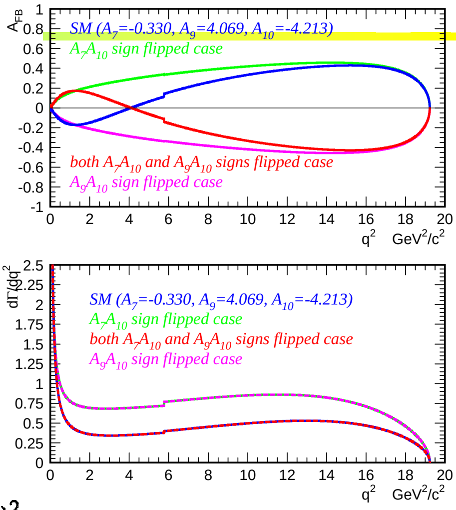
using $\frac{\tau_{B^+}}{\tau_{B^0}} = 1.076 \pm 0.008$

A Scary Slide about New Physics

$$\begin{aligned}
\mathcal{O}_1 &= (\bar{s}_\alpha\gamma_\mu L c_\beta)(\bar{c}_\beta\gamma^\mu L b_\alpha), \\
\mathcal{O}_2 &= (\bar{s}_\alpha\gamma_\mu L c_\alpha)(\bar{c}_\beta\gamma^\mu L b_\beta), \\
\mathcal{O}_3 &= (\bar{s}_\alpha\gamma_\mu L b_\alpha)\sum_{q=u,d,s,c,b}(\bar{q}_\beta\gamma^\mu L q_\beta), \\
\mathcal{O}_4 &= (\bar{s}_\alpha\gamma_\mu L c_\beta)\sum_{q=u,d,s,c,b}(\bar{q}_\beta\gamma^\mu L q_\alpha), \\
\mathcal{O}_5 &= (\bar{s}_\alpha\gamma_\mu L b_\alpha)\sum_{q=u,d,s,c,b}(\bar{q}_\beta\gamma^\mu R q_\beta), \\
\mathcal{O}_6 &= (\bar{s}_\alpha\gamma_\mu L c_\beta)\sum_{q=u,d,s,c,b}(\bar{q}_\beta\gamma^\mu R q_\alpha),
\end{aligned}$$

b→s γ

$$\begin{aligned}
\rightarrow\quad \mathcal{O}_7 &= \frac{e}{16\pi^2}\bar{s}_\alpha\sigma_{\mu\nu}(m_s L + m_b R)b_\alpha F^{\mu\nu}, \\
\mathcal{O}_8 &= \frac{g}{16\pi^2}\bar{s}_\alpha\sigma_{\mu\nu}(m_s L + m_b R)T^a_{\alpha\beta}b_\beta G^{a\mu\nu}, \\
\rightarrow\quad \mathcal{O}_9 &= \frac{e^2}{16\pi}\bar{s}_\alpha\gamma^\mu L b_\alpha\bar{\ell}\gamma_\mu\ell, \\
\rightarrow\quad \mathcal{O}_{10} &= \frac{e^2}{16\pi}\bar{s}_\alpha\gamma^\mu L b_\alpha\bar{\ell}\gamma_\mu\gamma_5\ell,
\end{aligned}$$



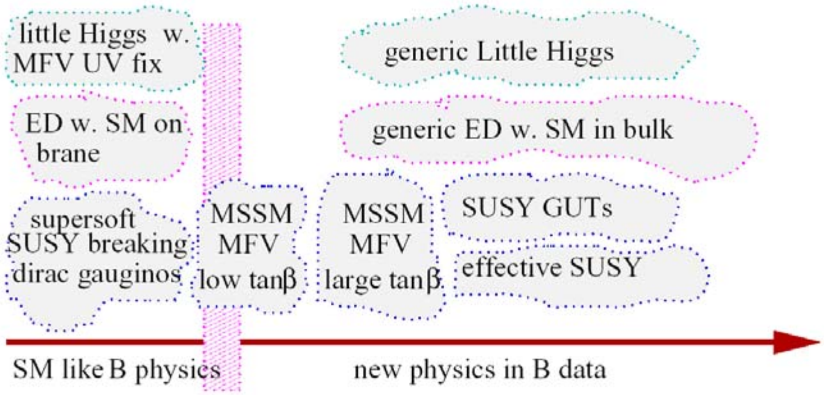
$$\frac{d}{d\hat{s}}(\Gamma_F^{K*} - \Gamma_B^{K*}) = \frac{G_F^2\alpha^2 m_B^5}{2^8\pi^5}|V_{ts}^*V_{tb}|^2\,\hat{s}\hat{u}(\hat{s})^2$$

$$\times\left[\mathrm{Re}(C_9{}^{\mathrm{eff}})C_{10}VA_1 + \frac{\hat{m}_b}{\hat{s}}C_7{}^{\mathrm{eff}}C_{10}(VT_2(1-\hat{m}_{K^*}) + A_1T_1(1+\hat{m}_{K^*}))\right].$$

New physics effects in B physics

Different New Physics scenarios
and their effects in *B* decays.

G.Hiller



Time evolution of B's

Time evolution:

$$\left|B^0_{phys}(t)\right\rangle = g_+(t)\left|B^0\right\rangle + (q/p)g_-(t)\left|\overline{B}^0\right\rangle$$

$$\left|\overline{B}^0_{phys}(t)\right\rangle = (p/q)g_-(t)\left|B^0\right\rangle + g_+(t)\left|\overline{B}^0\right\rangle$$

with

$$g_+(t) = e^{-iMt}e^{-\Gamma t/2}\cos(\Delta m t/2)$$

$$g_-(t) = e^{-iMt}e^{-\Gamma t/2} i\sin(\Delta m t/2)$$

$M = (M_H+M_L)/2$

CP violation: three types

Define decay amplitudes of B and anti-B to the same final state ***f***

$$A_f = \langle f | H | B^0 \rangle$$

$$\overline{A}_f = \langle f | H | \overline{B}^0 \rangle$$

Define also parameter λ

$$\lambda = \frac{q}{p} \frac{\overline{A}_f}{A_f}$$

Three types of CP violation (CPV):

$\not{CP}$ in decay: $|\overline{A}/A| \neq 1$

$\not{CP}$ in mixing: $|q/p| \neq 1$

$\Big\}$ $|\lambda| \neq 1$

$\not{CP}$ in interference between mixing and decay: even if $|\lambda| = 1$ if only $\mathrm{Im}(\lambda) \neq 0$

CP violation in decay

$\not{CP}$ in decay: $|\overline{A}/A| \neq 1$

(and of course also $|\lambda| \neq 1$)

$$a_f = \frac{\Gamma(B^+ \to f,t) - \Gamma(B^- \to \overline{f},t)}{\Gamma(B^+ \to f,t) + \Gamma(B^- \to \overline{f},t)} =$$

$$= \frac{1 - |\overline{A}/A|^2}{1 + |\overline{A}/A|^2}$$

Also possible for neutral B.

CP violation in decay

CPV in decay: |Ā/A| ≠ 1: how do we get there?

$$A_f = \sum_i A_i e^{i(\delta_i+\varphi_i)}$$

$$\bar{A}_{\bar{f}} = \sum_i A_i e^{i(\delta_i-\varphi_i)}$$

In general, A is a sum of amplitudes with Strong phases δ_i and weak phases ϕ_i. The amplitudes for anti-particles have same strong phases and opposite weak phases ->

$$\left|\frac{\bar{A}_{\bar{f}}}{A_f}\right| = \left|\frac{\sum_i A_i e^{i(\delta_i-\varphi_i)}}{\sum_i A_i e^{i(\delta_i+\varphi_i)}}\right|$$

$$\left|A_f\right|^2 - \left|\bar{A}_{\bar{f}}\right|^2 = \sum_{i,j} A_i A_j \sin(\varphi_i - \varphi_j)\sin(\delta_i - \delta_j)$$

CPV in decay: need at least two interfering amplitudes with different weak and strong phases.

CP violation in mixing

$\not{CP}$ in mixing: |q/p| ≠ 1 (again |λ| ≠ 1)

In general: probability for a B to turn into an anti-B can different from the probability for an anti-B to turn into a B.

$$\left|B^0_{phys}(t)\right\rangle = g_+(t)\left|B^0\right\rangle + (q/p)g_-(t)\left|\bar{B}^0\right\rangle$$

$$\left|\bar{B}^0_{phys}(t)\right\rangle = (p/q)g_-(t)\left|B^0\right\rangle + g_+(t)\left|\bar{B}^0\right\rangle$$

Example: semileptonic decays:

$$\left\langle l^-\nu X\right|H\left|B^0_{phys}(t)\right\rangle = (q/p)g_-(t)A^*$$

$$\left\langle l^+\nu X\right|H\left|\bar{B}^0_{phys}(t)\right\rangle = (p/q)g_-(t)A$$

CP violation in mixing

$$a_{sl} = \frac{\Gamma(\overline{B}^0_{phys}(t) \to l^+ \nu X) - \Gamma(B^0_{phys}(t) \to l^- \nu X)}{\Gamma(\overline{B}^0_{phys}(t) \to l^+ \nu X) + \Gamma(B^0_{phys}(t) \to l^- \nu X)} =$$

$$= \frac{1 - |q/p|^4}{1 + |q/p|^4}$$

-> Small, since to first order `|q/p|~1.` Next order:

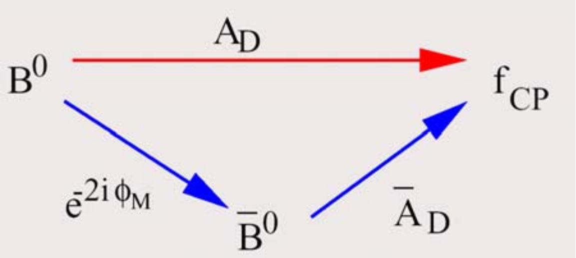
$$\frac{q}{p} = -\frac{|M_{12}|}{M_{12}}\left[1 - \frac{1}{2}\mathrm{Im}\left(\frac{\Gamma_{12}}{M_{12}}\right)\right]$$

Expect O(0.01) effect in semileptonic decays

CP violation in the interference between decays with and without mixing

CP violation in the interference between mixing and decay to a state accessible in both B^0 and anti-B^0 decays

For example: a CP eigenstate f_{CP} like $\pi^+ \pi^-$



$$\lambda = \frac{q}{p}\frac{\overline{A}_f}{A_f}$$

`We can get CP violation if Im(λ) ≠ 0, even if |λ| = 1`

CP violation in the interference between decays with and without mixing

Decay rate asymmetry:

$$a_{f_{CP}} = \frac{P(\overline{B}^0 \to f_{CP},t) - P(B^0 \to f_{CP},t)}{P(\overline{B}^0 \to f_{CP},t) + P(B^0 \to f_{CP},t)}$$

Decay rate: $P(B^0 \to f_{CP},t) \propto \left|\langle f_{CP}|H|B^0_{phys}(t)\rangle\right|^2$

Decay amplitudes vs time:

$$\langle f_{CP}|H|B^0_{phys}(t)\rangle = g_+(t)\langle f_{CP}|H|B^0\rangle + (q/p)g_-(t)\langle f_{CP}|H|\overline{B}^0\rangle$$

$$= g_+(t)A_{f_{CP}} + (q/p)g_-(t)\overline{A}_{f_{CP}}$$

$$\langle f_{CP}|H|\overline{B}^0_{phys}(t)\rangle = (p/q)g_-(t)\langle f_{CP}|H|B^0\rangle + g_+(t)\langle f_{CP}|H|\overline{B}^0\rangle$$

$$= (p/q)g_-(t)A_{f_{CP}} + g_+(t)\overline{A}_{f_{CP}}$$

CP violation in the interference between decays with and without mixing

$$a_{f_{CP}} = \frac{P(\overline{B}^0 \to f_{CP},t) - P(B^0 \to f_{CP},t)}{P(\overline{B}^0 \to f_{CP},t) + P(B^0 \to f_{CP},t)} =$$

$$\lambda = \frac{q}{p}\frac{\overline{A}_f}{A_f}$$

$$= \frac{(1-|\lambda_{f_{CP}}|^2)\cos(\Delta m t) - 2\,\mathrm{Im}(\lambda_{f_{CP}})\sin(\Delta m t)}{1+|\lambda_{f_{CP}}|^2}$$

Non-zero effect if Im(λ) ≠ 0,
even if |λ| = 1

If in addition |λ| = 1 ->

$$a_{f_{CP}} = -\mathrm{Im}(\lambda_{f_{CP}})\sin(\Delta m t)$$

CP violation in the interference between decays with and without mixing

One more form for λ:

$$\lambda_{f_{CP}} = \frac{q}{p}\frac{\overline{A}_{f_{CP}}}{A_{f_{CP}}} = \eta_{f_{CP}}\frac{q}{p}\frac{\overline{A}_{\overline{f}_{CP}}}{A_{f_{CP}}}$$

η_{fcp}=+-1 CP parity of f_{CP}

-> we get one more (–1) sign when comparing asymmetries in two states with opposite CP parity

$$a_{f_{CP}} = -\mathrm{Im}(\lambda_{f_{CP}})\sin(\Delta m t)$$

Direct and indirect CP violation

Direct CP: due to phases in ΔF=1 decays
-> CP violation in decay

$$\langle f|H|B^0\rangle = A_f \neq \overline{A}_f = \langle f|H|\overline{B}^0\rangle$$

Indirect CP: due to phases in ΔF=2 decays
-> CP violation in mixing

$$1 \neq \frac{q}{p} = -\frac{|M_{12}|}{M_{12}}\left[1-\frac{1}{2}\mathrm{Im}\left(\frac{\Gamma_{12}}{M_{12}}\right)\right]$$

CP violation in the interference between mixing and decay: indirect. However, if measurement of $\mathrm{Im}(\lambda_{f_{CP}}) \neq 0$ in more than one final state -> must be direct CPV as well.