Belle: recent results and future plans

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Experimental apparatus: Belle at KEK-B

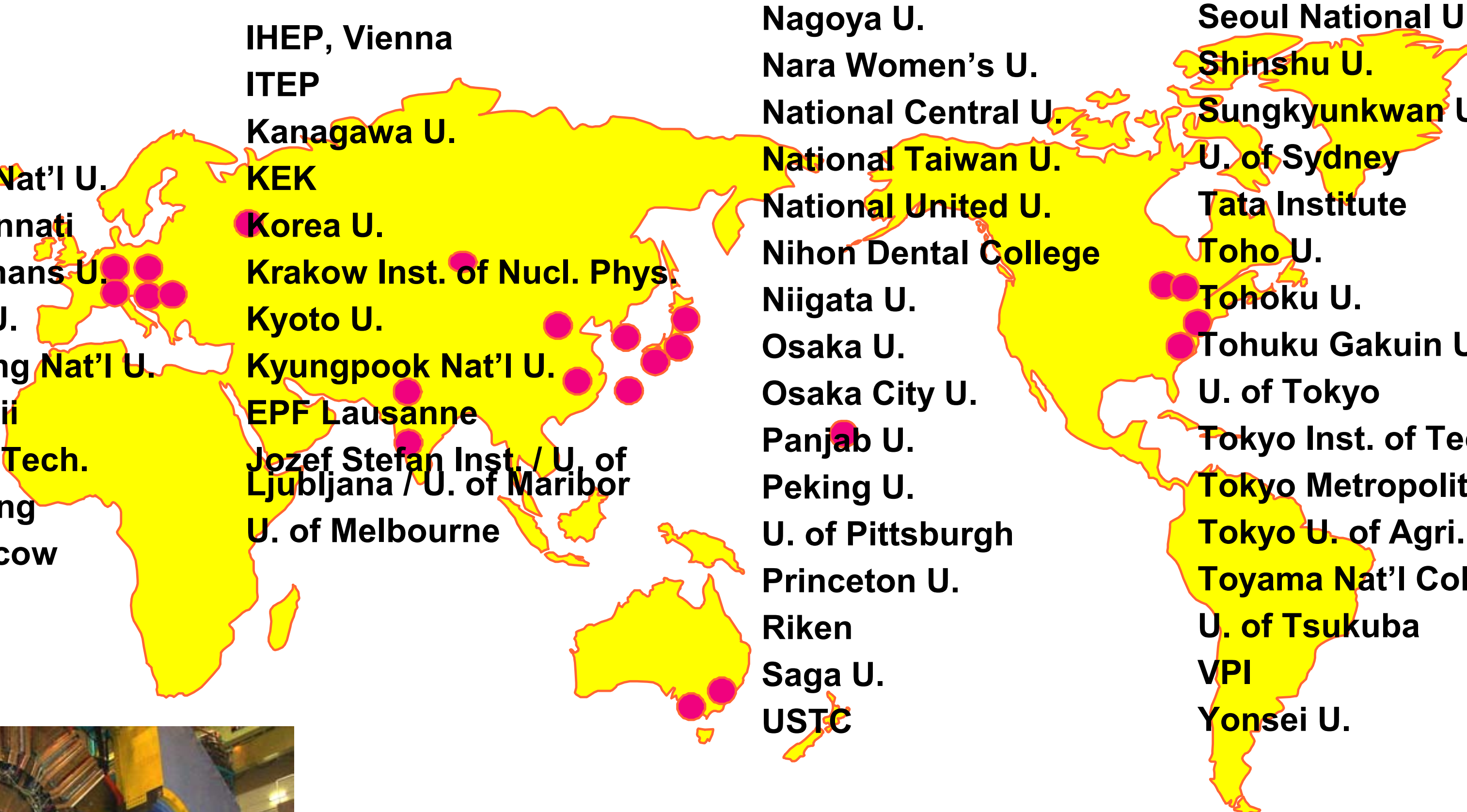
CP violation in the B system

Searching for New Physics: FCNC processes

- Observation of b→d penguins: $B \to \rho\gamma, \omega\gamma$ decays
- CP violation in b→s decays
- A_{fb} vs q^2 in $B \to K^* l^+ l^-$ 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
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National United U.
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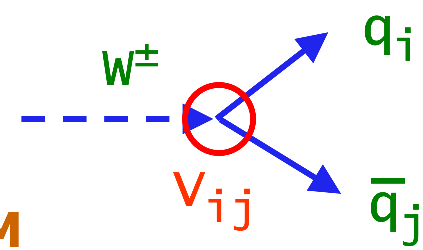
Tohoku U.
Tohuku Gakuin U.
U. of Tokyo
Tokyo Inst. of Tech.
Tokyo Metropolitan U.
Tokyo U. of Agri. and Tech.
Toyama Nat'l College
U. of Tsukuba
VPI
Yonsei U.

13 countries, 55 institutes, ~400 collaborators

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

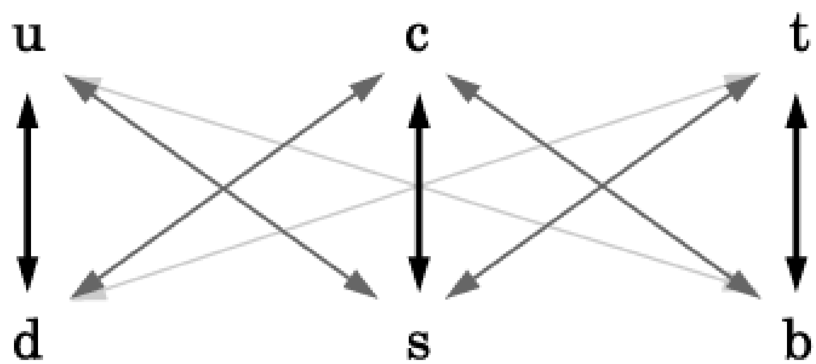


CKM matrix is unitary

deviations could signal processes not included in SM

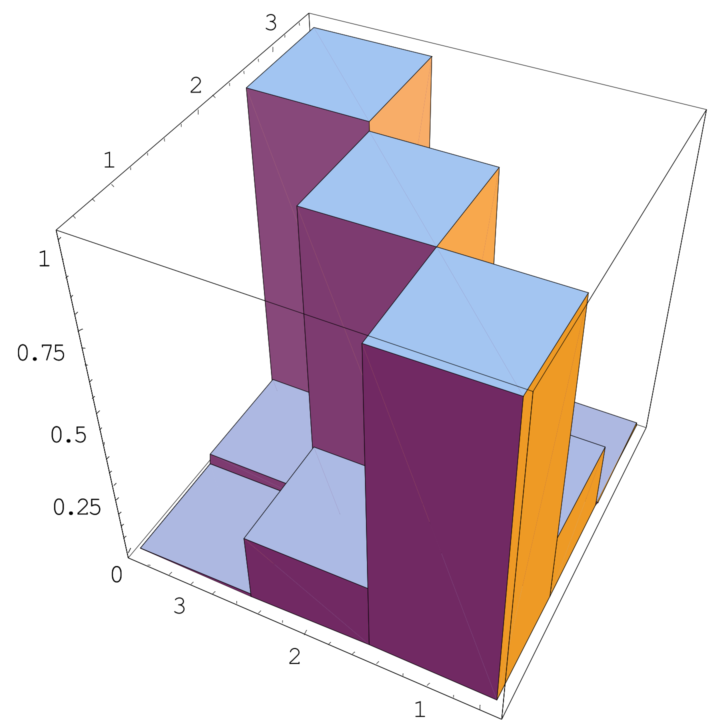
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\bar{\rho}-i\bar{\eta}) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\bar{\rho}-i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix}$$

CKM matrix



Transitions between members of the same family more probable (=thicker lines) than others

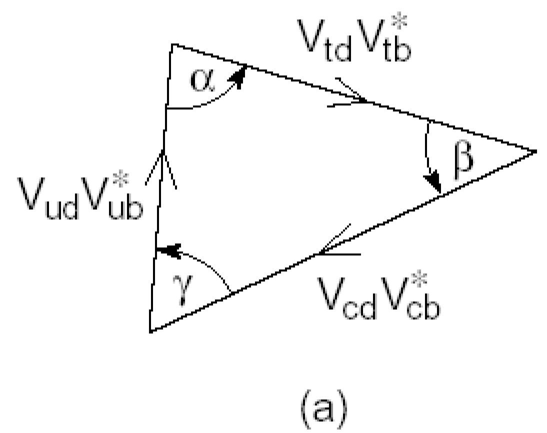
-> CKM: almost a diagonal matrix, but not completely ->



Unitarity triangle

Unitarity condition:

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

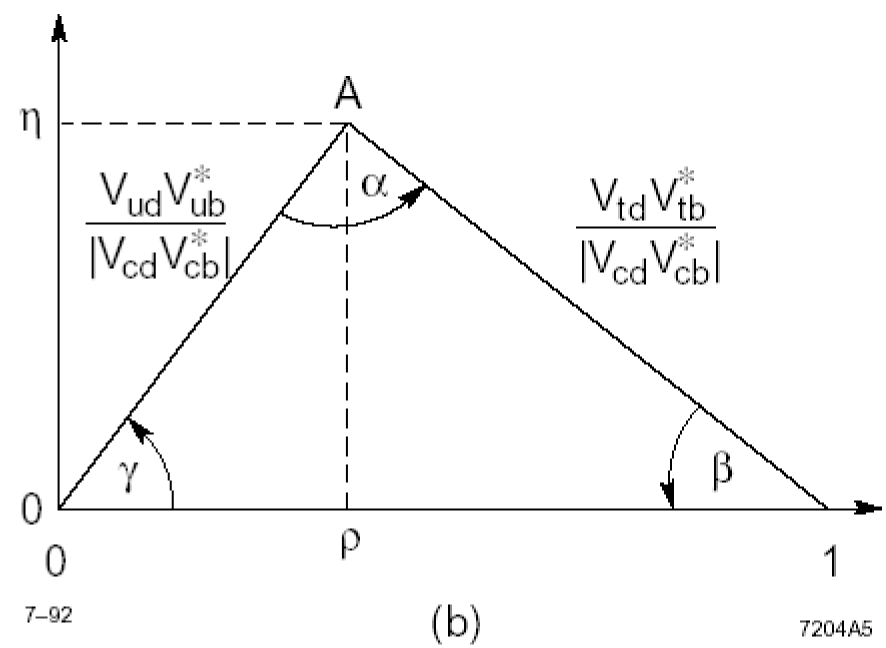


Another notation:

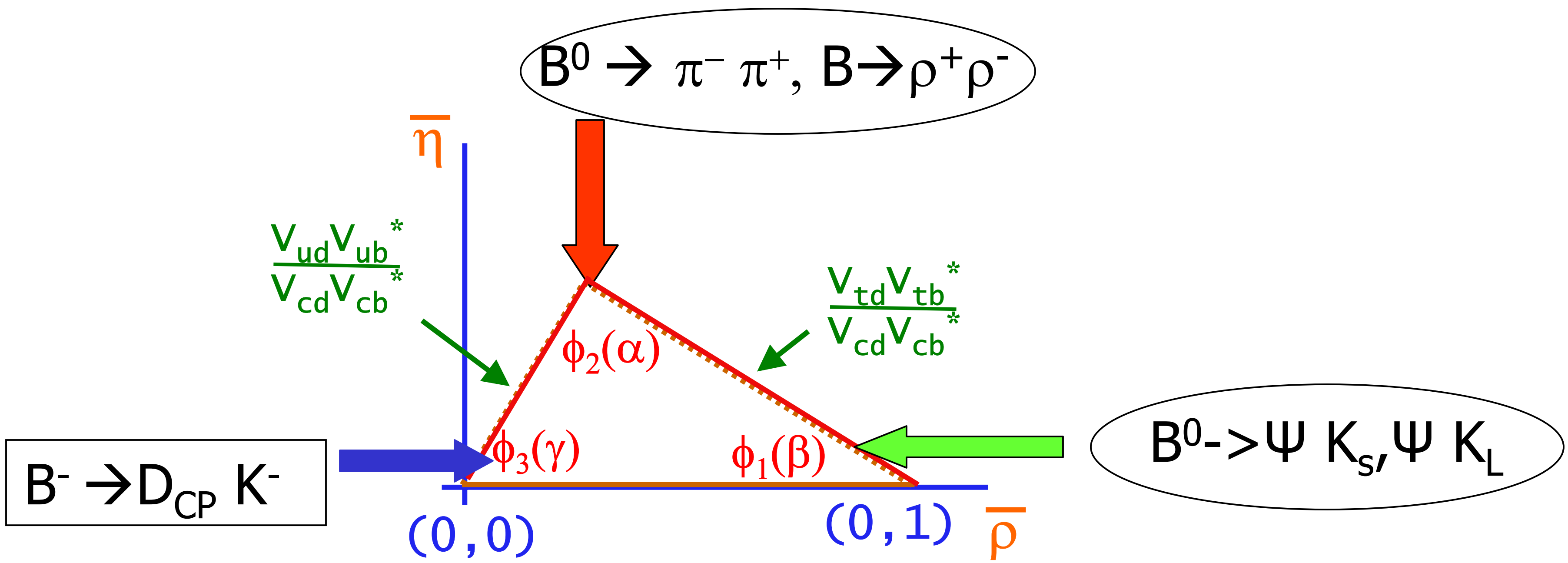
$\phi_1=\beta$

$\phi_2=\alpha$

$\phi_3=\gamma$

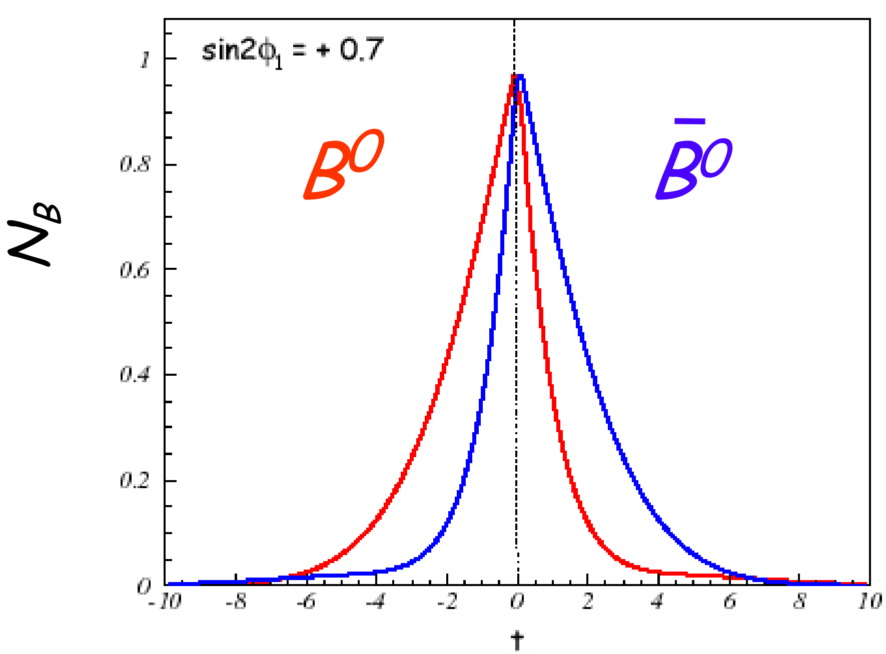


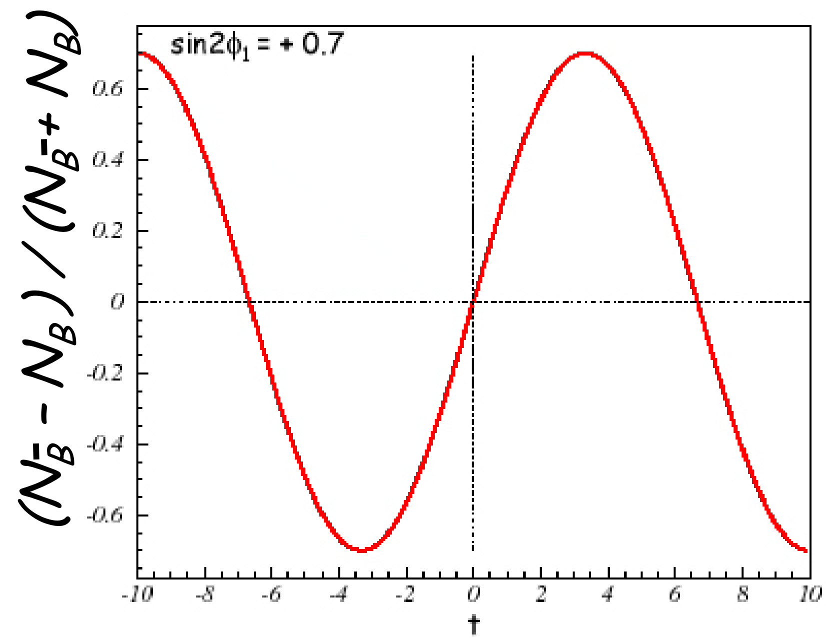
Three Angles: (ϕ_1,ϕ_2,ϕ_3) or (β, α, γ)



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

CP Violation in B → f_{CP} decays

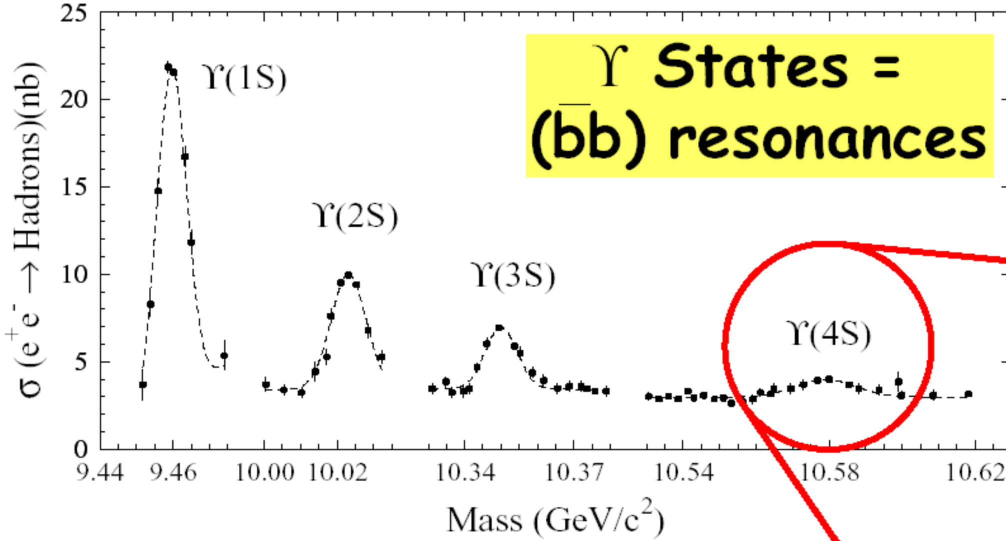


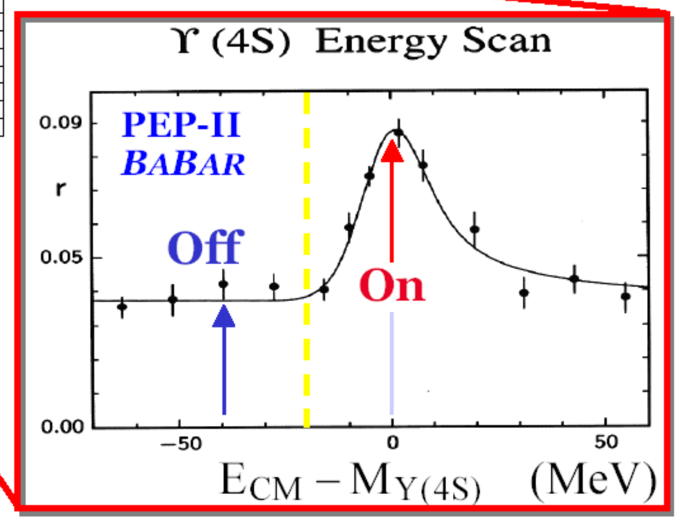


$$A_{CP}(t) = \frac{\Gamma(\overline{B}^0(t) \to f_{CP}) - \Gamma(B^0(t) \to f_{CP})}{\Gamma(\overline{B}^0(t) \to f_{CP}) + \Gamma(B^0(t) \to f_{CP})} = -\xi_f \sin 2\phi_1 \sin \Delta m_B t$$

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

B meson production at Υ(4s)





Cross Sections at Υ(4S):

$b\bar{b} \sim 1.1$ nb

$c\bar{c} \sim 1.3$ nb

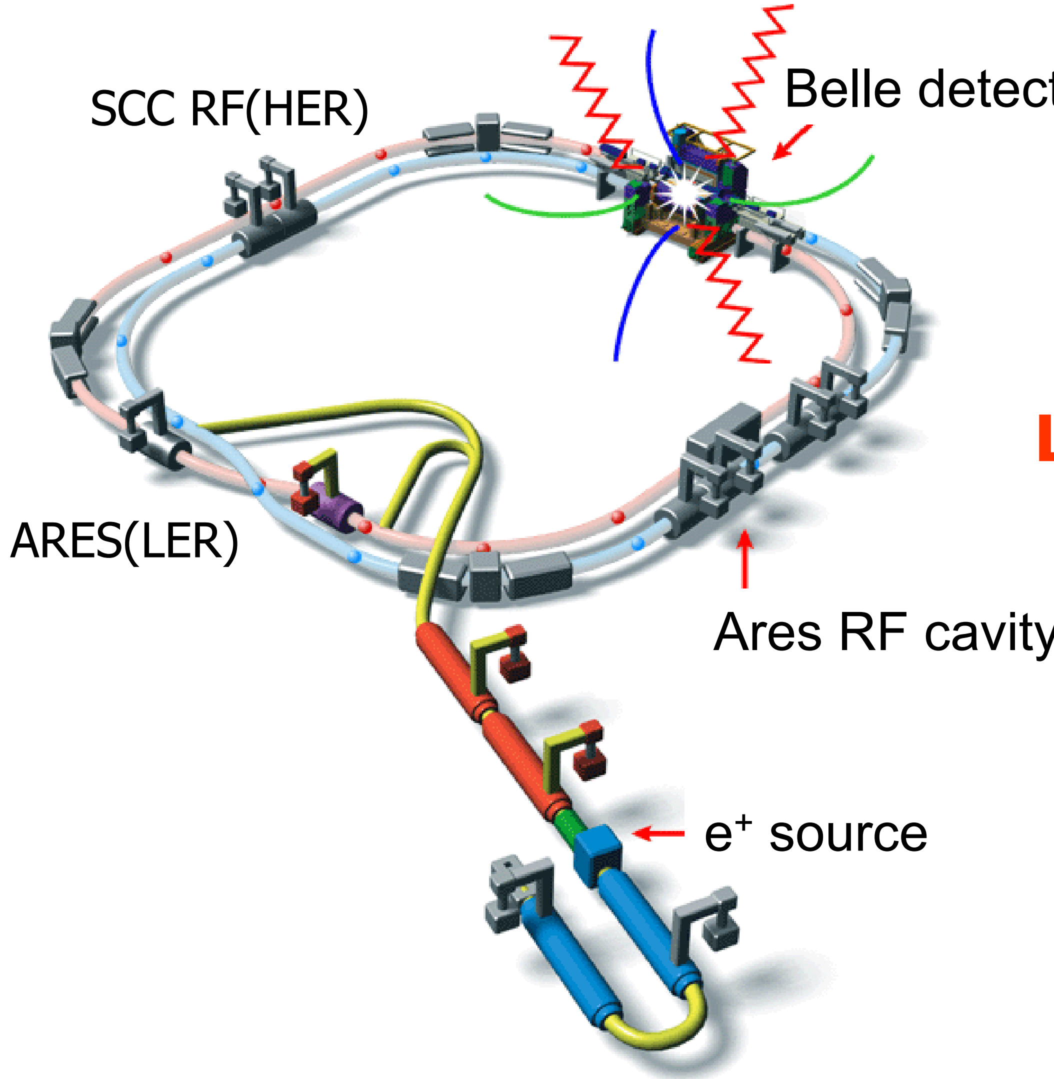
$d\bar{d}$, $s\bar{s} \sim 0.3$ nb

$u\bar{u} \sim 1.4$ nb

$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$

$L = 1$ state

The KEKB Collider



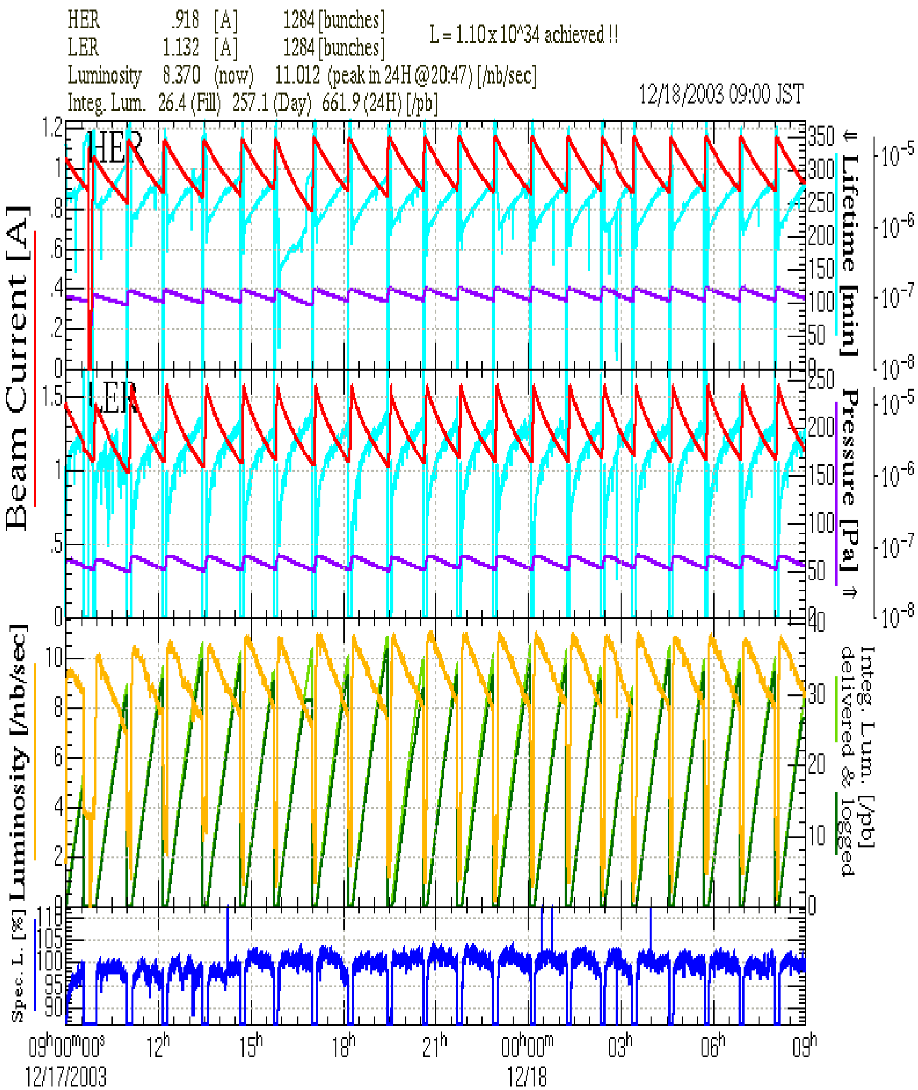
8 x 3.5 GeV
22mrad crossing angle

World record:

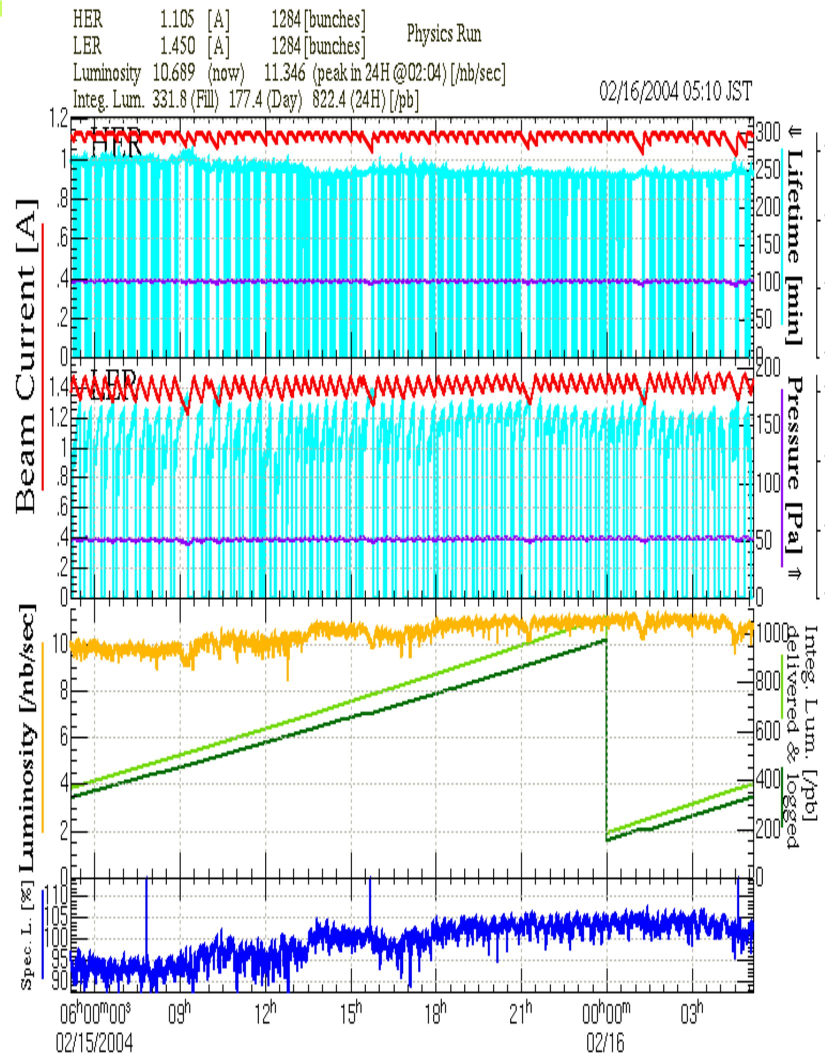
L = 1.6 x 10^{34}/cm^2/sec

Normal injection

Continuous injection



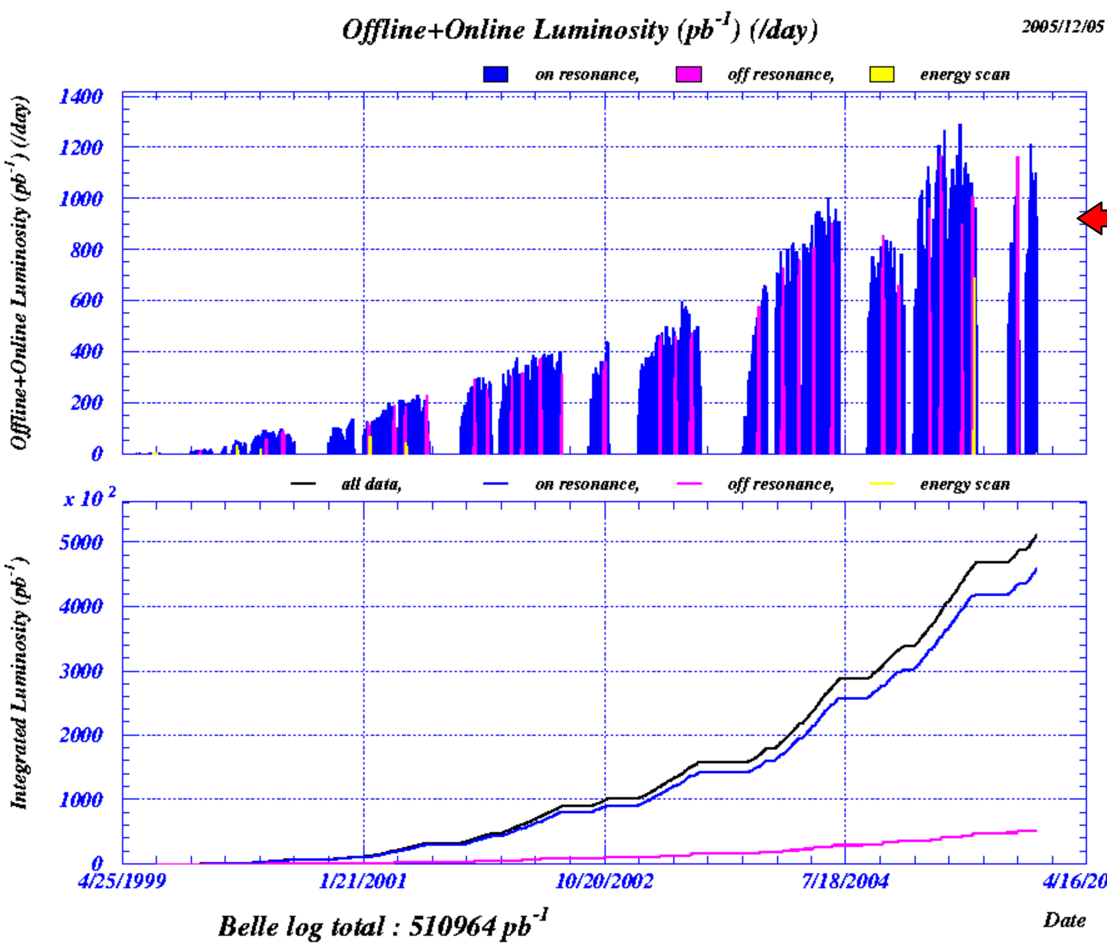
661/pb/day



→1182/pb/day

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

Accumulated > 500 M BB-pairs



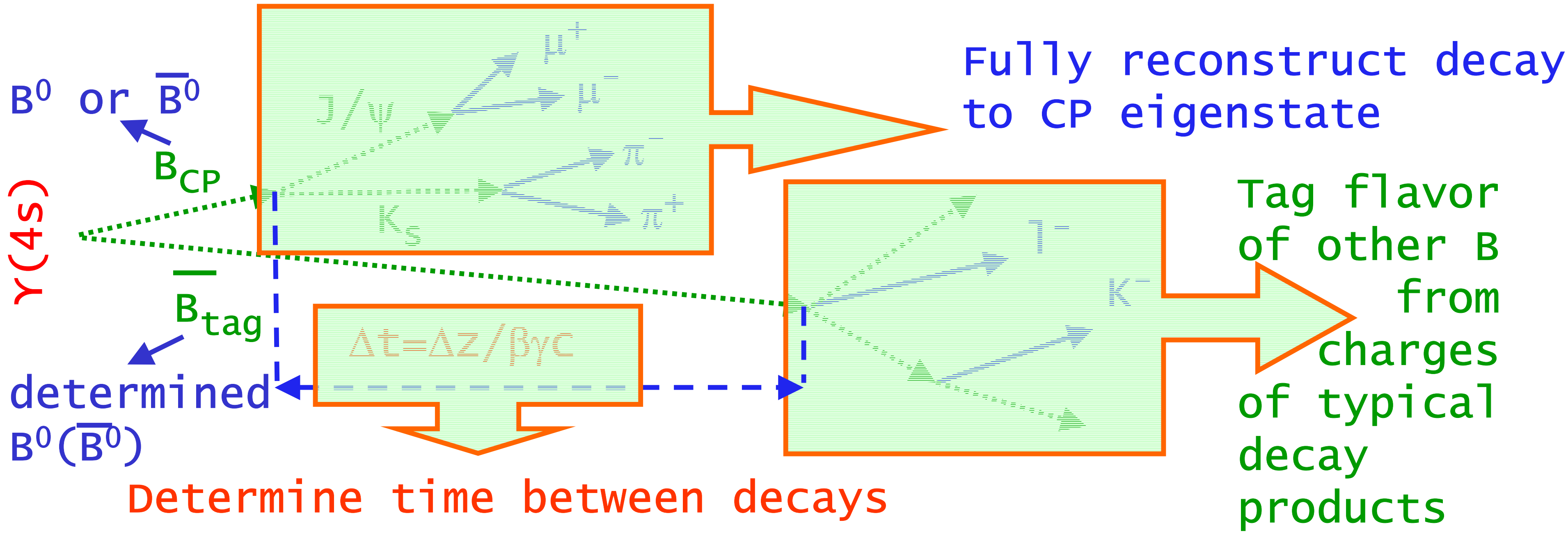
1 fb^{-1}/day

Total =512 fb^{-1}

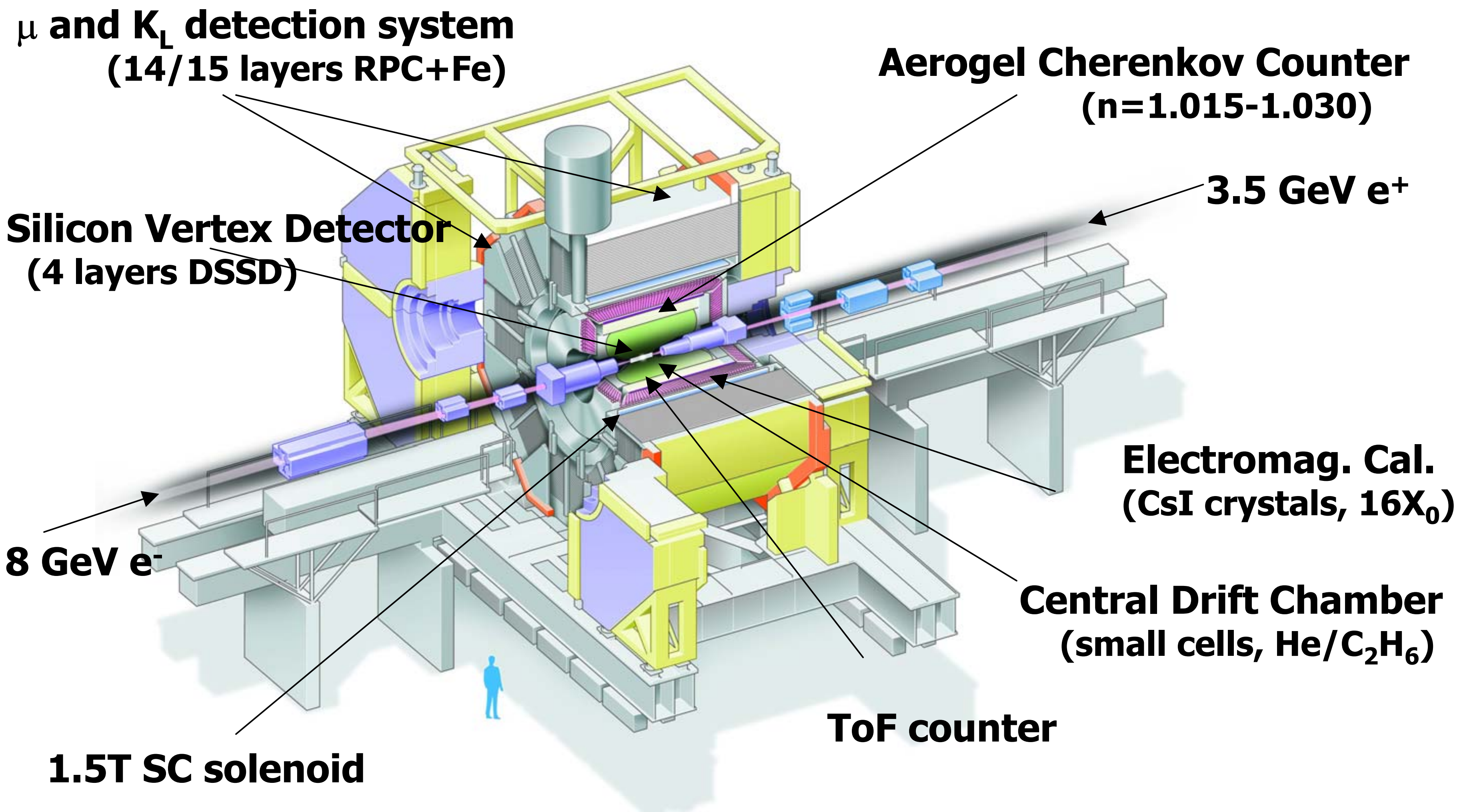
Today: some results with 350 fb^{-1} (386 x 10^6) B B pairs

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

Principle of measurement

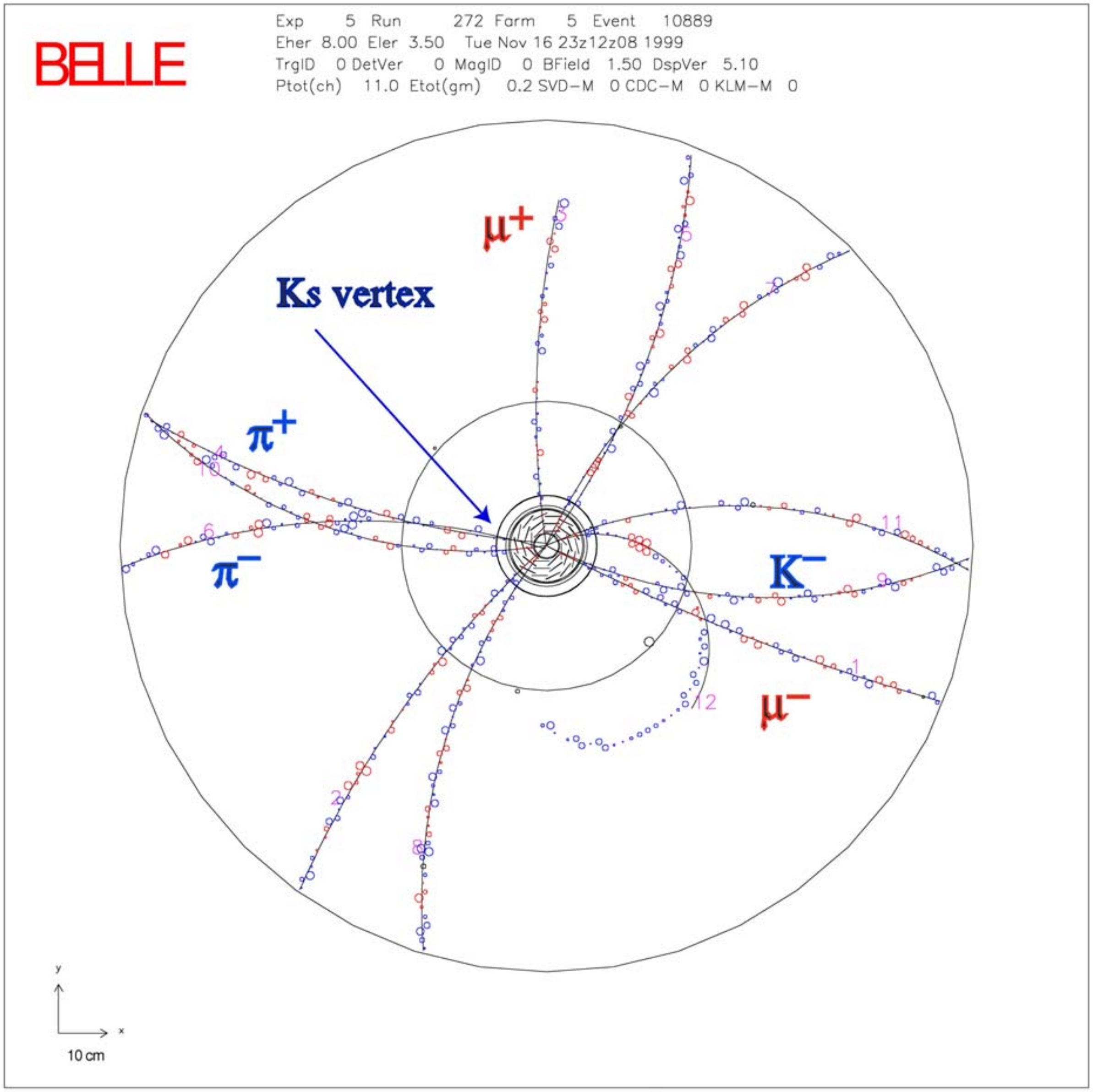


Belle spectrometer at KEK-B

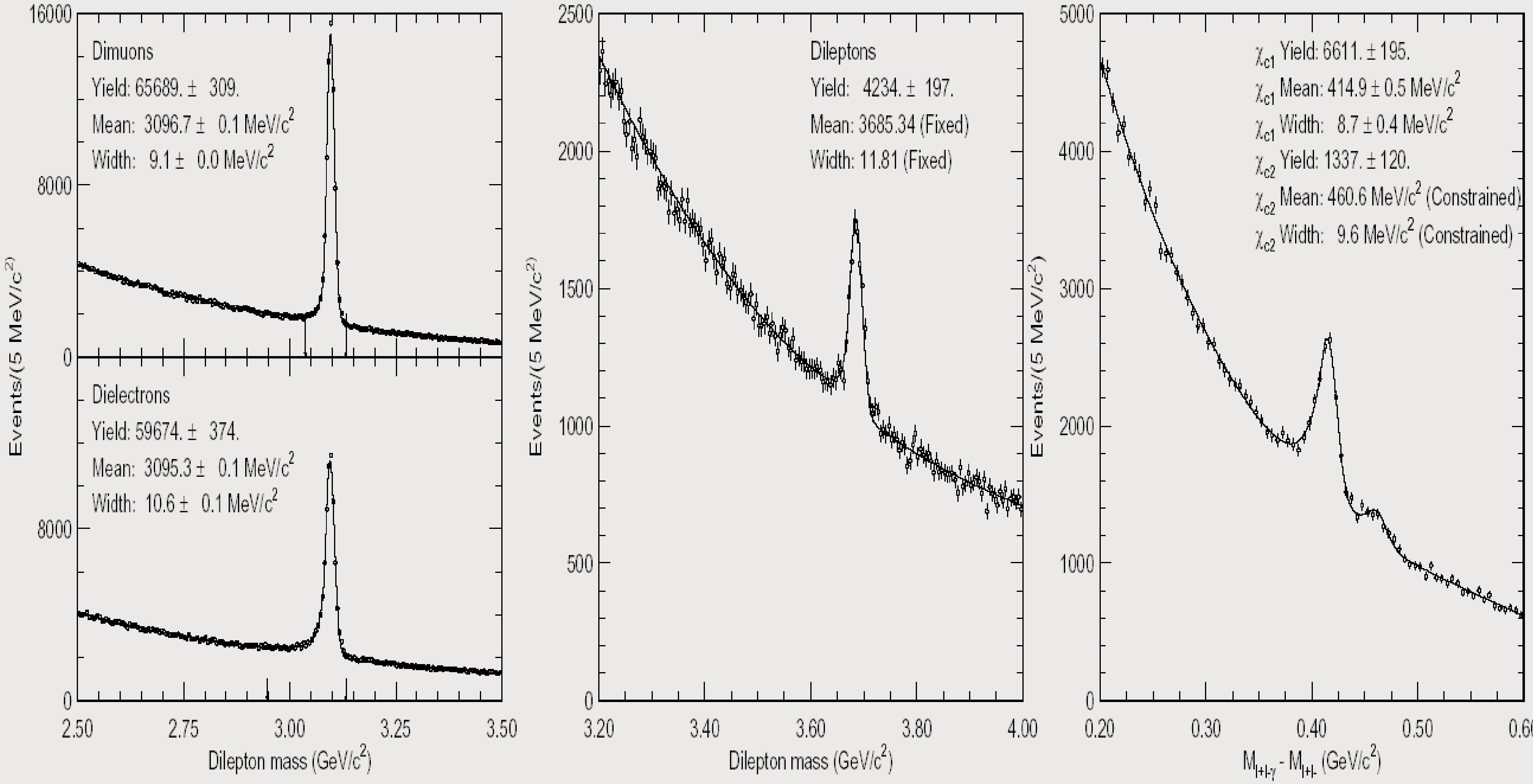


A golden channel event

$B^0 \rightarrow J/\Psi\ K_s$



Reconstructing chamonium states



$J/\psi \rightarrow \mu^+\mu^-, e^+e^-$

$\sigma_M = 9.6(10.7)\mathrm{GeV}/c^2$

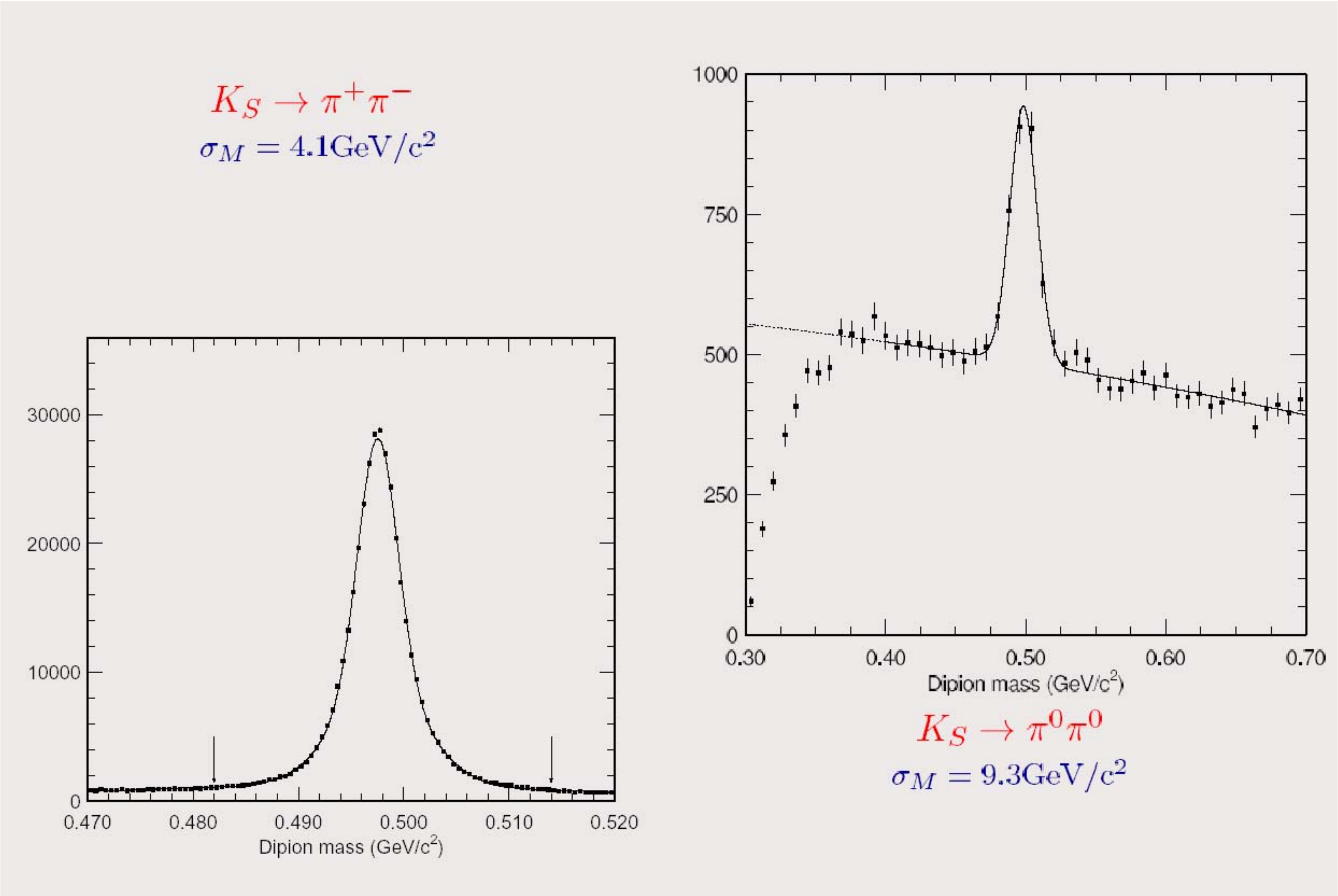
$\psi(2s) \rightarrow \mu^+\mu^-, e^+e^-$

$\sigma_M = 12.1\mathrm{GeV}/c^2$

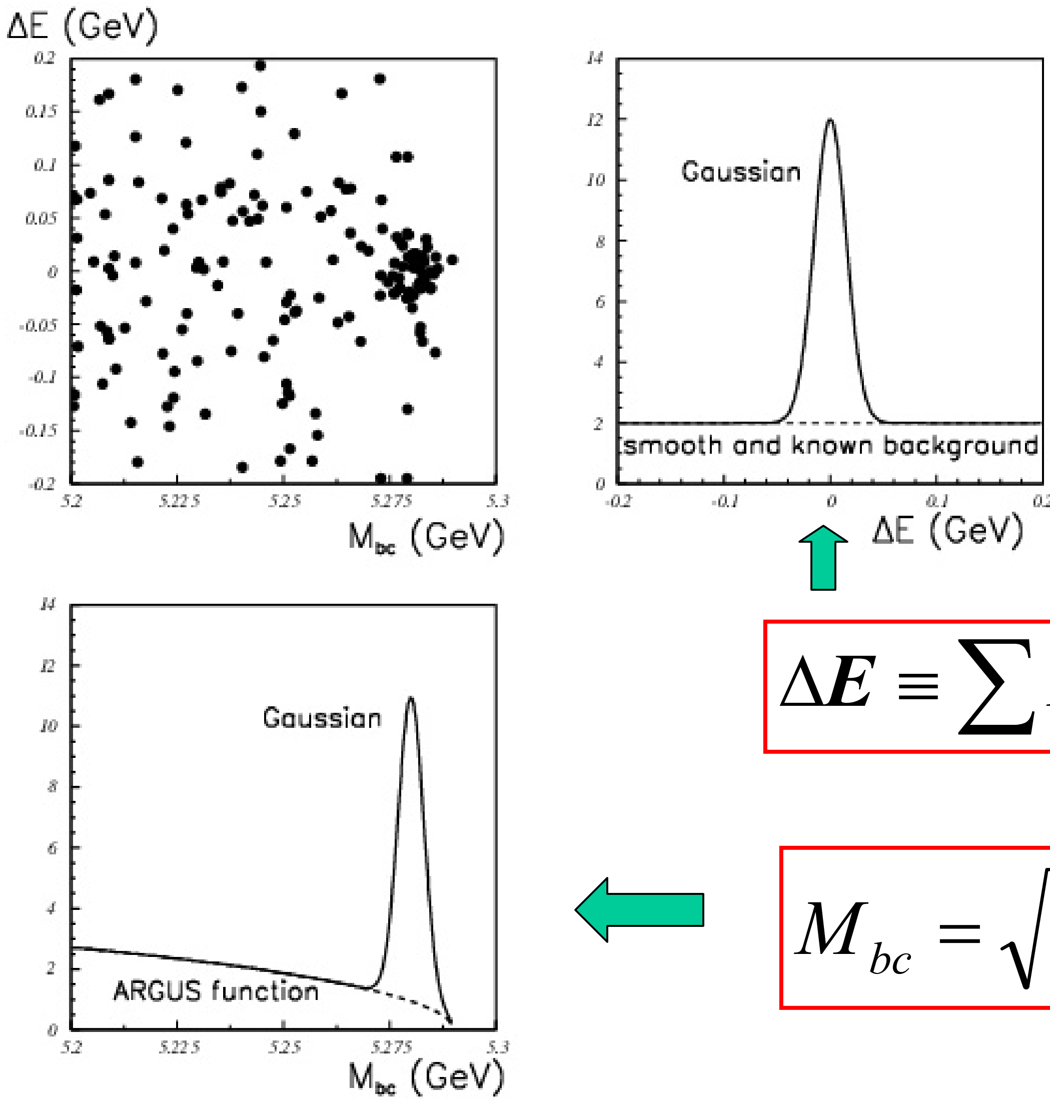
$\chi_{c1}, \chi_{c2} \rightarrow J/\psi\gamma$

$\sigma_{\Delta M} = 7.0\mathrm{GeV}/c^2$

Reconstructing K^0_S



Reconstruction of B meson decays



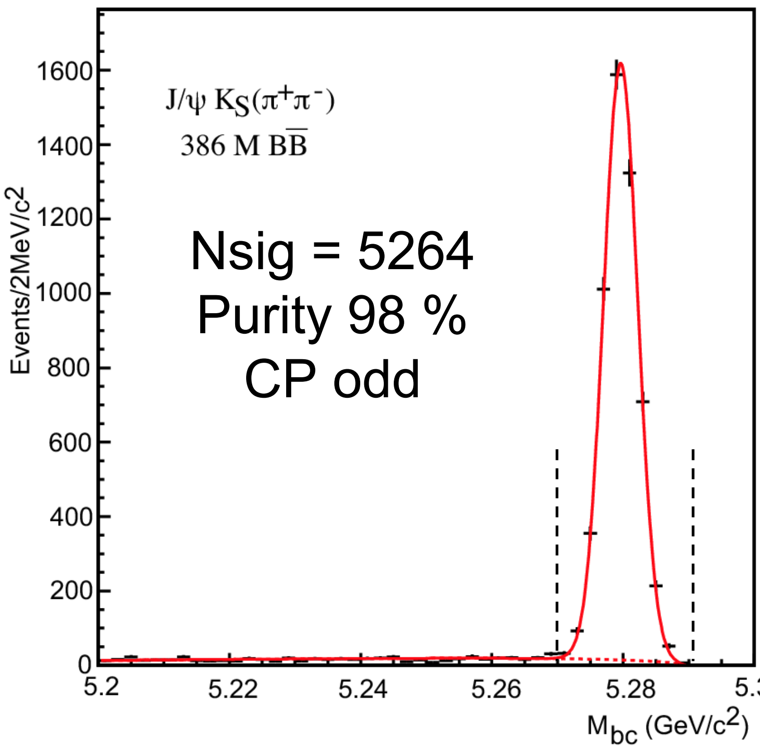
Reconstructing rare B meson decays at Y(4s): use two variables,
beam constrained mass M_{bc}
and
energy diference ΔE

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

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

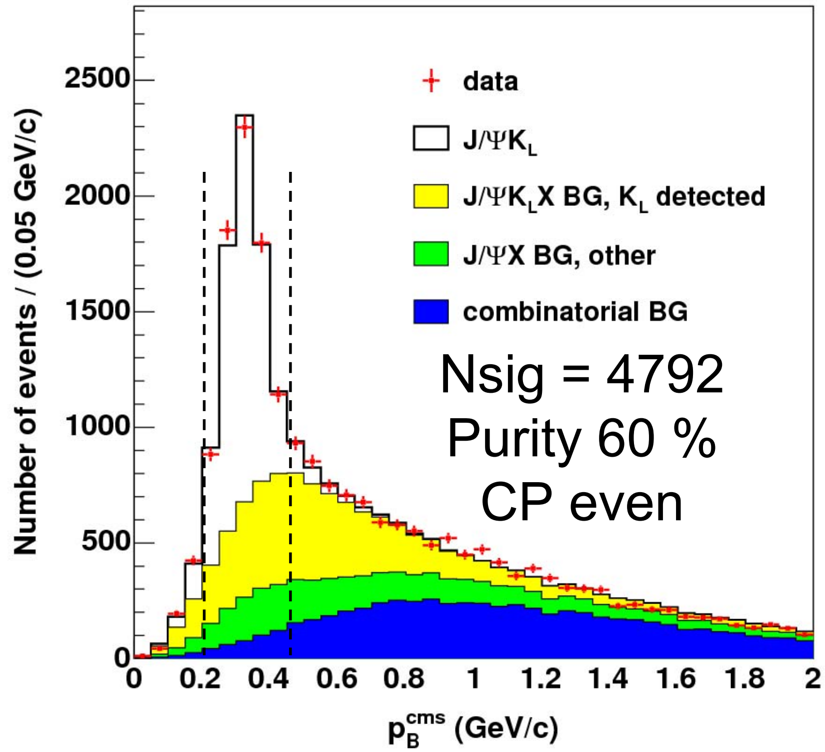
2005: $B^0 \rightarrow J/\psi \bar{K}^0$ with 386 M $B\bar{B}$ pairs

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



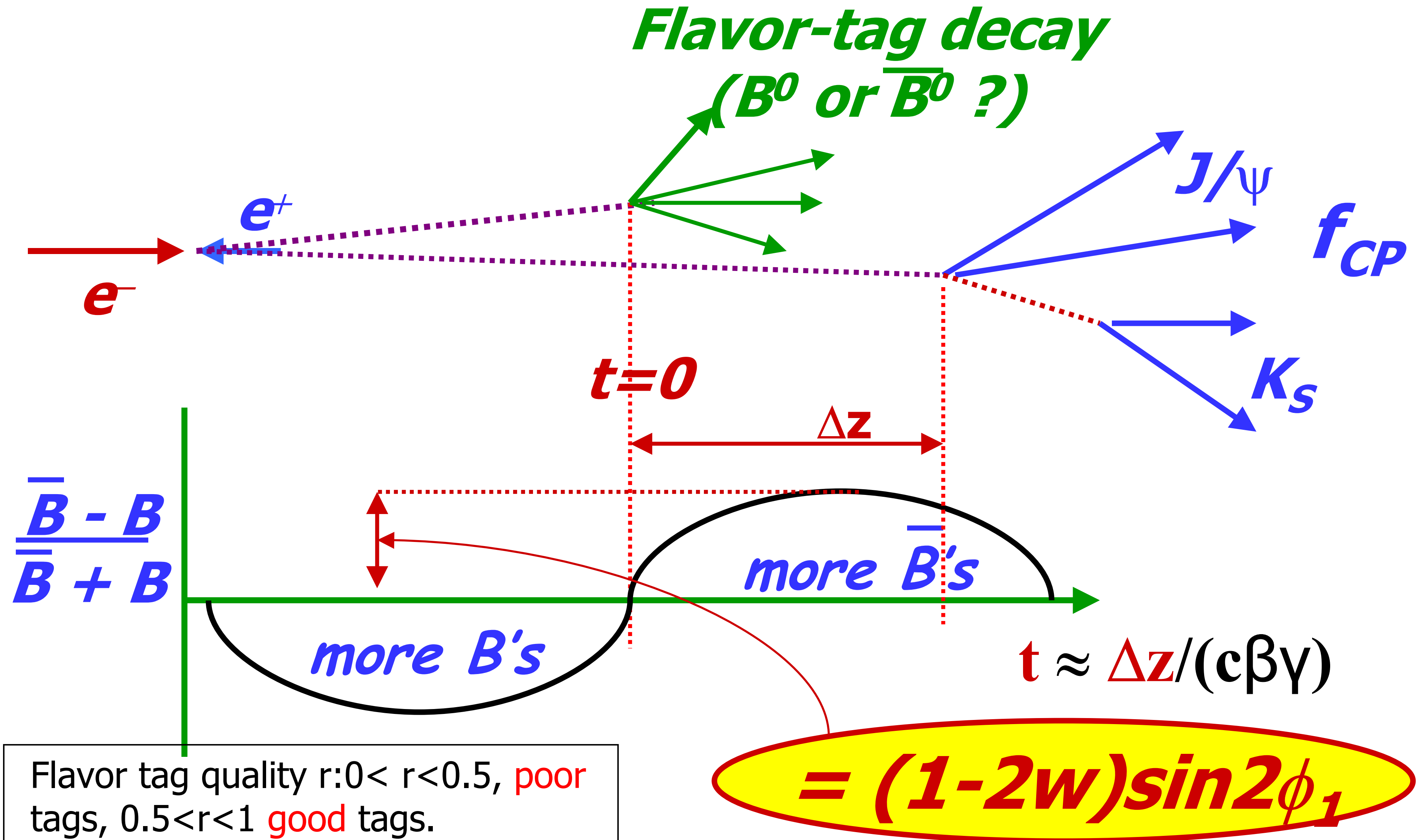
$$M_{bc} = \sqrt{E_{beam}^{*2} - P_{J/\psi Ks}^{*2}}$$

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



p_B^* (momentum in CM)

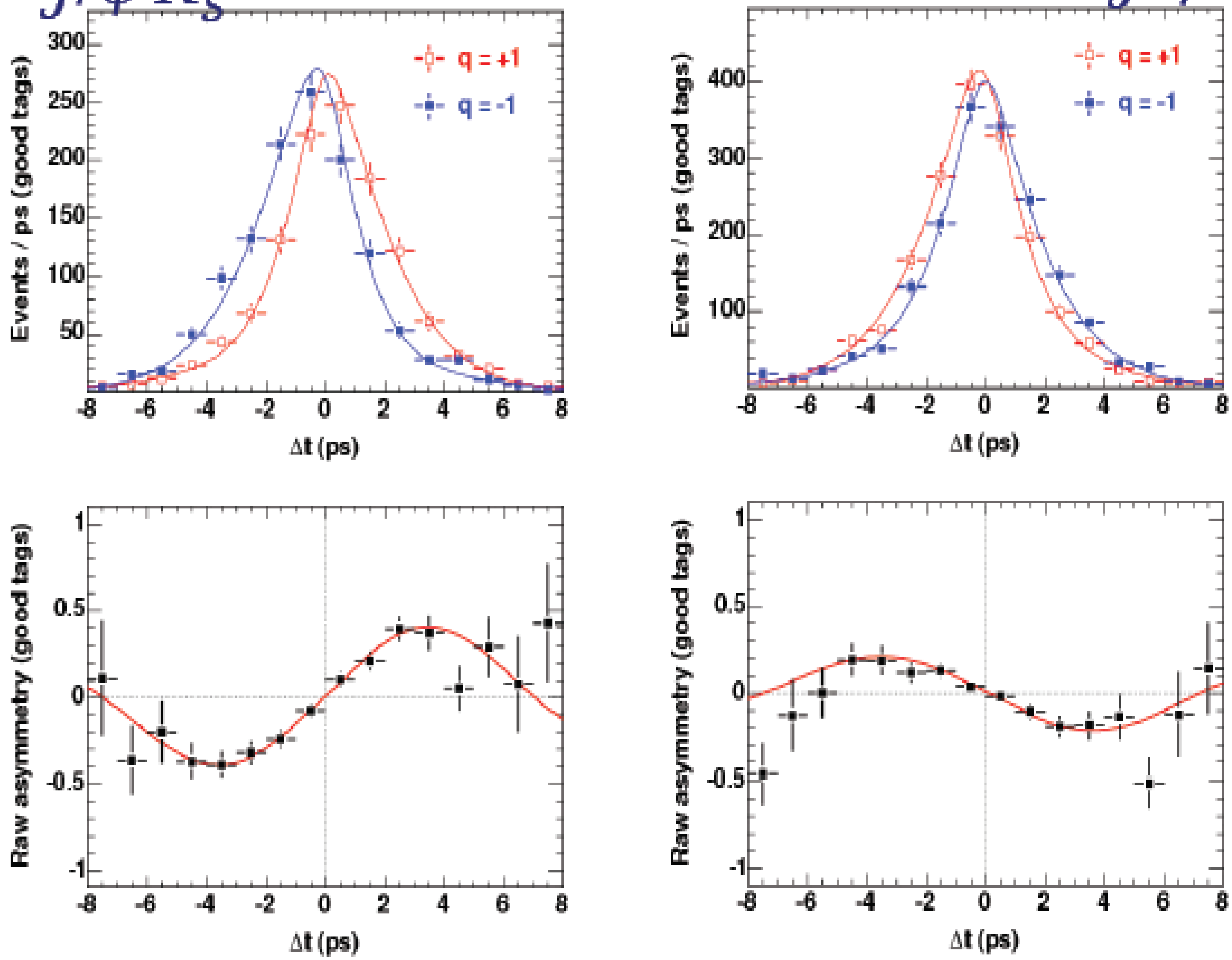
Principle of CPV Measurement



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

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

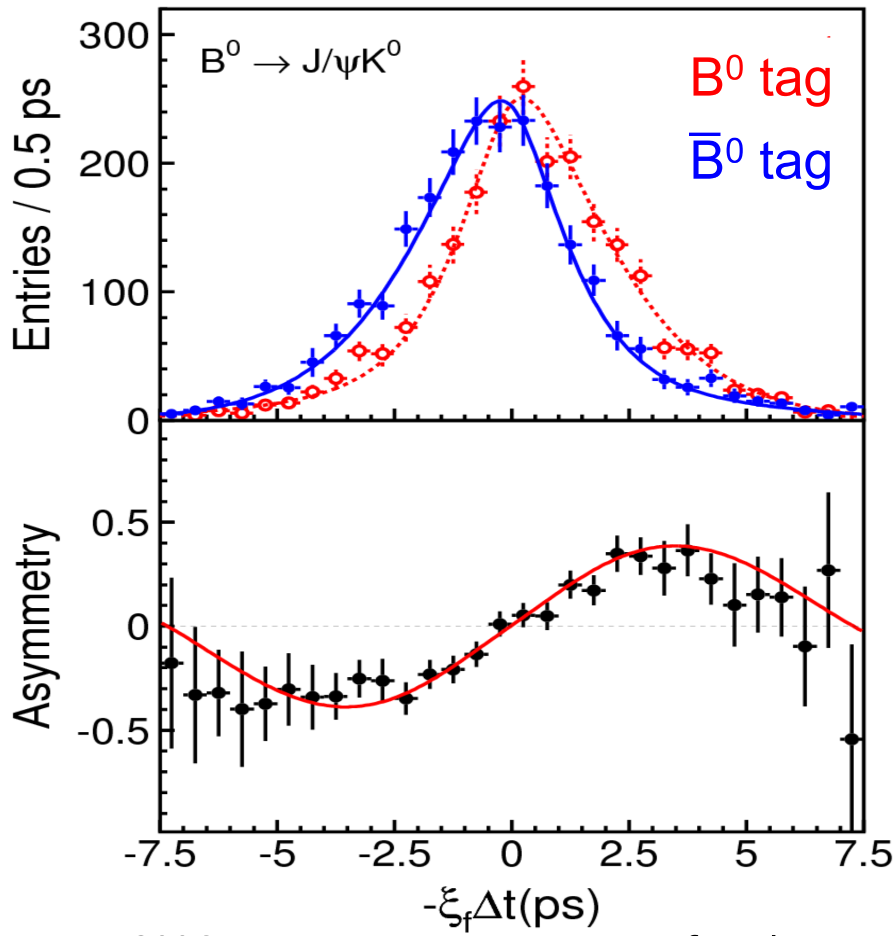
$J/\psi\ K_S$ $J/\psi\ K_L$



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*)

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…….

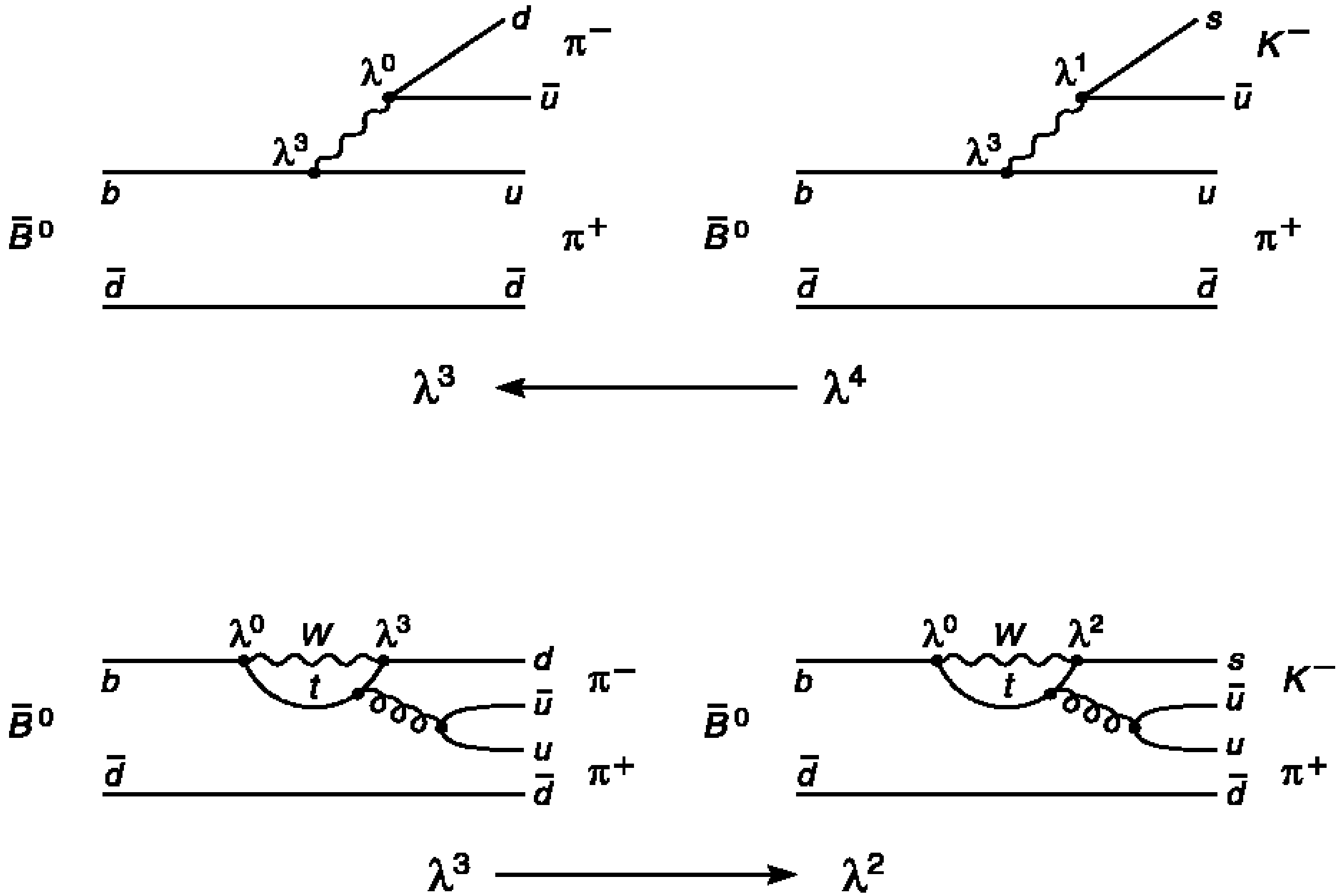
Evidence for such direct CP violation would be given by the difference between the asymmetry parameters in a decay such as $B \rightarrow \pi^+ \pi^-$ from that of $B \rightarrow J/\psi K_S$. This can be considered the ε' experiment for the B system."

Lincoln Wolfenstein, 1999

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

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.

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 $B\bar{B}$

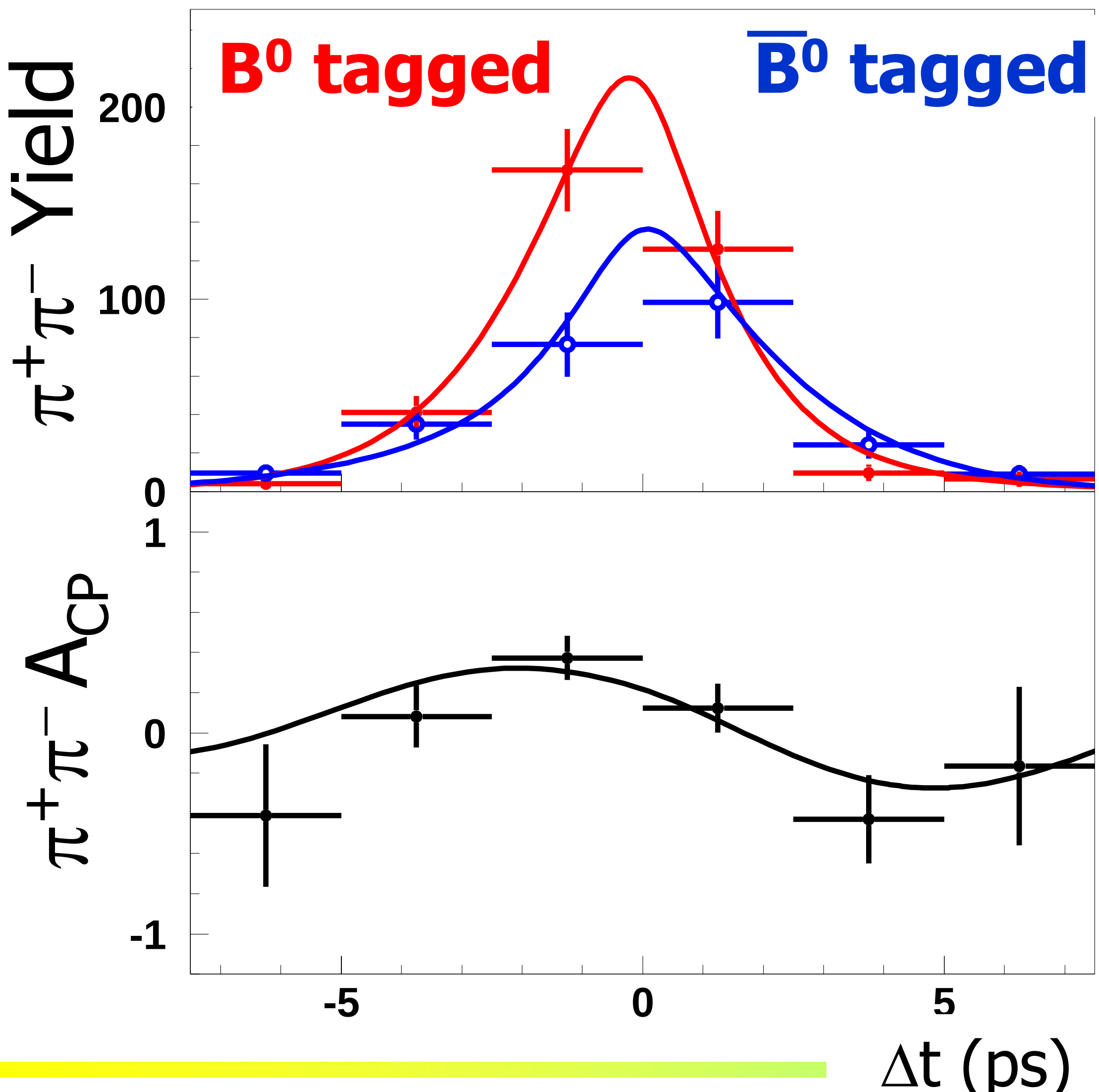
with 467±33 $B^0 \to \pi^+\pi^-$ events

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

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

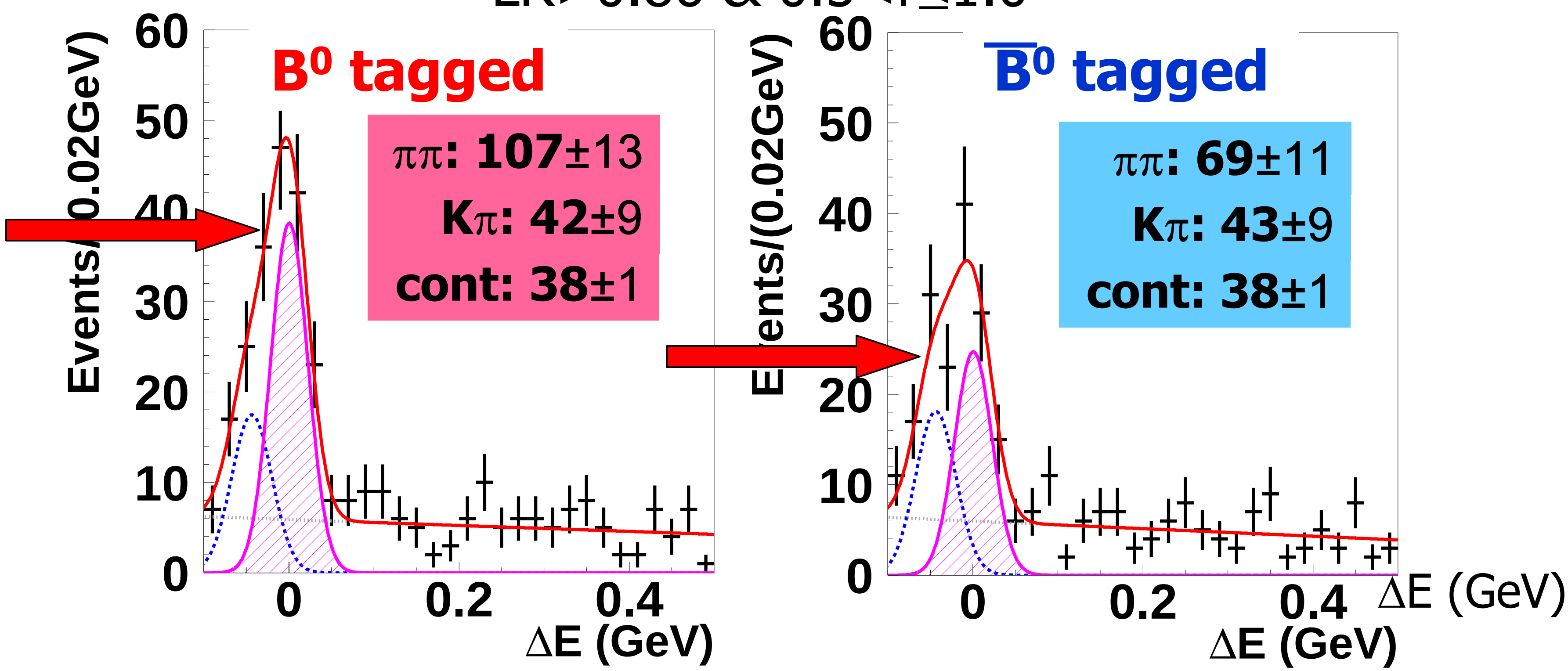
- Compelling evidence for direct CP violation in $B \to \pi^+\pi^-$ with 4.0σ significance
- Confirms previous Belle results.
- Isospin analysis for this mode alone gives (95.4% C.L) $0^\circ < \phi_2 < 19^\circ$ & $71^\circ < \phi_2 < 180^\circ$

Consistency Checks with time-integrated fits

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

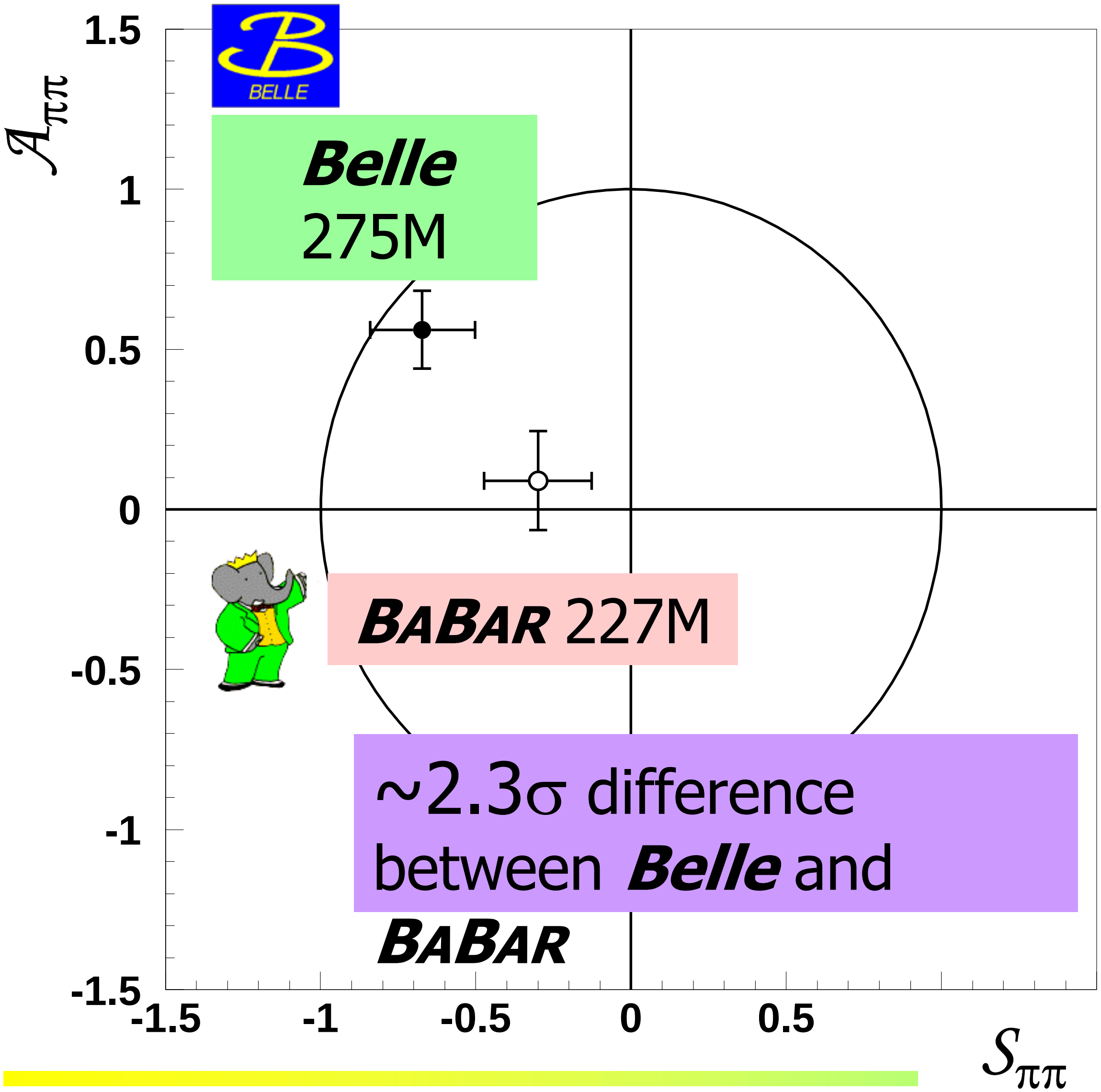
Counting experiment consistent with unbinned time-dependent fits.

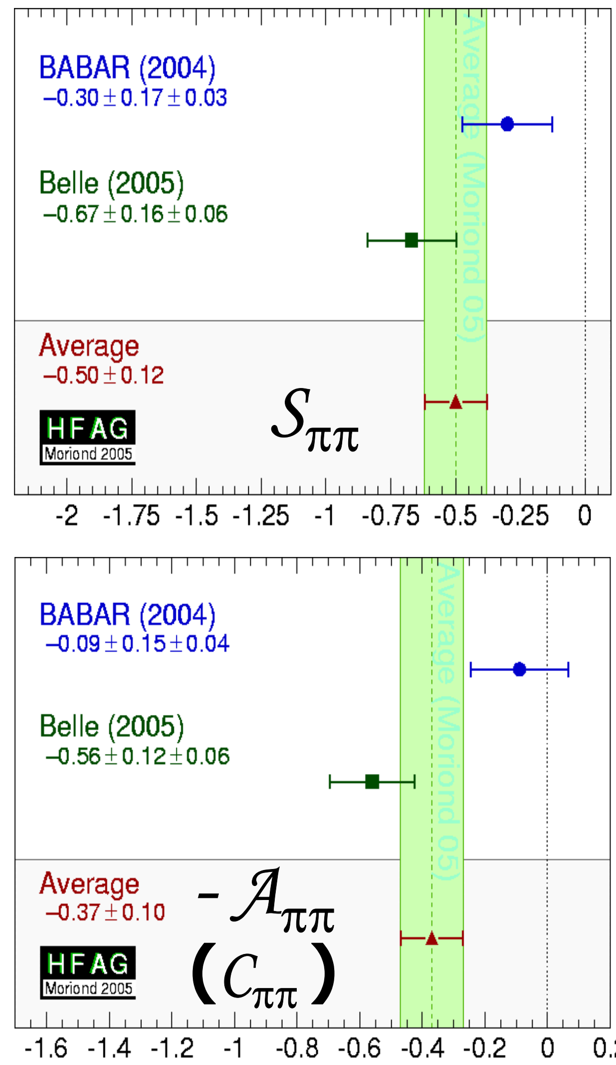
LR>0.86 & 0.5<r≤1.0



Visible indication of direct CP violation.

2005: Status of B→$\pi^+ \pi^-$





Direct CPV asymmetry in B Decays

Asymmetry in B decay rates

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

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

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

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

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.

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

PRL 93, 131801 (2004)

227M $B\bar{B}$

➢Evidence for DCPV (4.2σ)

$\mathcal{A} = -0.133 \pm 0.030 \pm 0.009$

PRL 93, 191802 (2004)

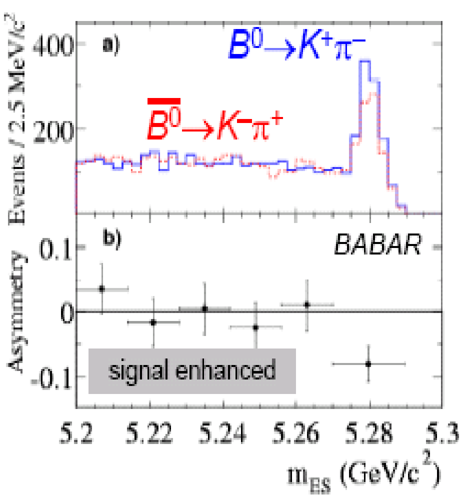
275M $B\bar{B}$

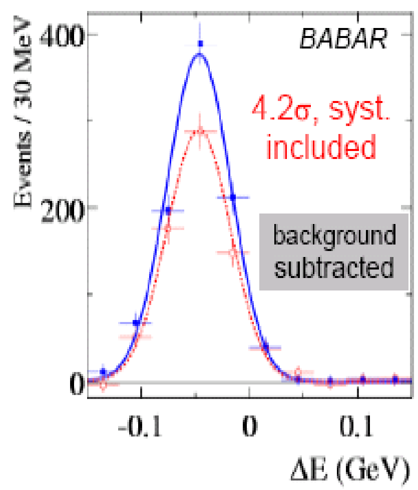
➢Evidence for DCPV (3.9σ)

$\mathcal{A} = -0.101 \pm 0.025 \pm 0.005$

$$n_{K\pi} = 1606 \pm 51$$
$$A_{K\pi} = -0.133 \pm 0.030 \pm 0.009$$

$$n\left(B^0 \to K^+\pi^-\right) = 910$$
$$n\left(\bar{B}^0 \to K^-\pi^+\right) = 696$$





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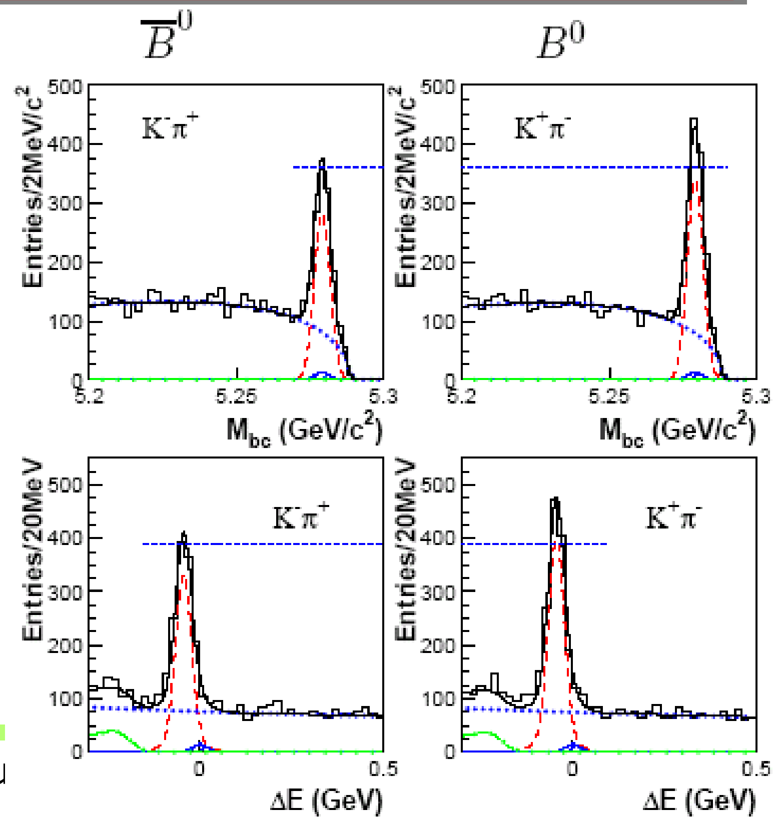
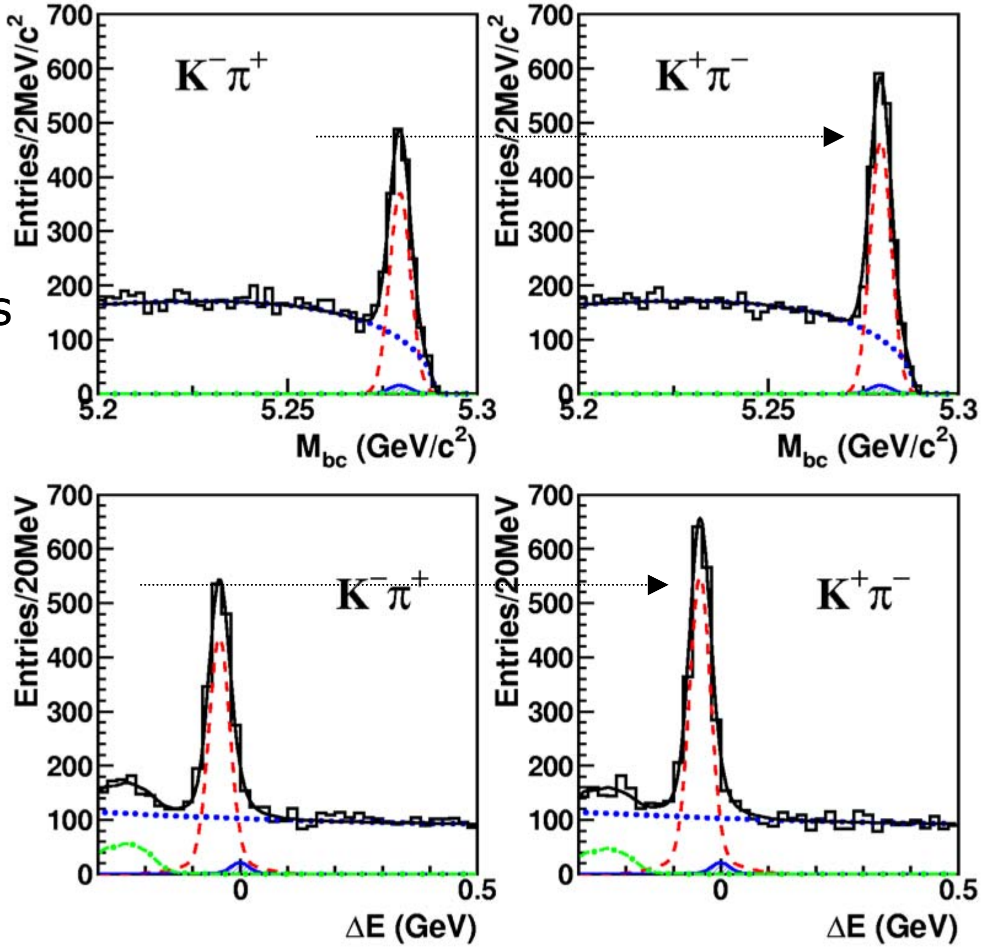


2005: "Observation" of Direct CPV in $B \to K^-\pi^+$

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

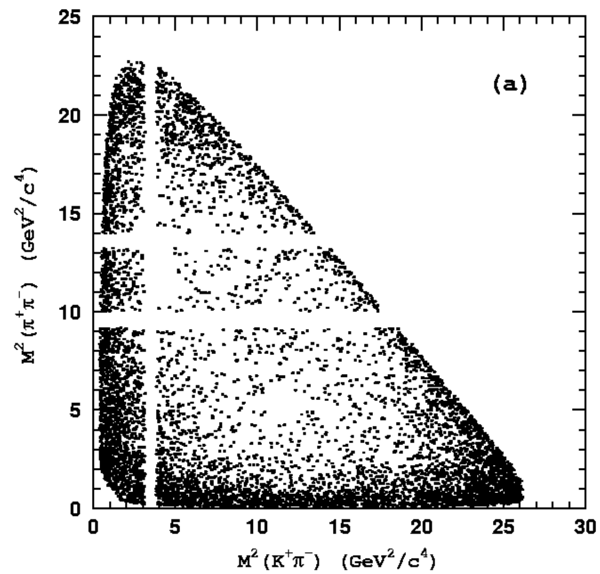
A new approach to direct CPV using the Dalitz plot in $B^{\pm} \to K^{\pm} \pi^{+} \pi^{-}$ (hep-ex/0509001)

Sample used for $B^{\pm} \to K^{\pm} \pi^{+}\pi^{-}$ 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.

Combined Dalitz plot, signal region



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

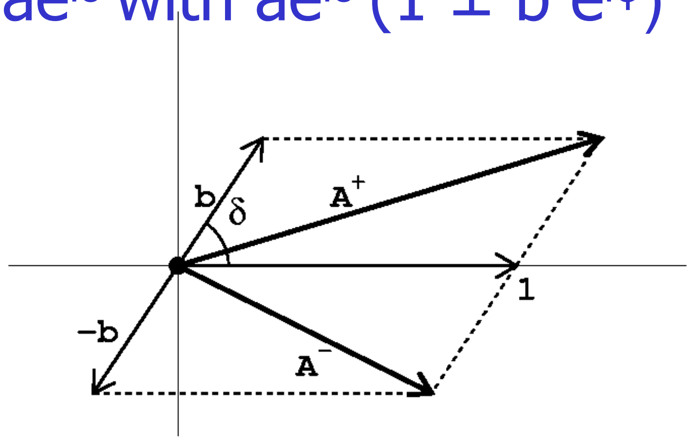


FIG. 9: Illustartion of the amplitude parametrization with Eq. 7.

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
$\rho(770)^0 K^{\pm}$	$7.85 \pm 0.93^{+0.64}_{-0.59}$	$-21 \pm 14^{+14}_{-19}$	$0.28 \pm 0.11^{+0.07}_{-0.09}$	$-125 \pm 32^{+10}_{-85}$	3.9
$\omega(782)K^{\pm}$	$0.15 \pm 0.12^{+0.03}_{-0.02}$	$100 \pm 31^{+38}_{-21}$	0 (fixed)	–	–
$f_0(980)K^{\pm}$	$17.7 \pm 1.6^{+1.1}_{-3.3}$	$67 \pm 11^{+10}_{-11}$	$0.30 \pm 0.19^{+0.05}_{-0.10}$	$-82 \pm 8^{+2}_{-2}$	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

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

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

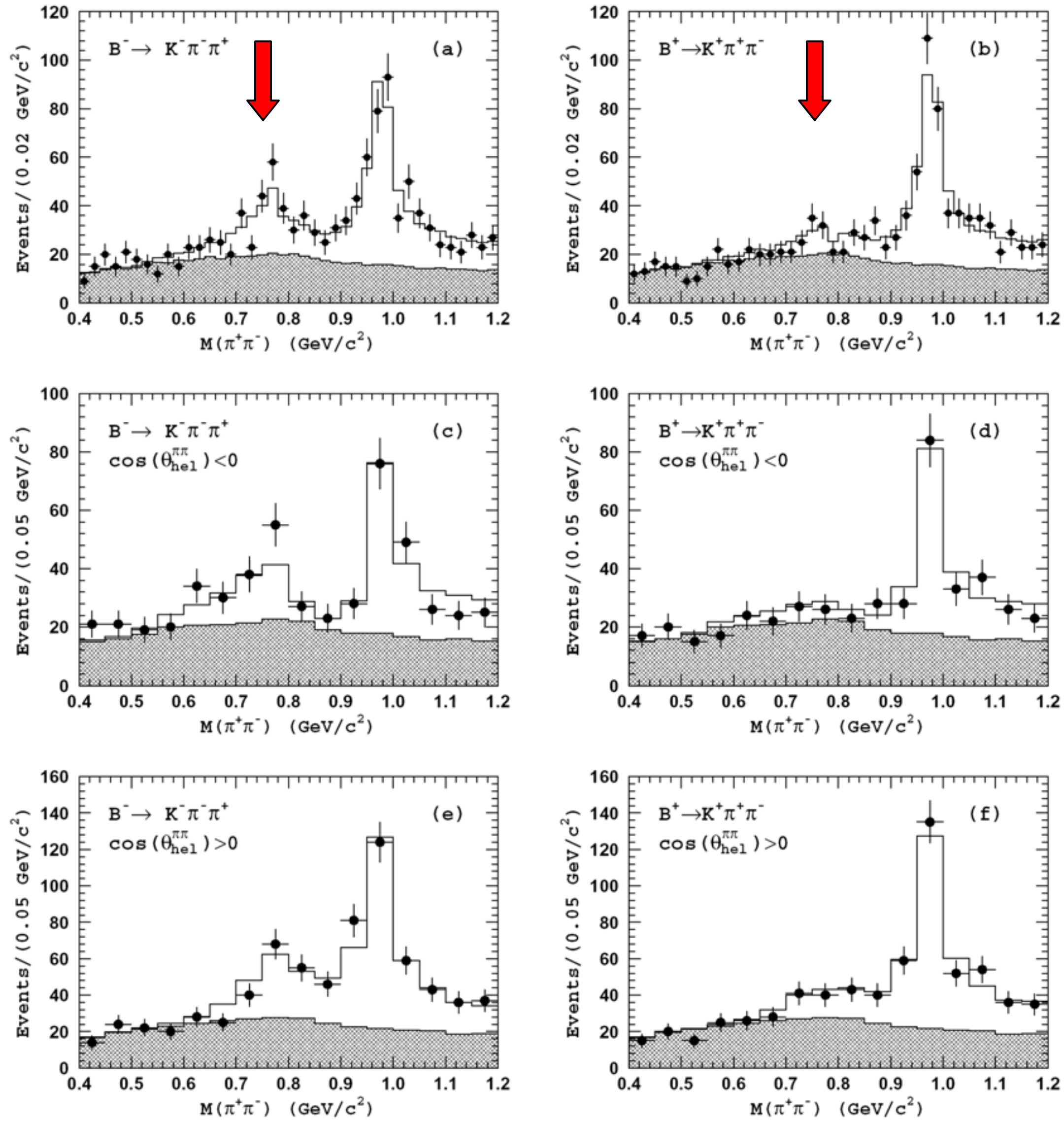


FIG. 7: $M(\pi^+\pi^-)$ mass spectra for B^- (left column) and B^+ (right column) for different helicity regions: (a,b) no helicity cuts; (c,d) $\cos\theta_H^{\pi\pi} < 0$; (e,f) $\cos\theta_H^{\pi\pi} > 0$; Points with error bars are data, the open histogram is the fit result and the hatched histogram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

Comparison of result to predictions and BaBar

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

First evidence for DCPV in a charged meson decay

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

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

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

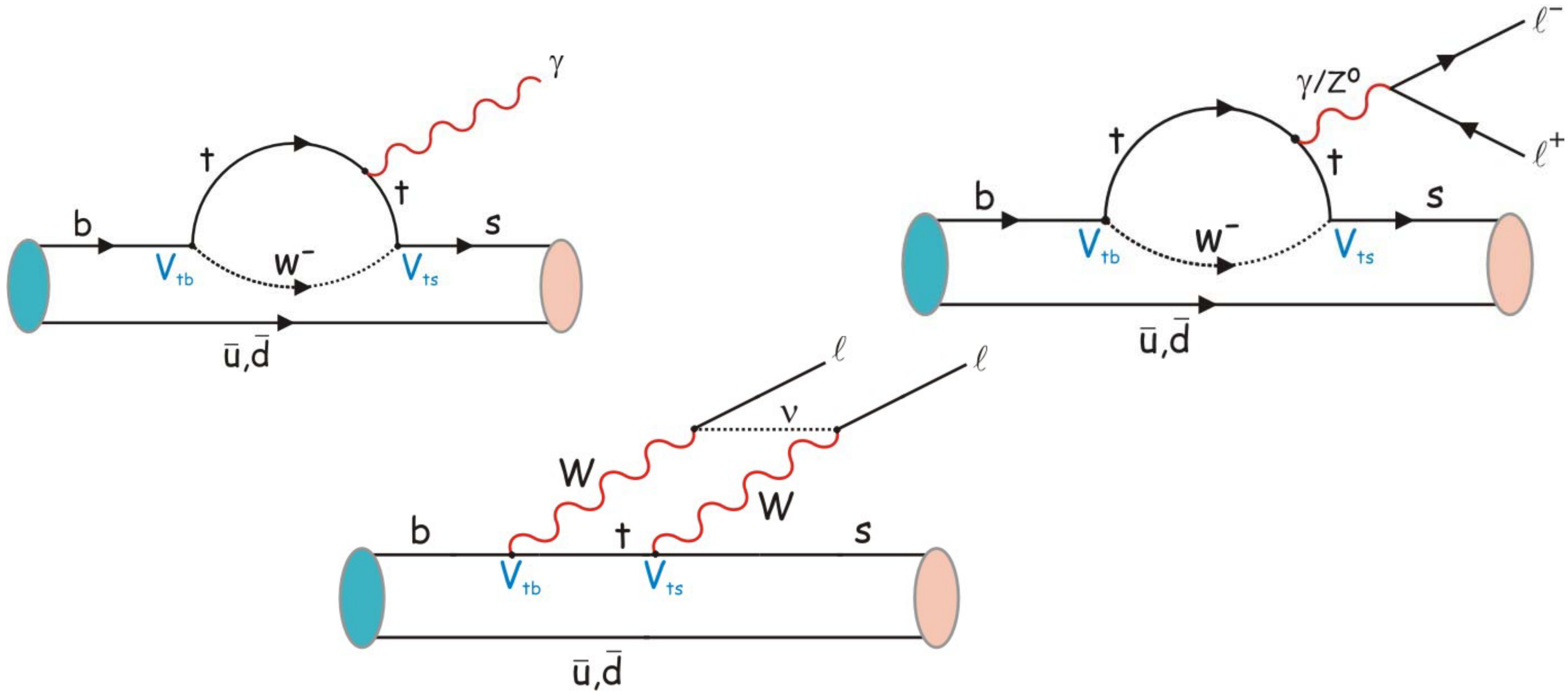
$$A_{CP}(B^{\pm} \to \rho^0 K^{\pm}) = -13.6^{+4.5+6.9+3.7+62.7}_{-5.7-4.4-3.1-55.4}\%$$

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

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

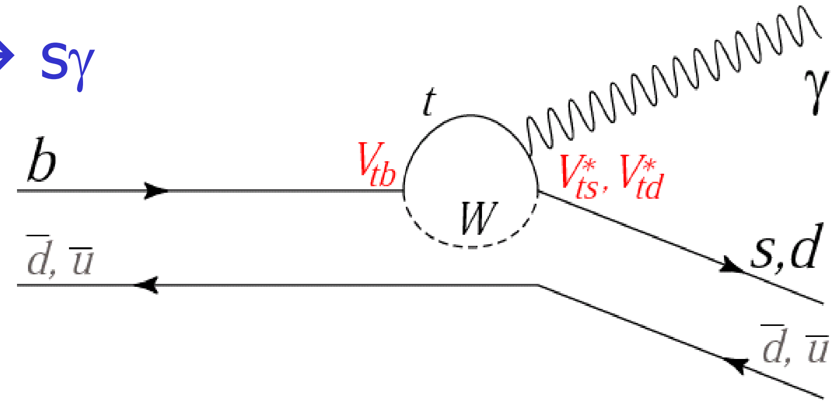
Why FCNC decays?

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 $b \to s\gamma$



Interesting:

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

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

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

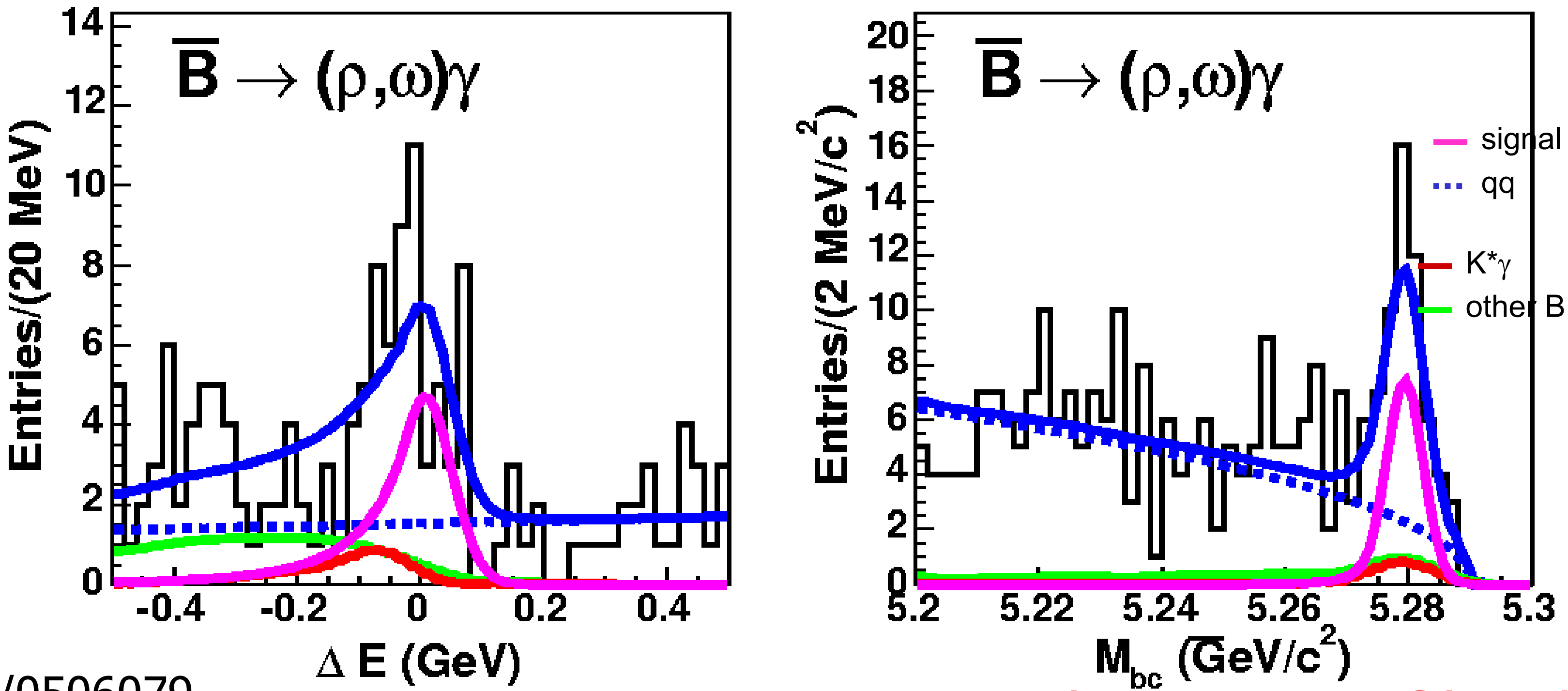
Addresses the same physics issue as B_s- B_s mixing (future Tevatron RunII +LHCb goal).

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

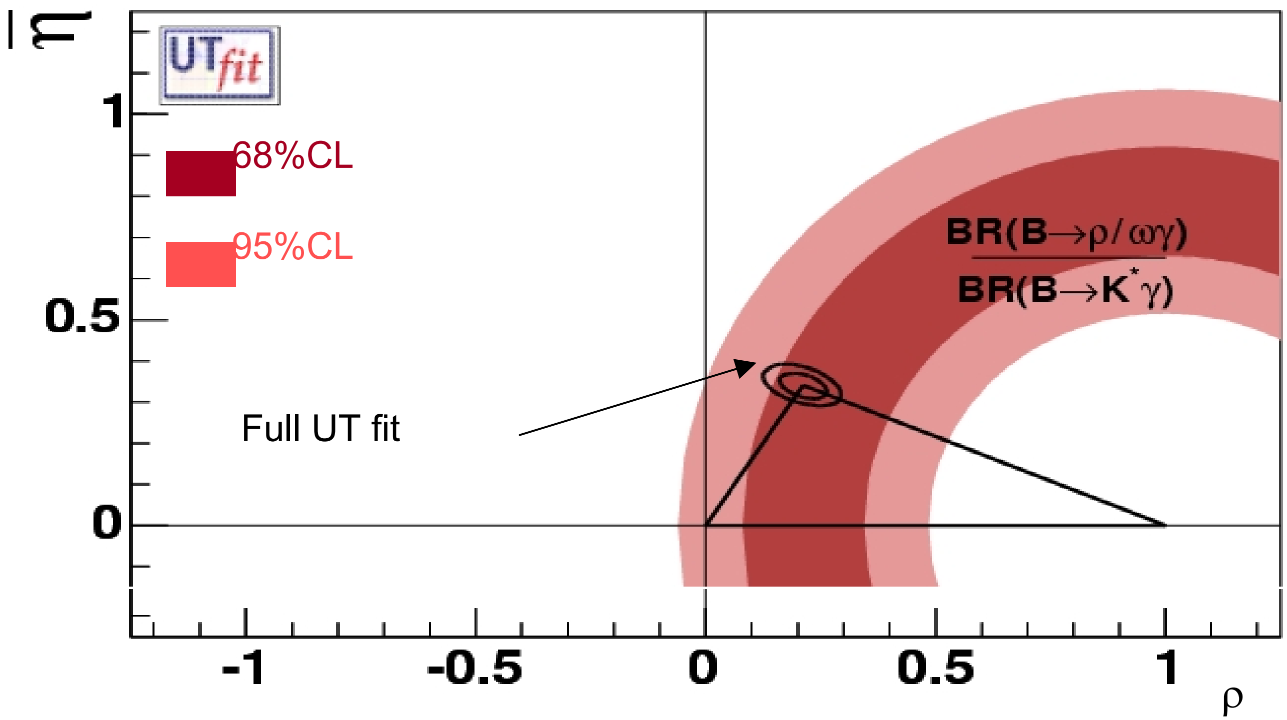
Together with the evidence of B→K^0 K modes, Belle has demonstrated the existence of a new quark level transition: b→d

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

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

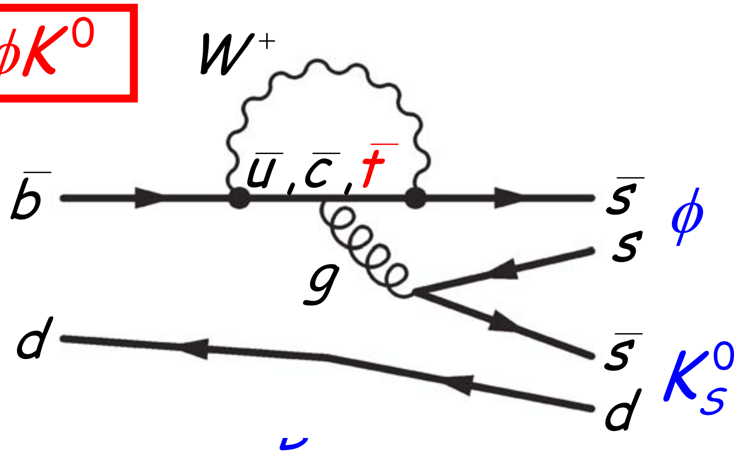
SU(3) breaking correction

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



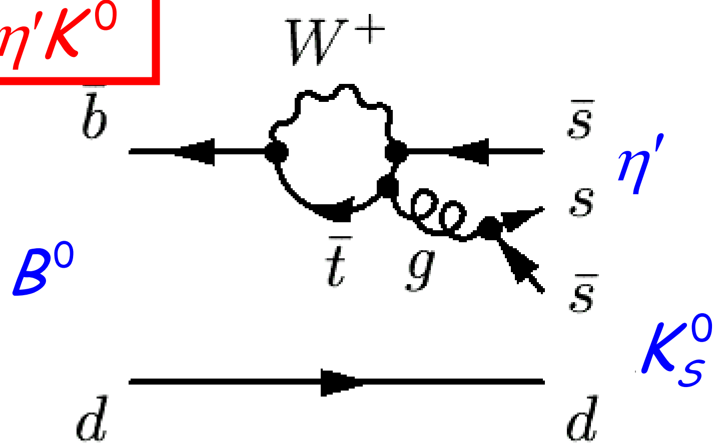
How can New Physics contribute to b→s?

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

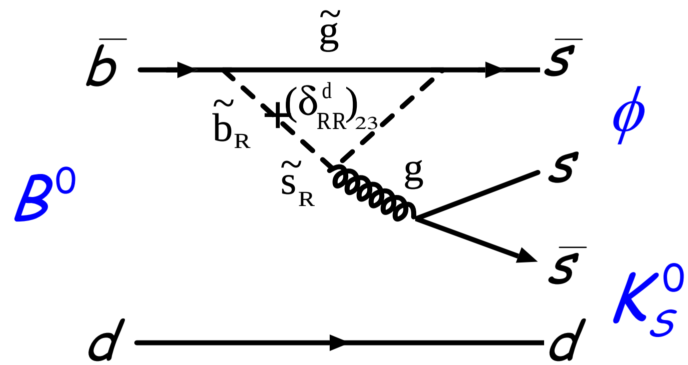


"Internal Penguin"

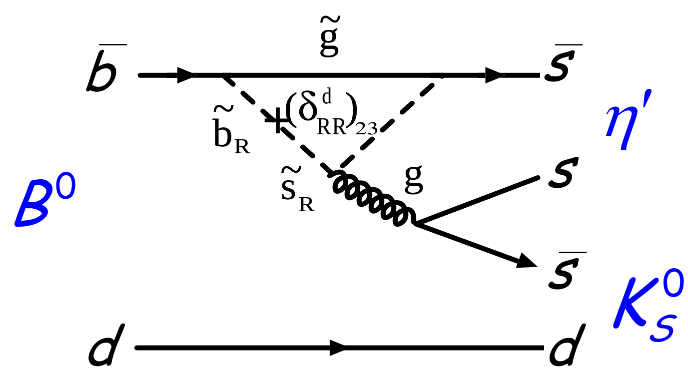
$B^0 \to \eta' K^0$



New physics in loops?

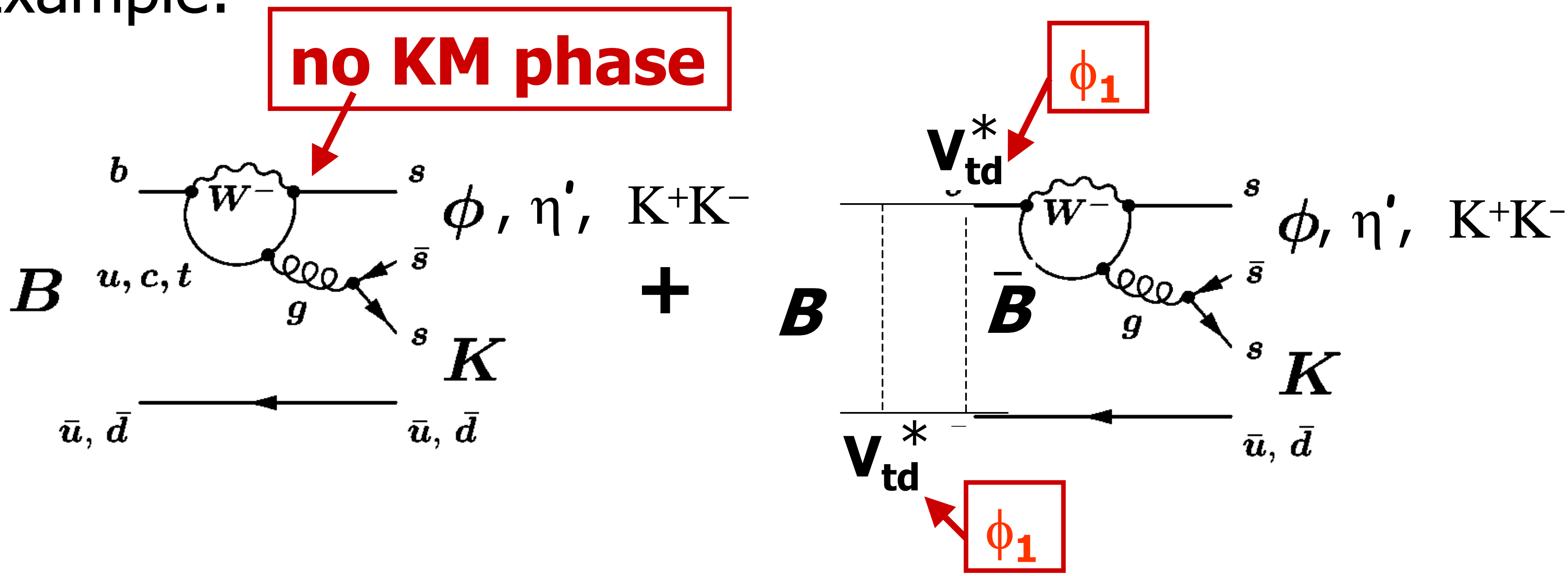


Many new phases are possible in SUSY



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

Example:



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

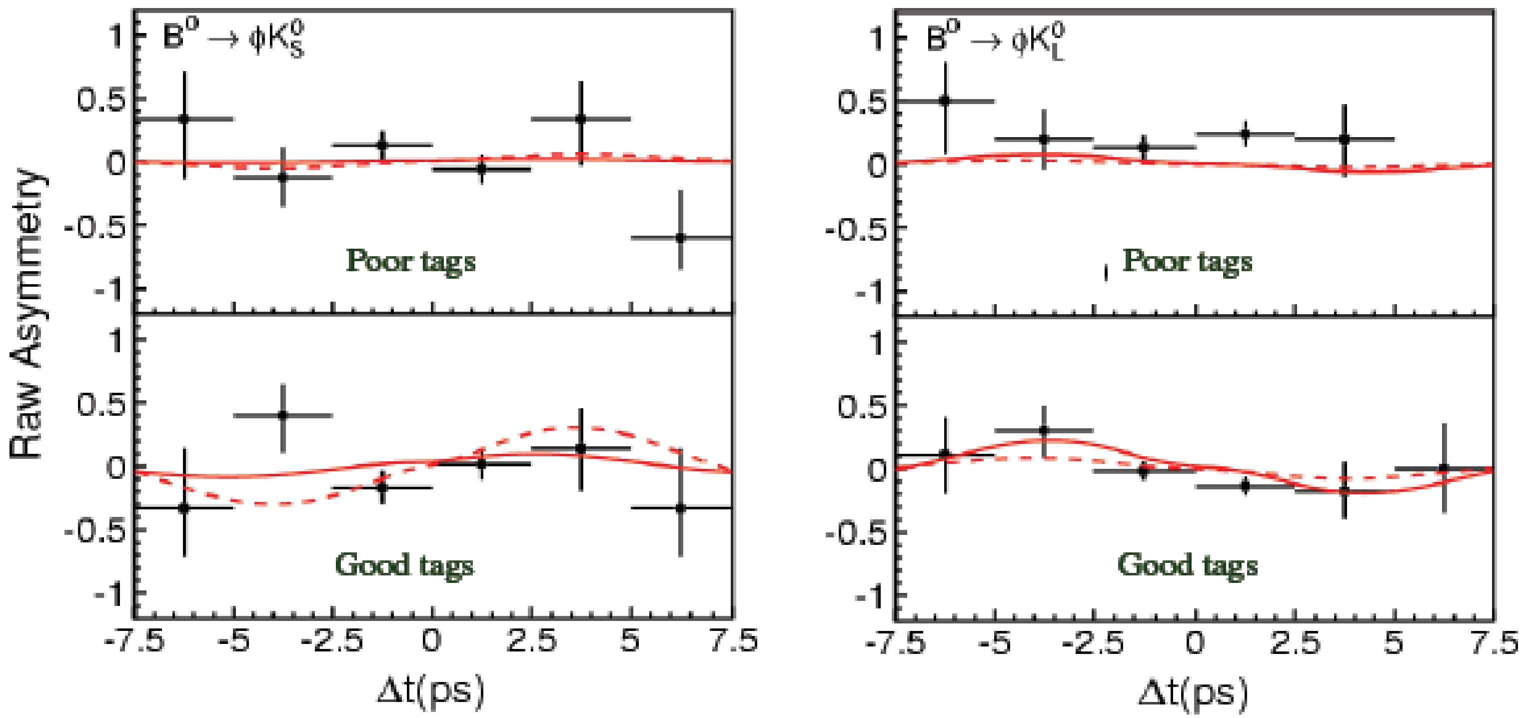
unless there are other, non-SM particles in the loop

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

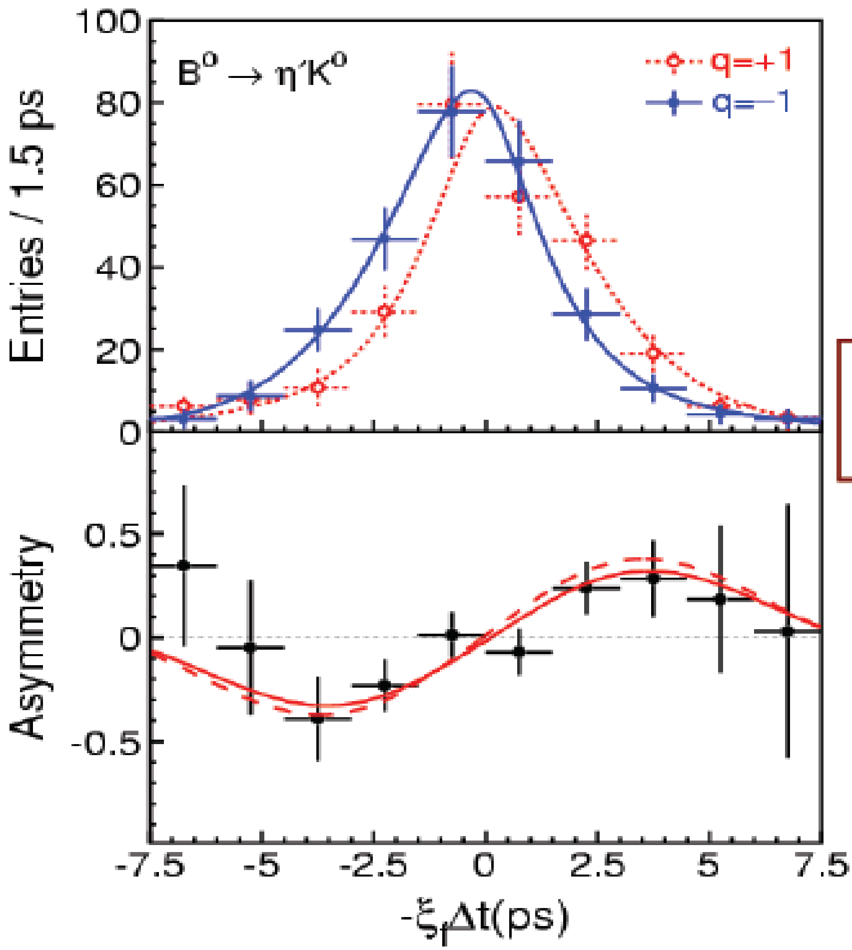


''$\sin 2\phi_1$''$= +0.19 \pm 0.32$ ''$\sin 2\phi_1$''$= +1.54 \pm 0.59$

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

"Compelling Evidence" for CP Violation in a b→s mode

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

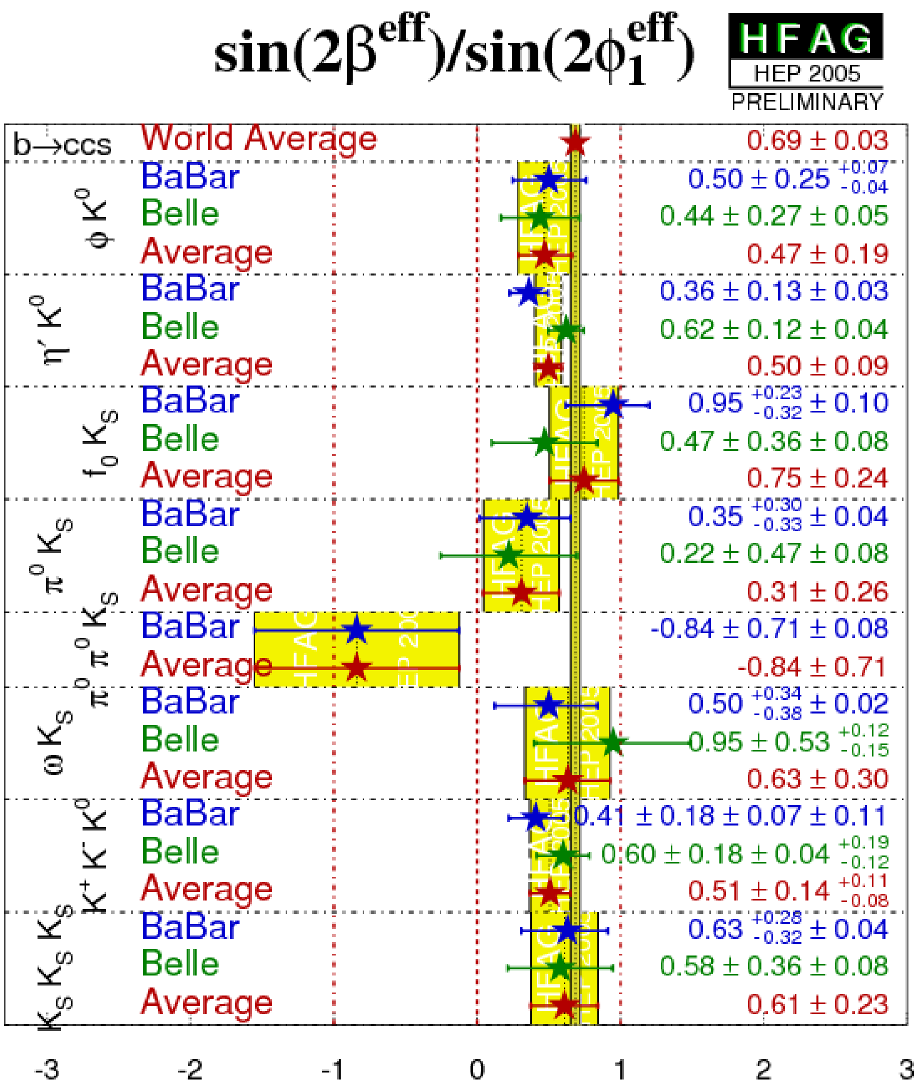


$$''\sin 2\phi_1'' = +0.62 \pm 0.12 \pm 0.04$$
$$A = -0.04 \pm 0.08 \pm 0.06$$

significance $> 4\sigma$

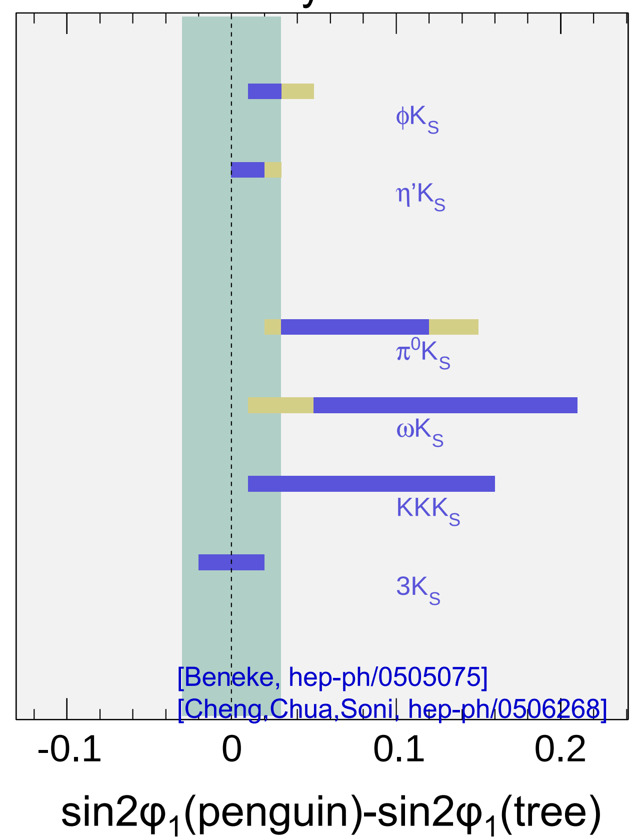
Many b→s modes were studied:

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



Belle data: hep-ex/0507037

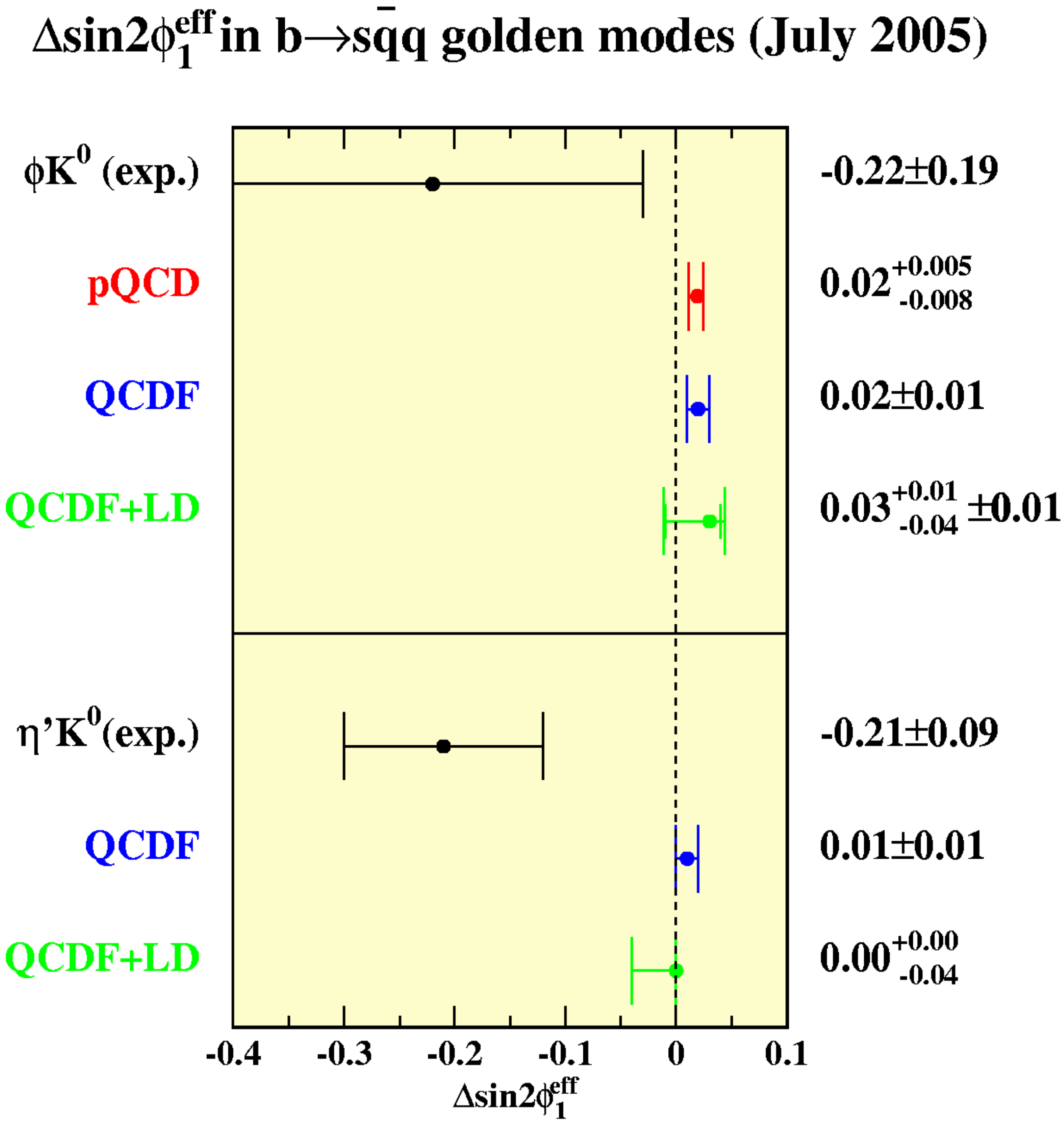
recent theory estimates :



New Physics ?

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

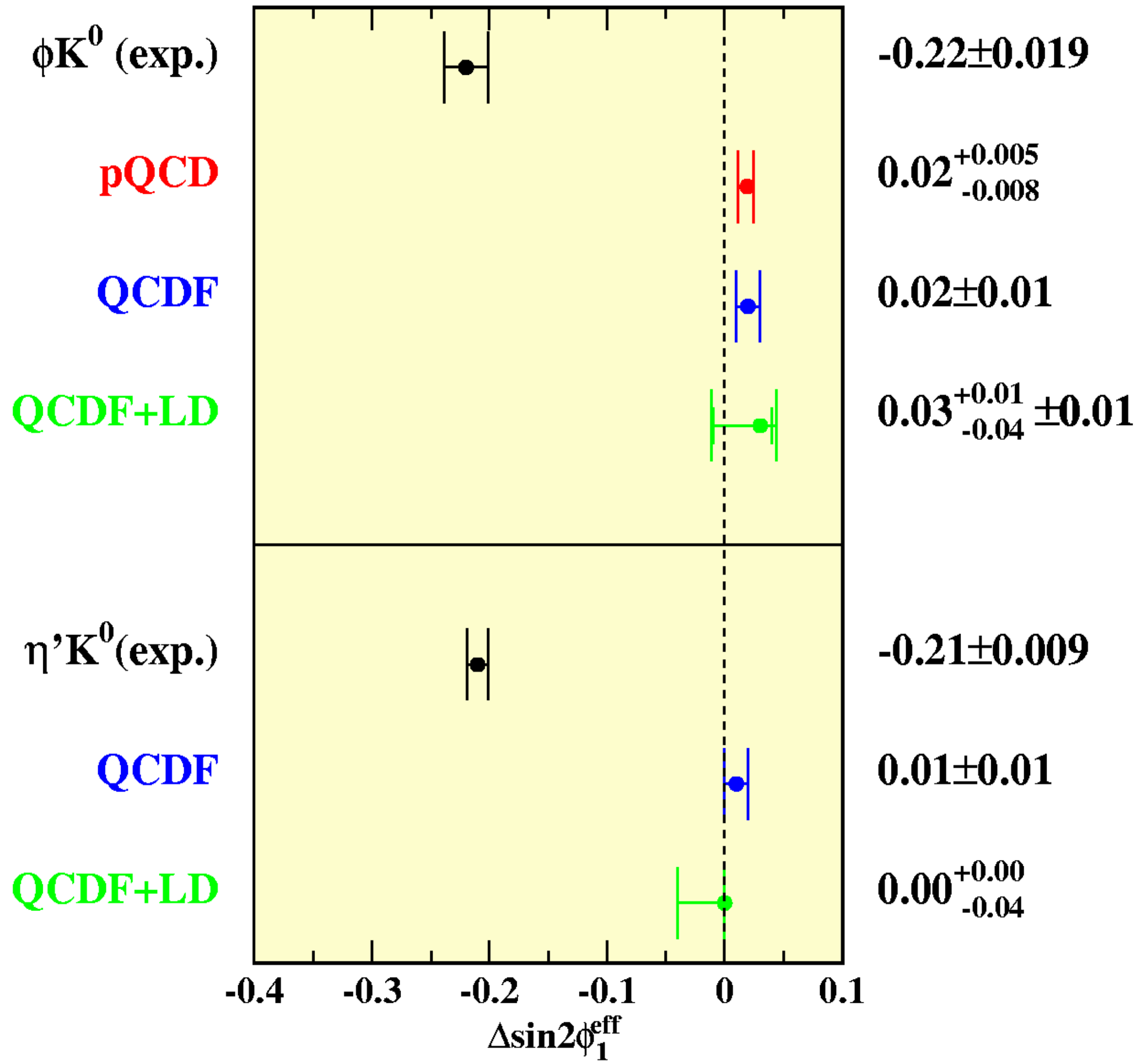
Theory corrections are small and opposite in sign to the measured deviations.



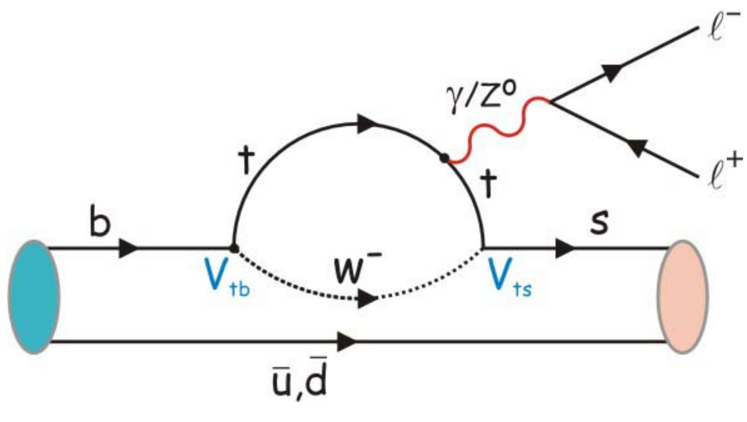
Are there New Physics effects of order 0.2 in b→s CPV ?

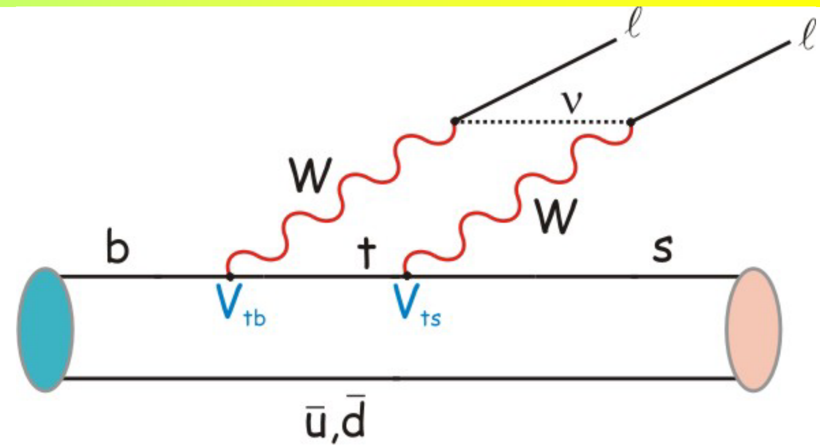
Super B Factory level statistics will allow us to answer this question.

Projection for Super B Factory ($50 ab^{-1}$)



Another FCNC decay: B → K* l+ l-





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

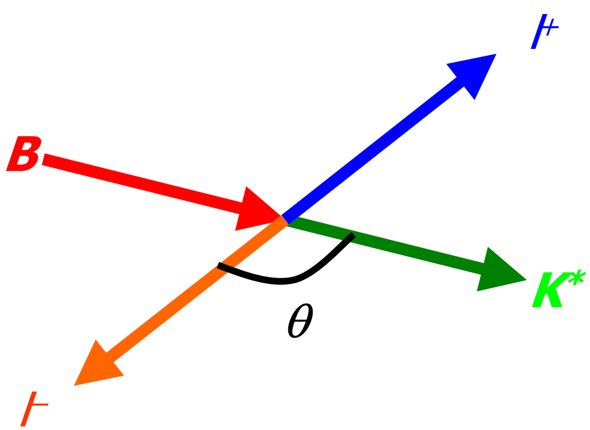
Important for further searches for the physics beyond SM

$$\frac{d\Gamma\left(b \to s\ell^+\ell^-\right)}{d\hat{s}} = \left(\frac{\alpha_{em}}{4\pi}\right)^2 \frac{G_F^2 m_b^5 \left|V_{ts}^* V_{tb}\right|^2}{48\pi^3}\left(1-\hat{s}\right)^2$$

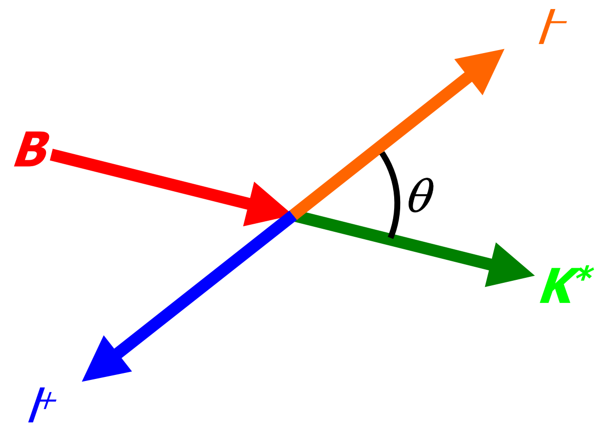
$$\times\left[\left(1+2\hat{s}\right)\left(\left|C_9^{\text{eff}}\right|^2+\left|C_{10}^{\text{eff}}\right|^2\right)+4\left(1+\frac{2}{\hat{s}}\right)\left|C_7^{\text{eff}}\right|^2+12\,\text{Re}\left(C_7^{\text{eff}} C_9^{\text{eff}*}\right)\right]$$

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



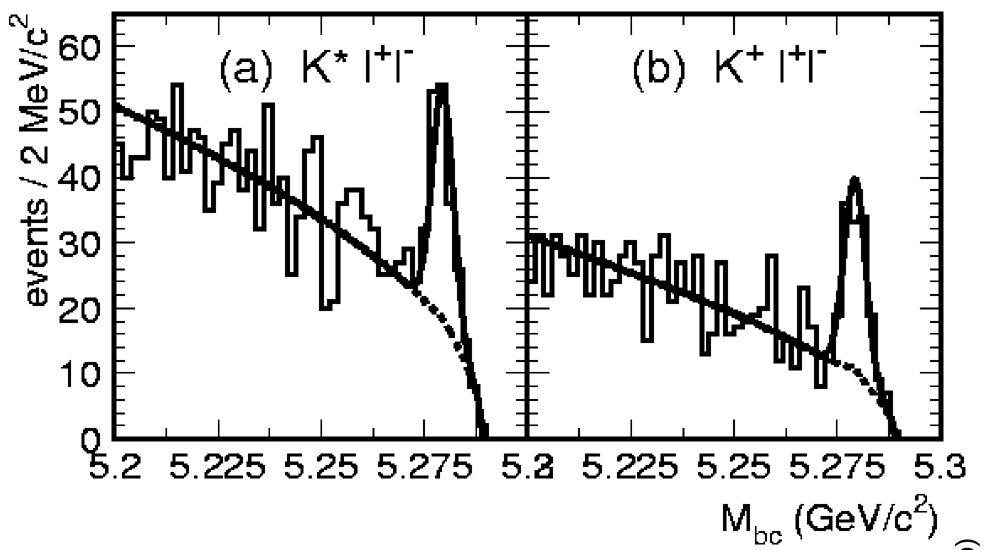
Forward event

[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 $A_{FB}(B \rightarrow K^*ll)(q^2)$

hep-ex/0508009



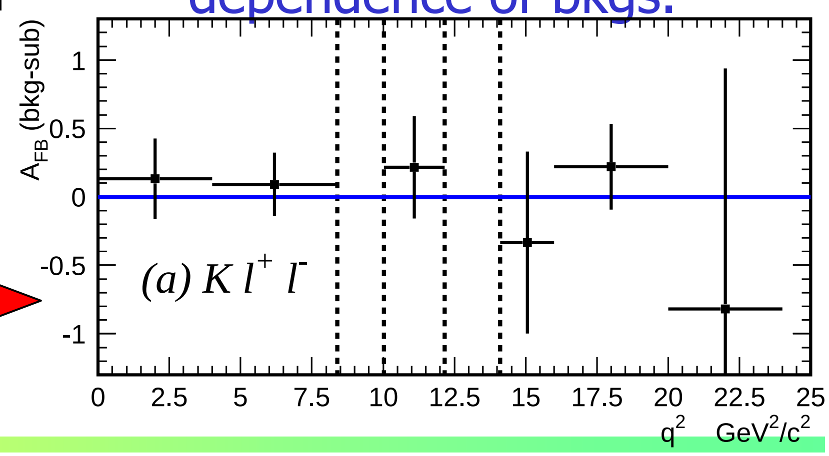
$$
\begin{aligned}
& P(q^2, \cos\theta; A_9/A_7, A_{10}/A_7) \\
= \;& f_{\rm sig}\epsilon_{\rm sig}(q^2,\cos\theta)\frac{d^2\Gamma}{dq^2 d\cos\theta}(q^2,\cos\theta)/N_{\rm sig} \\
+ \;& f_{\rm cfcf}\epsilon_{\rm cfcf}(q^2,\cos\theta)\frac{d^2\Gamma}{dq^2 d\cos\theta}(q^2,\cos\theta)/N_{\rm cfcf} \\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

Treat q^2, cos(θ) dependence of bkgs.

Sample for $B \rightarrow K^*$ l l events 113±13

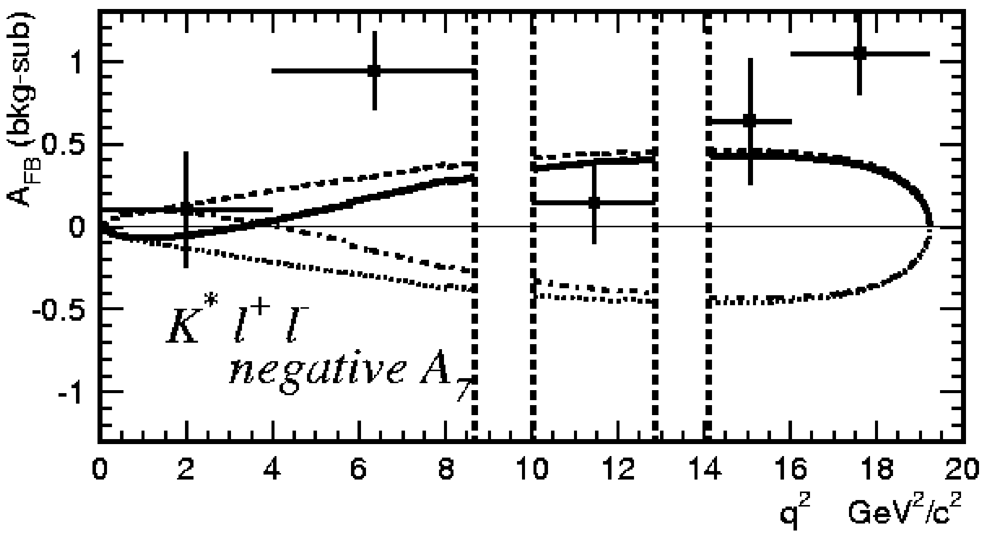
$B \rightarrow K$ l l control sample 96±12

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

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

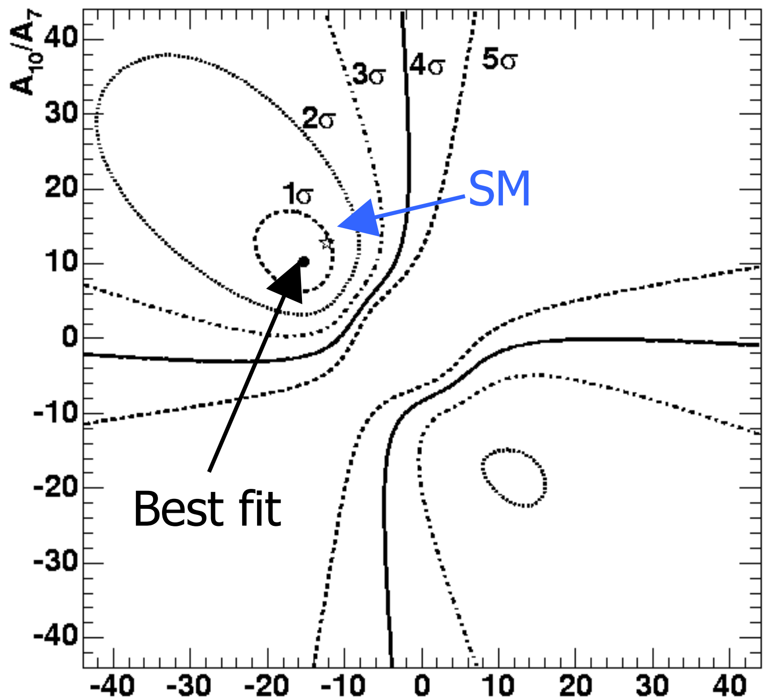
control sample:

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

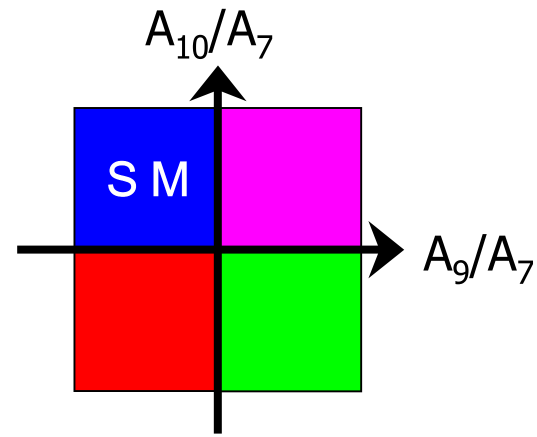
Observed integrated A_{FB} rules out some radical New Physics Models with incorrect signs/magnitudes of C_9 and C_{10}

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

A_{10}/A_7



A_9/A_7



$|A_7|$ 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	$10.3^{+5.2}_{-3.5} \pm 1.8$	$11.1^{+6.0}_{-3.9} \pm 2.4$

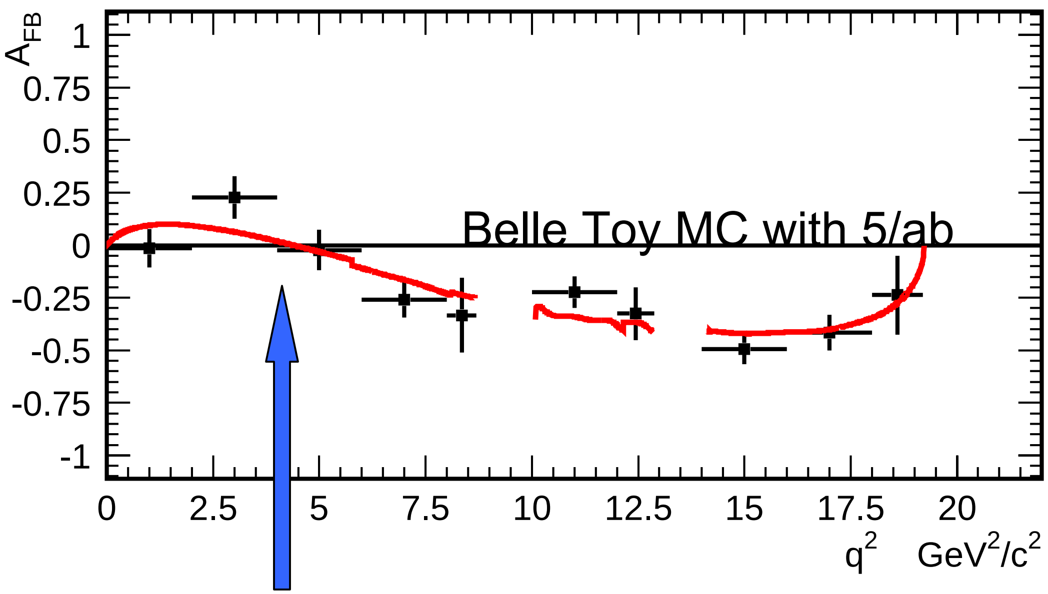
$$-1401 < A_9 A_{10}/A_7^2 < -26.4.$$

at 95% C.L.

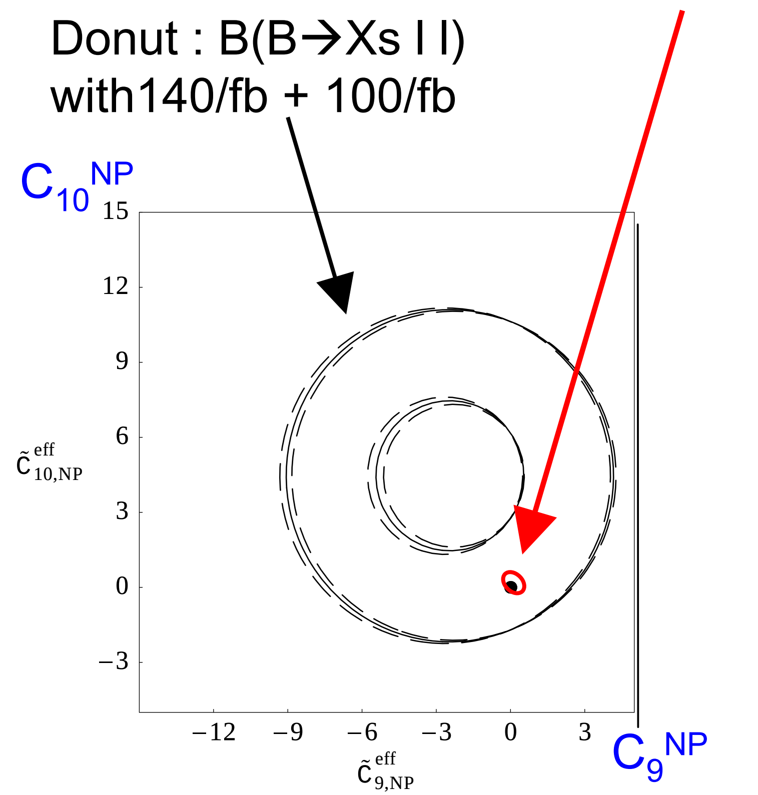
$A_{FB}(B \rightarrow K^* l^+ l^-)[q^2]$ at Super B Factory

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

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



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



Fundamental Questions in Flavor Physics

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

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

Are there new operators with quarks enhanced by New Physics ?

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

Are there right-handed currents ?

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

Are there new flavor changing neutral currents ?

Experiments: $b \to s\, \nu\, \nu$ bar, D-Dbar mixing+CPV+rare, $\tau \to \mu\, \gamma$

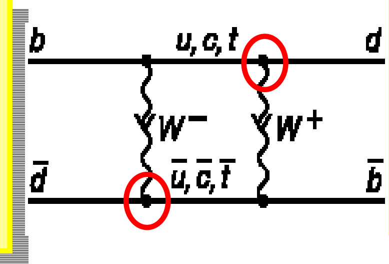
These questions can only be answered at a Super B Factory.

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.**

<u>cf. Physics of top quark</u>
First estimate of mass: BB mixing → ARGUS
Direct production, Mass, width etc. → CDF/D0
Off-diagonal couplings, phase → BaBar/Belle



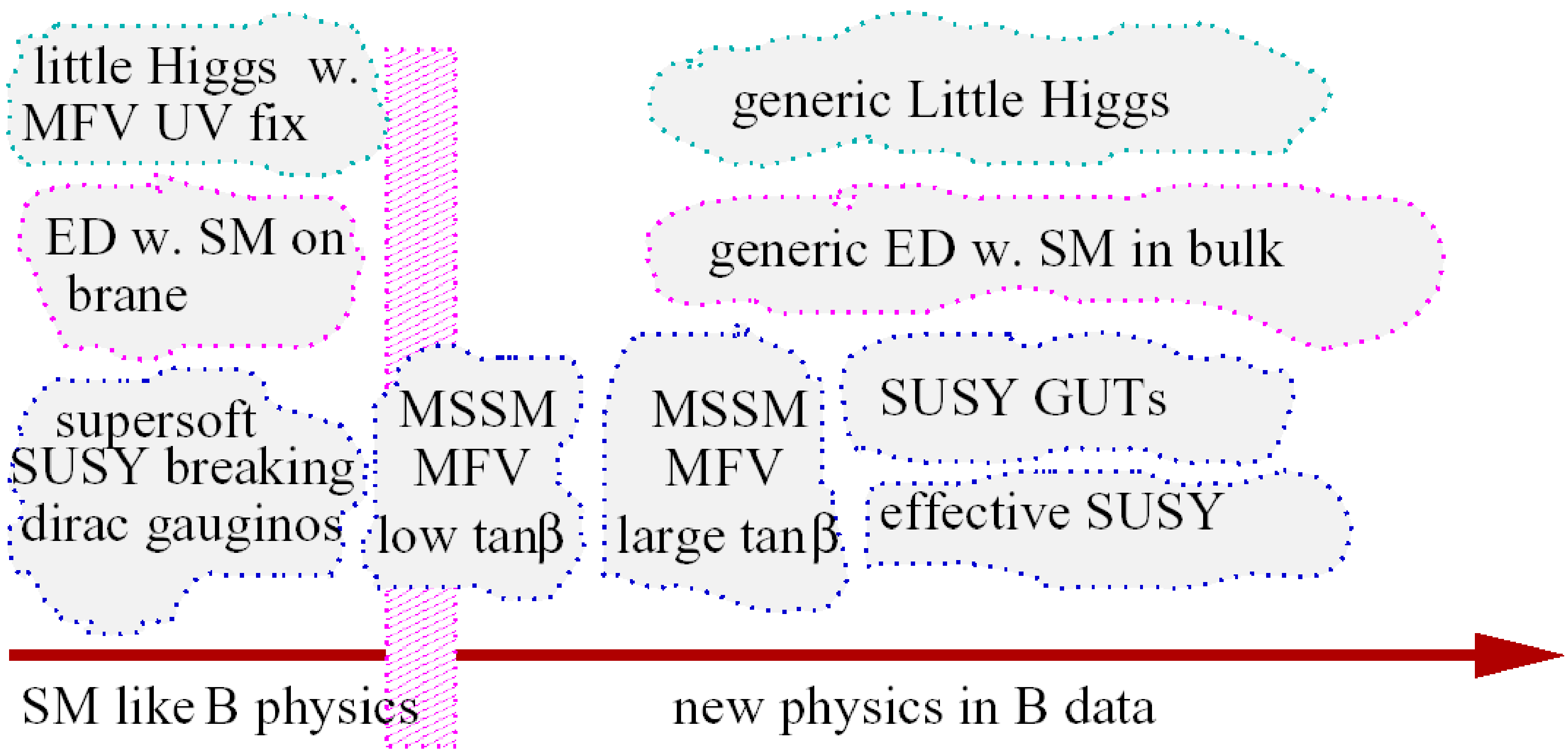
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- 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.**

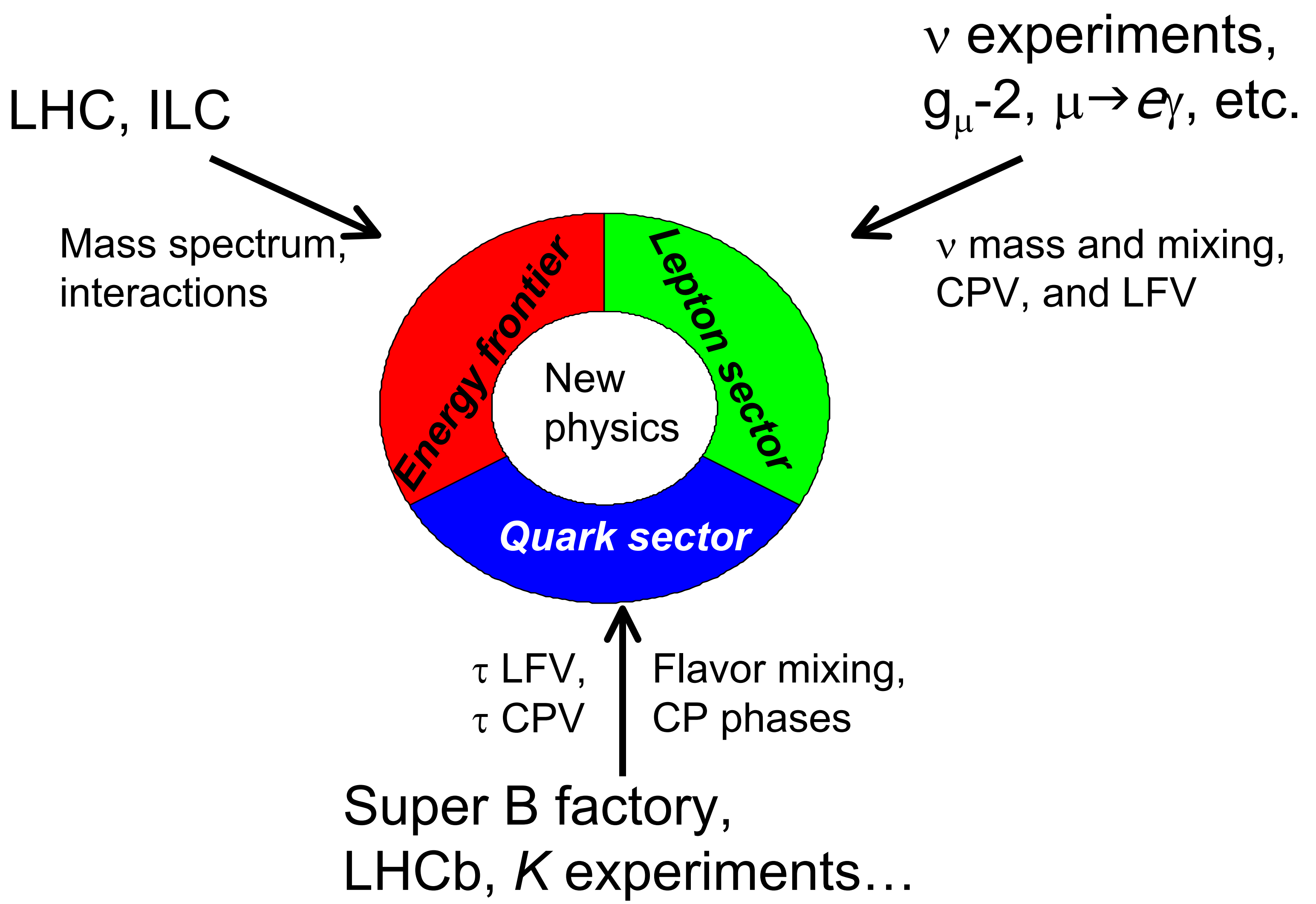
New physics effects in B physics

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

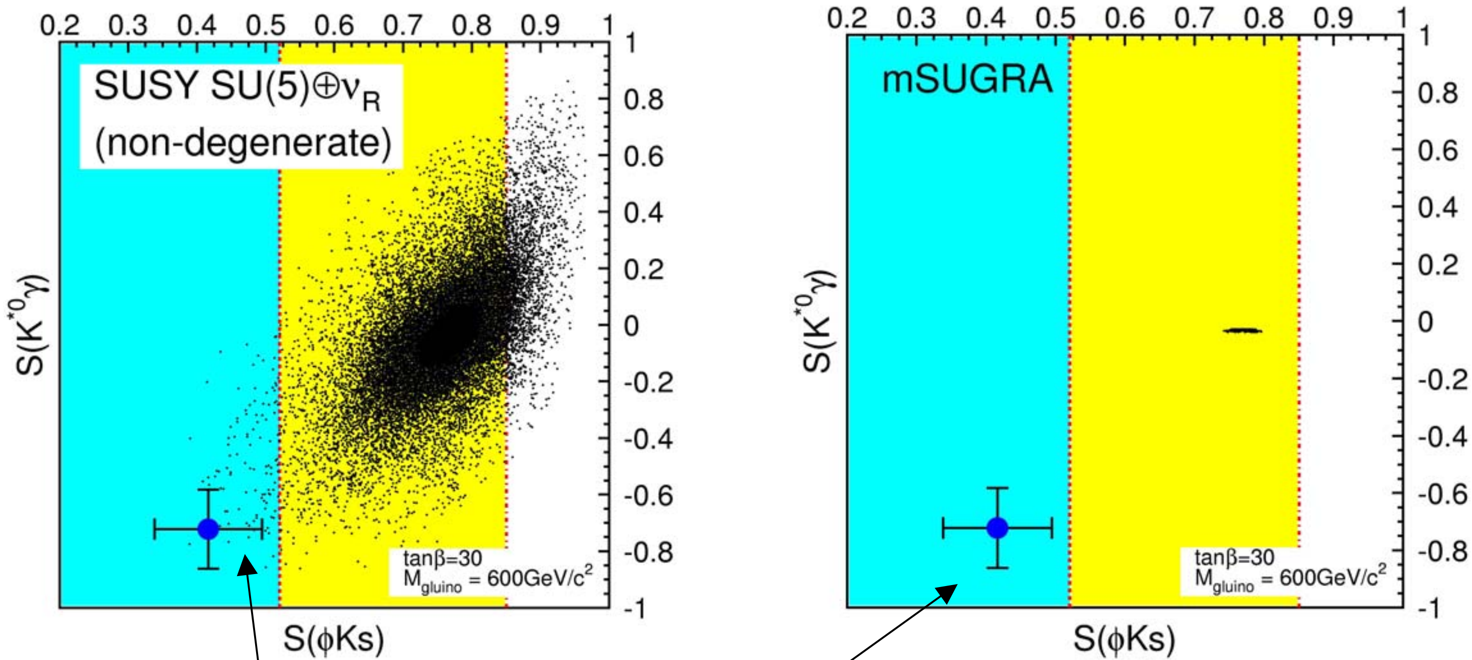
G.Hiller



A Broad Unbiased Approach to New Physics



CPV in b → s and diagnosis of new physics



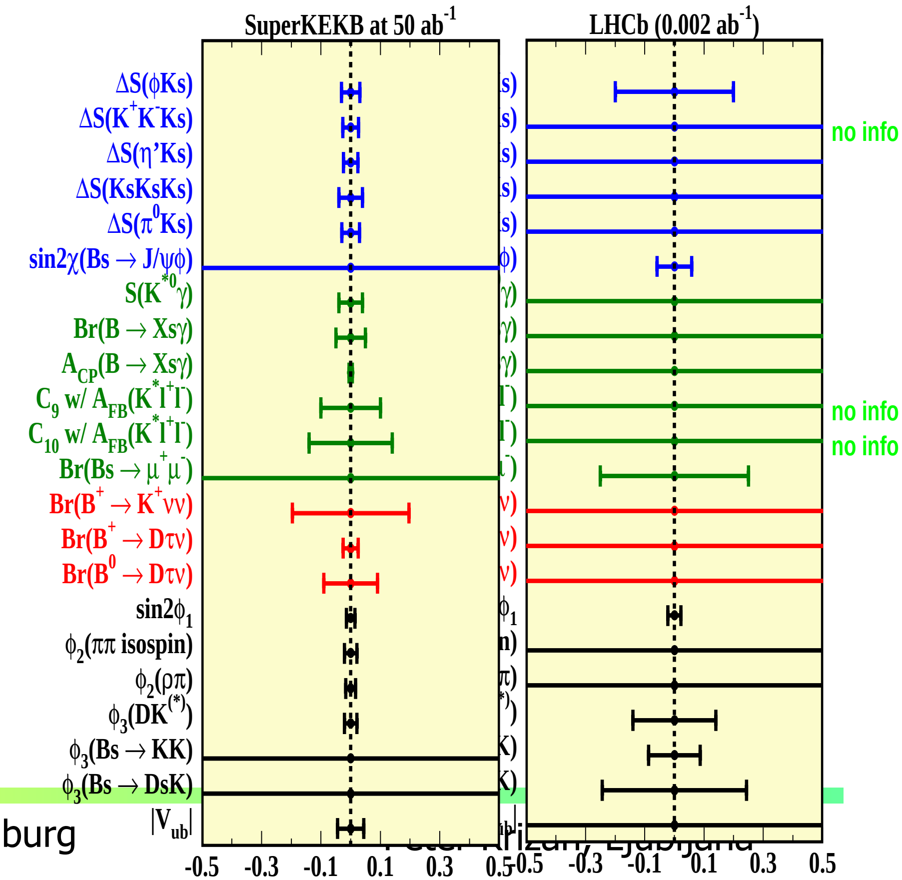
Expected precision at $5ab^{-1}$

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

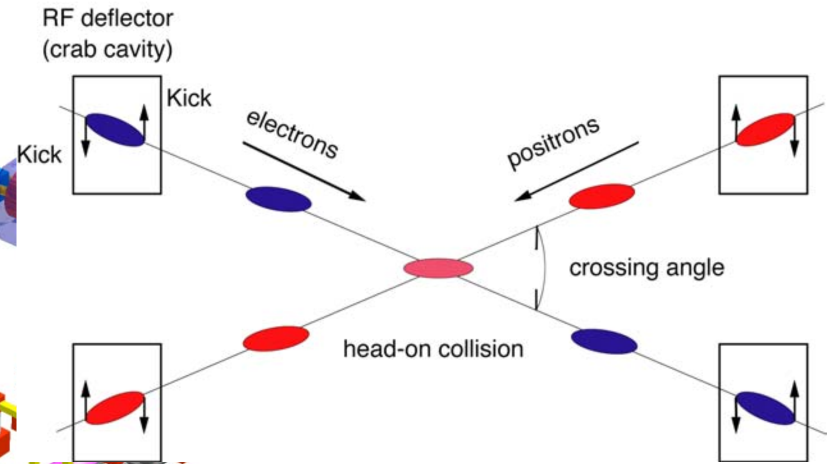
Super-B and LHCb: complementary

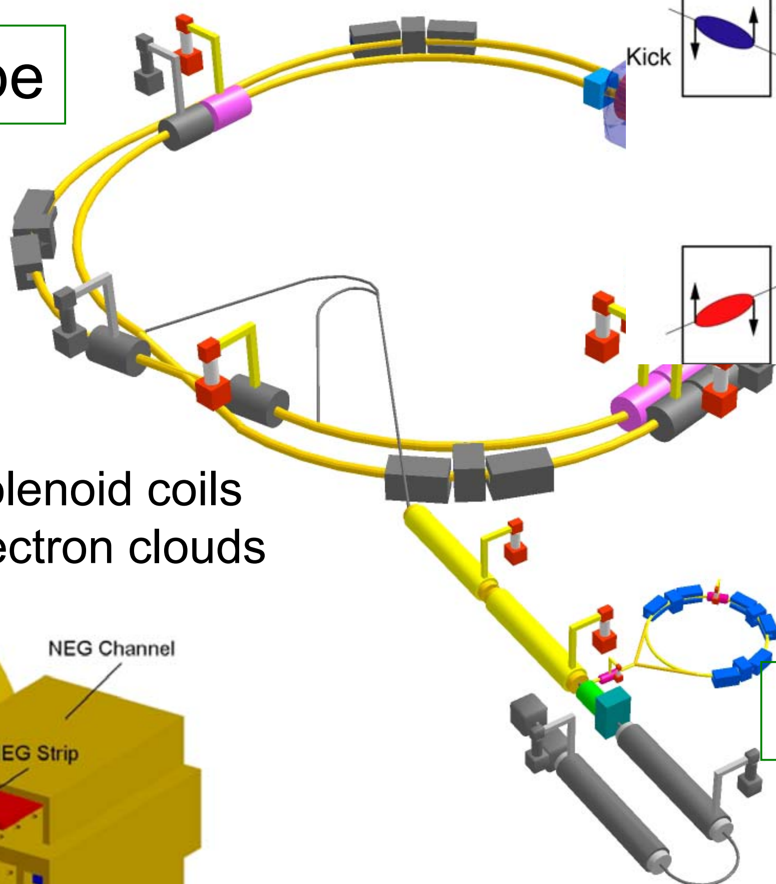
- **Clean environment** → measurements that no other experiment can perform. Examples: CPV in $B \to \phi K^0$, $B \to \eta' K^0$ for new phases, $B \to K_S \pi^0 \gamma$ for right-handed currents.
- **"B-meson beam" technique** → access to new decay modes. Example: discover $B \to K \nu\nu$.
- **Measure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



Super B Factory at KEK

New Beam pipe

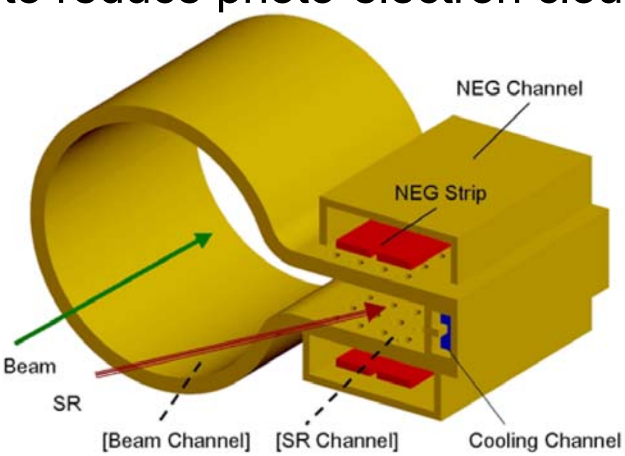




More RF power

Damping ring

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



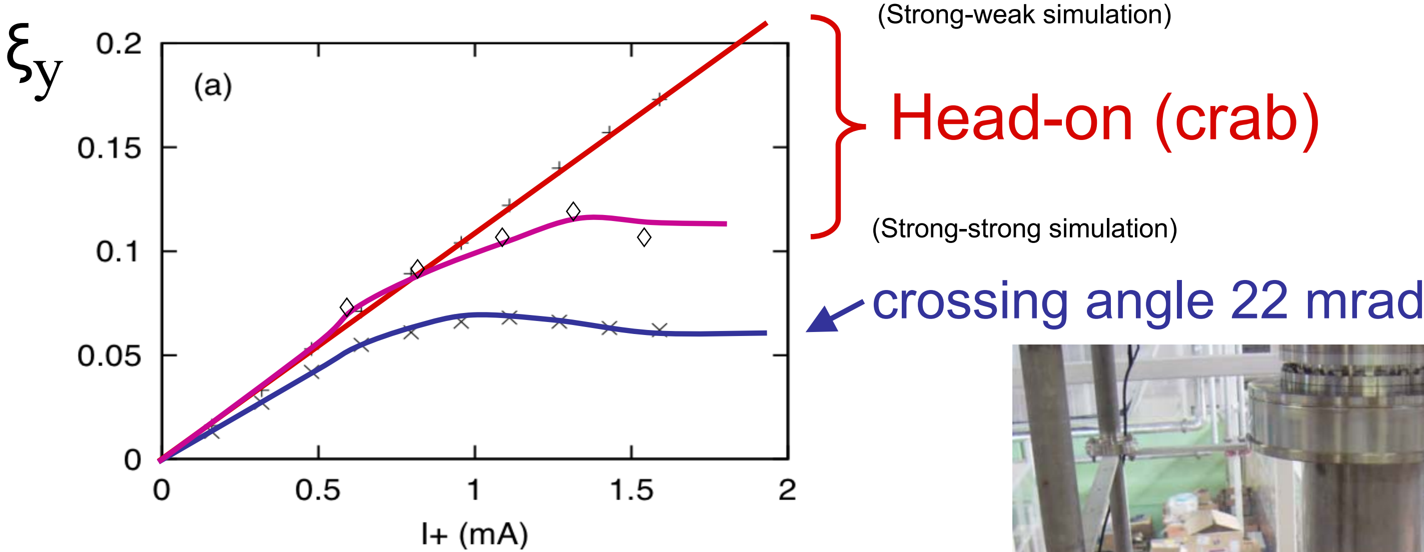
Linac upgrade

$L = 4 \times 10^{35} / cm^2 / s$

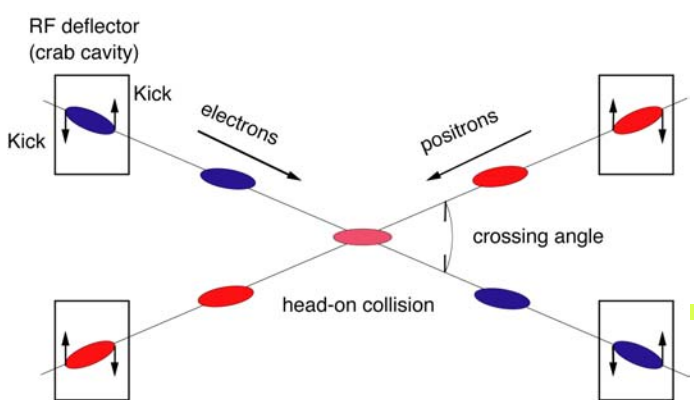
Crab crossing in the near future

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

K. Ohmi



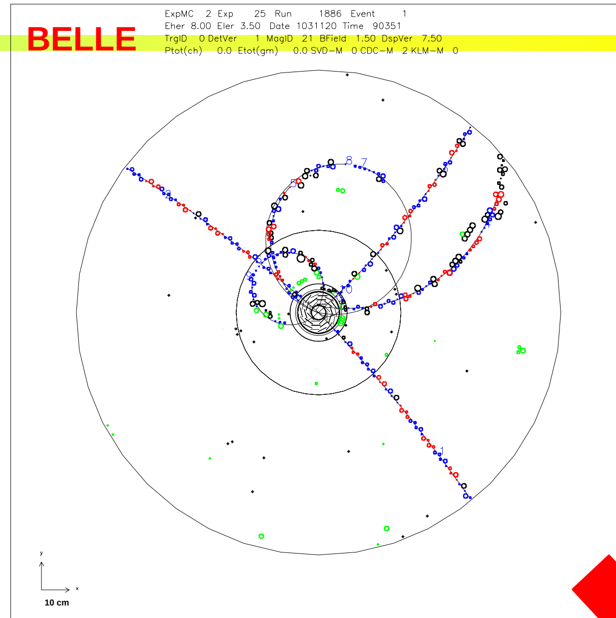
- Superconducting crab cavities are now being tested, will be installed in KEKB around March 2006.

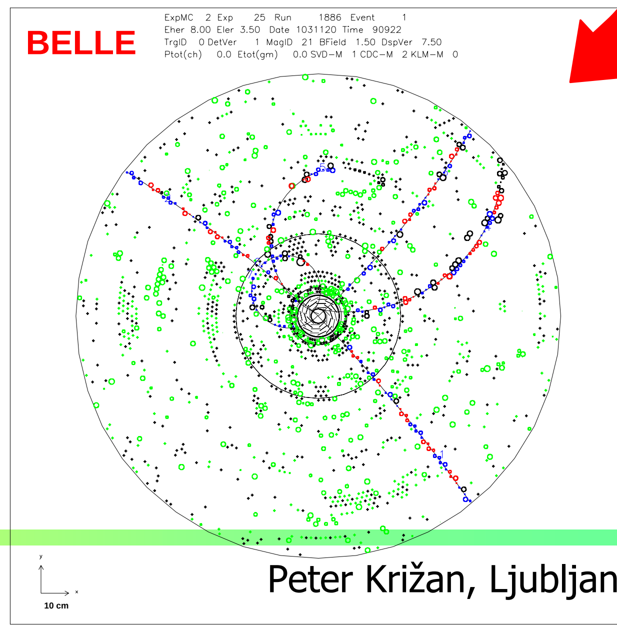


Requirements for the Super B detector

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 ← sμμ recon. eff.
  - hermeticity ← ν "reconstruction"

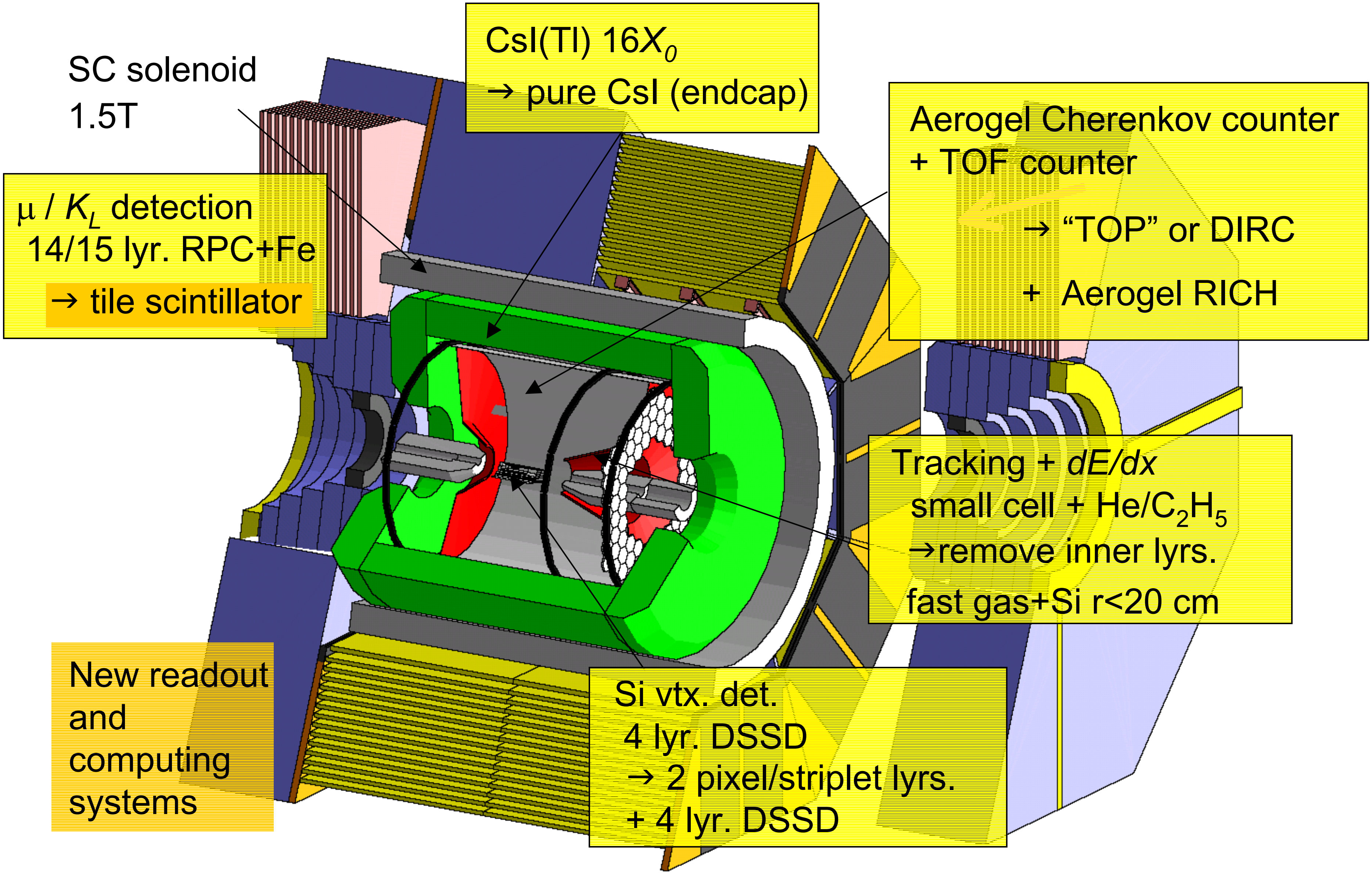




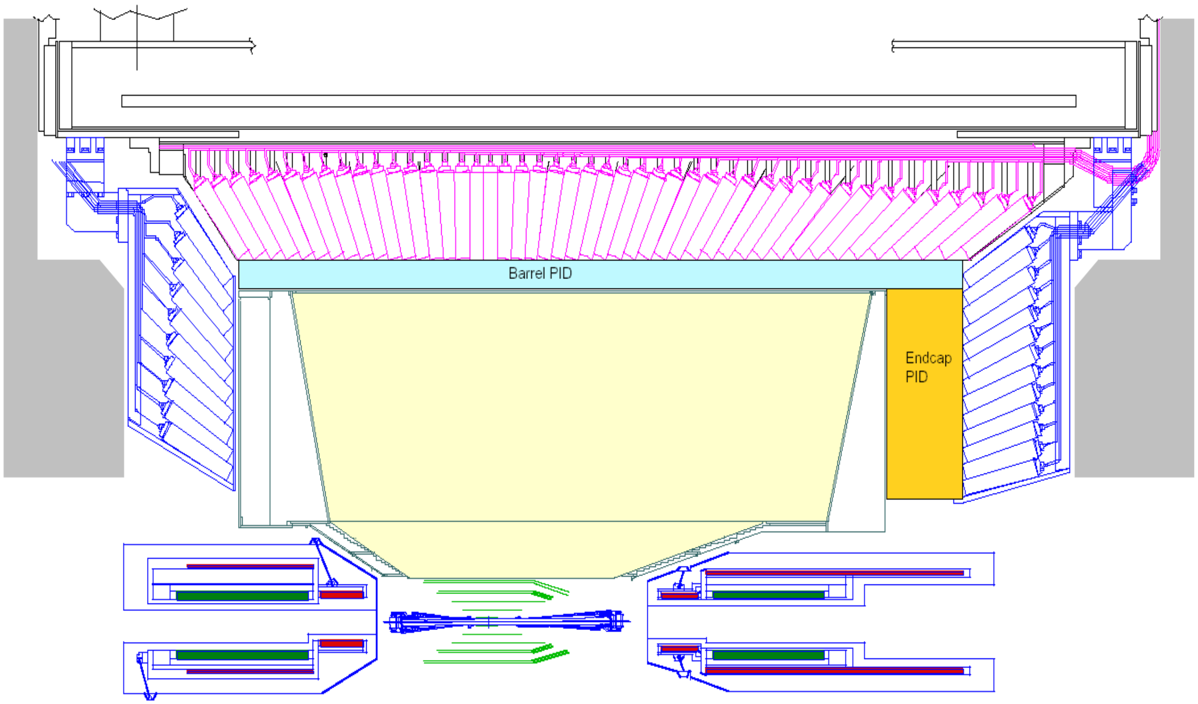
Possible solution:

- 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.

Belle Upgrade for Super-B



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

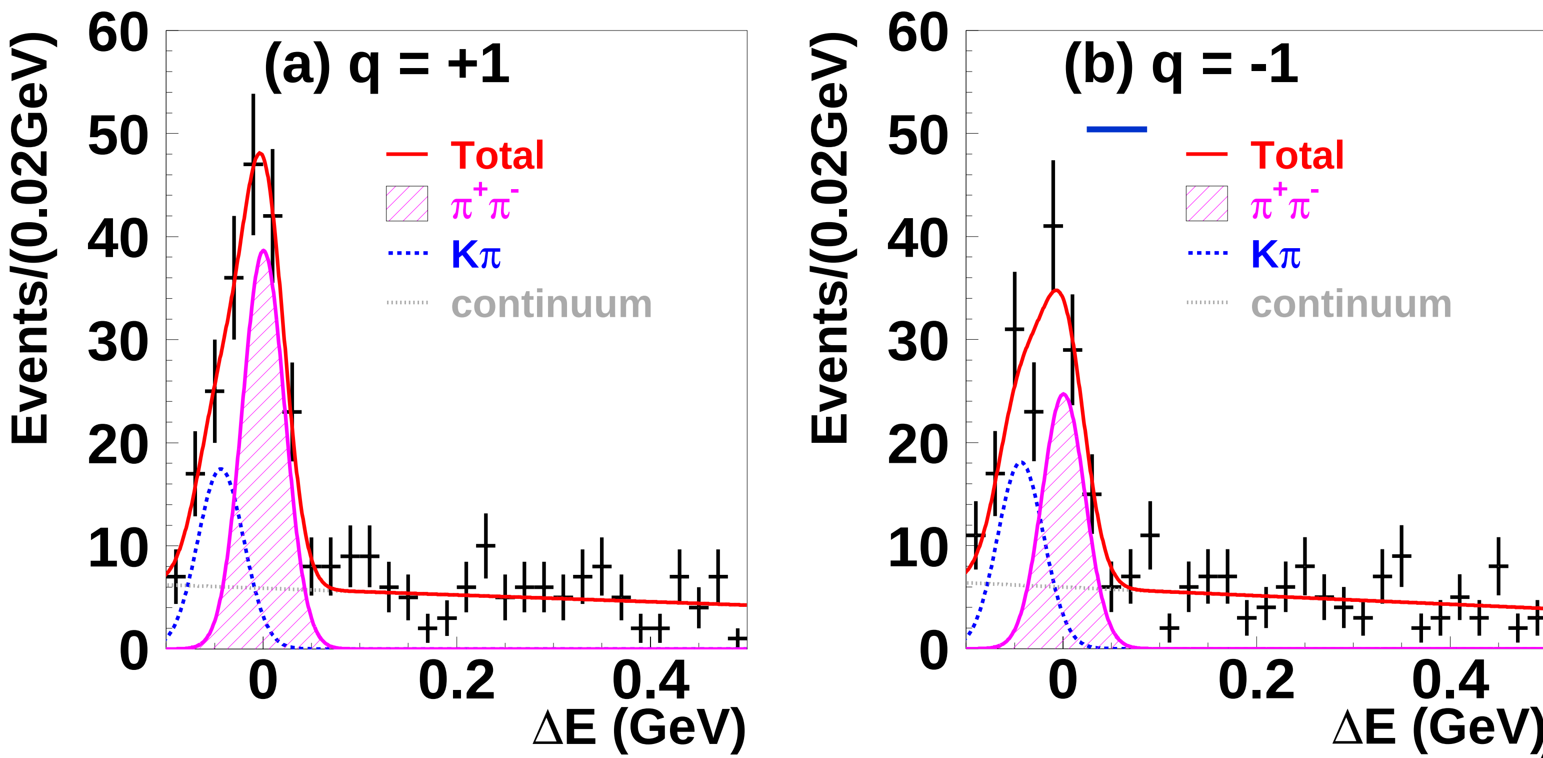
improve purity in fully reconstructed B decays

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

keep high the efficiency for tagging kaons

Why excellent particle identification?

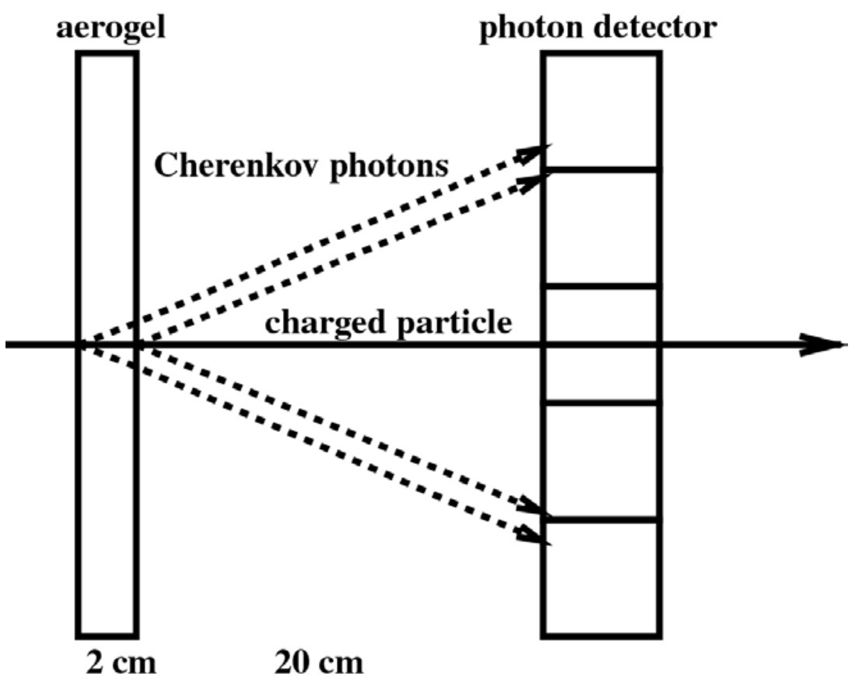
Remember $B \rightarrow \pi\pi$ decays: $B \rightarrow \pi K$ rate 10x bigger than $B \rightarrow \pi\pi$!



ΔE (GeV)

→ We would see no effect without excellent PID!

Proximity focusing RICH in the forward region



K/π separation at 4 GeV/c

$\theta_c(\pi) \sim 308$ mrad (n = 1.05)

$\theta_c(\pi) - \theta_c(K) \sim 23$ mrad

$d\theta_c$(meas.) = $\sigma_0 \sim 13$ mrad

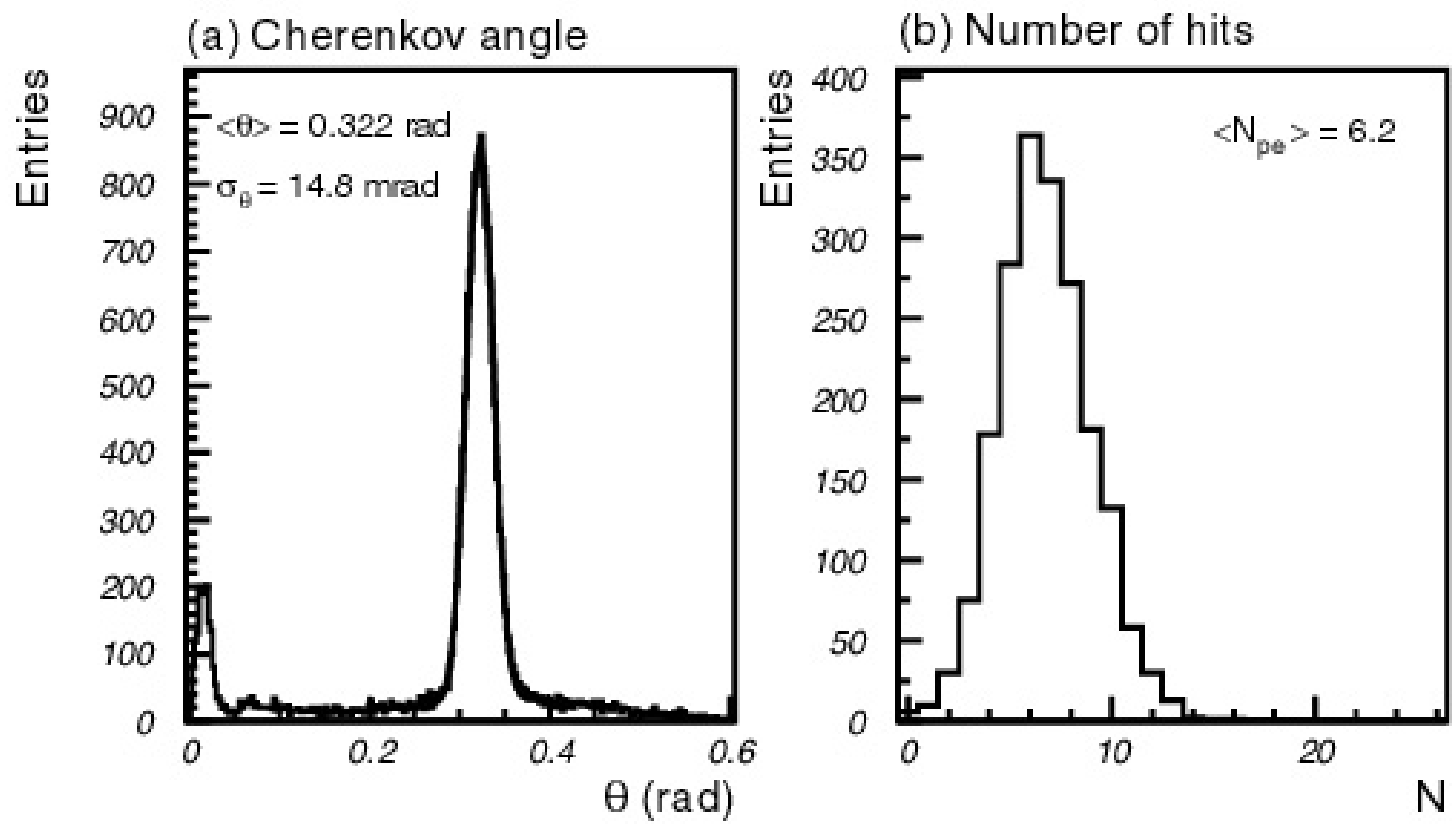
With 20mm thick aerogel and 6mm PMT pad size

→ 6σ separation with $N_{pe} \sim 10$

Beam test: Cherenkov angle resolution and number of photons

Beam test results with 2cm thick aerogel tiles:

>4σ K/π separation

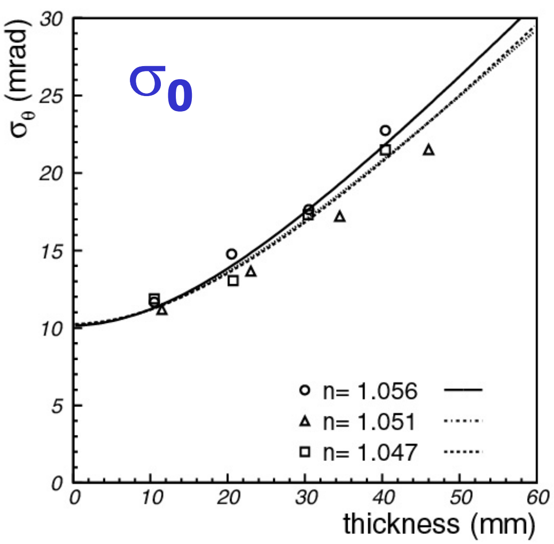


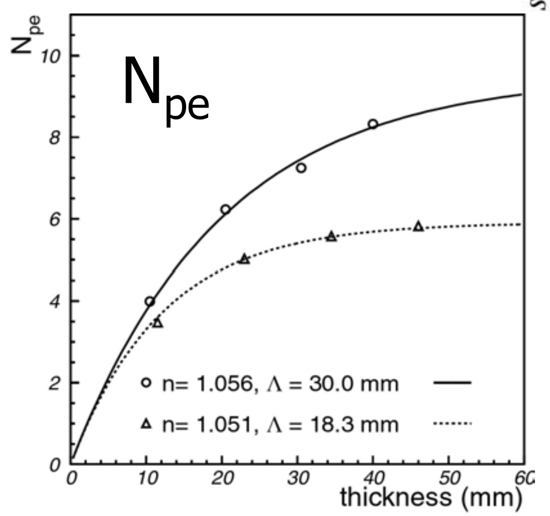
-> Number of photons has to be increased.

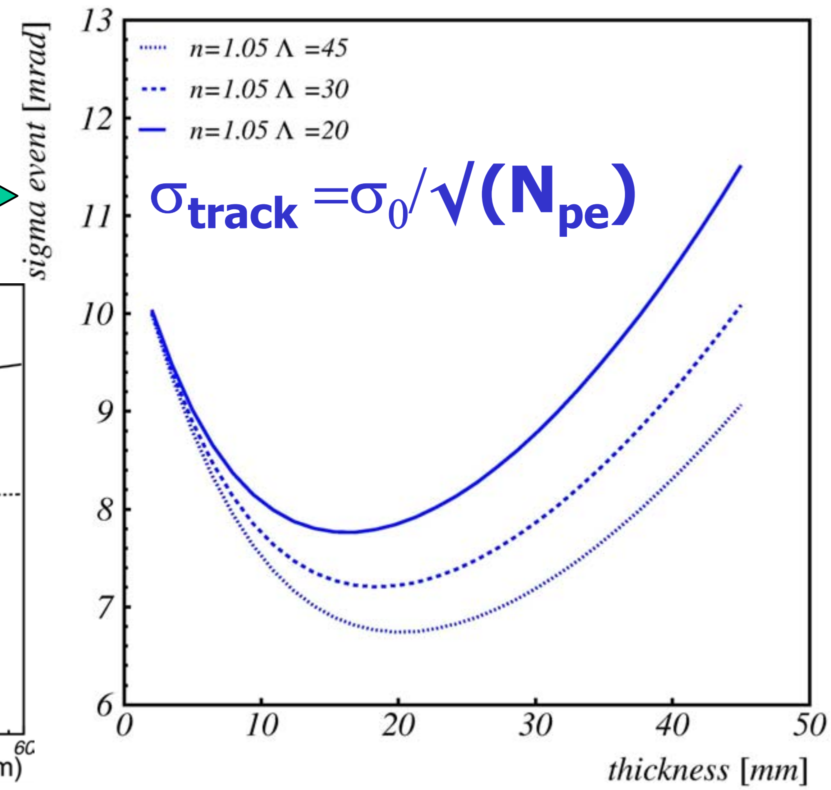
How to increase the number of photons?

What is the optimal radiator thickness?

Use beam test data on σ_0 and N_{pe}







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

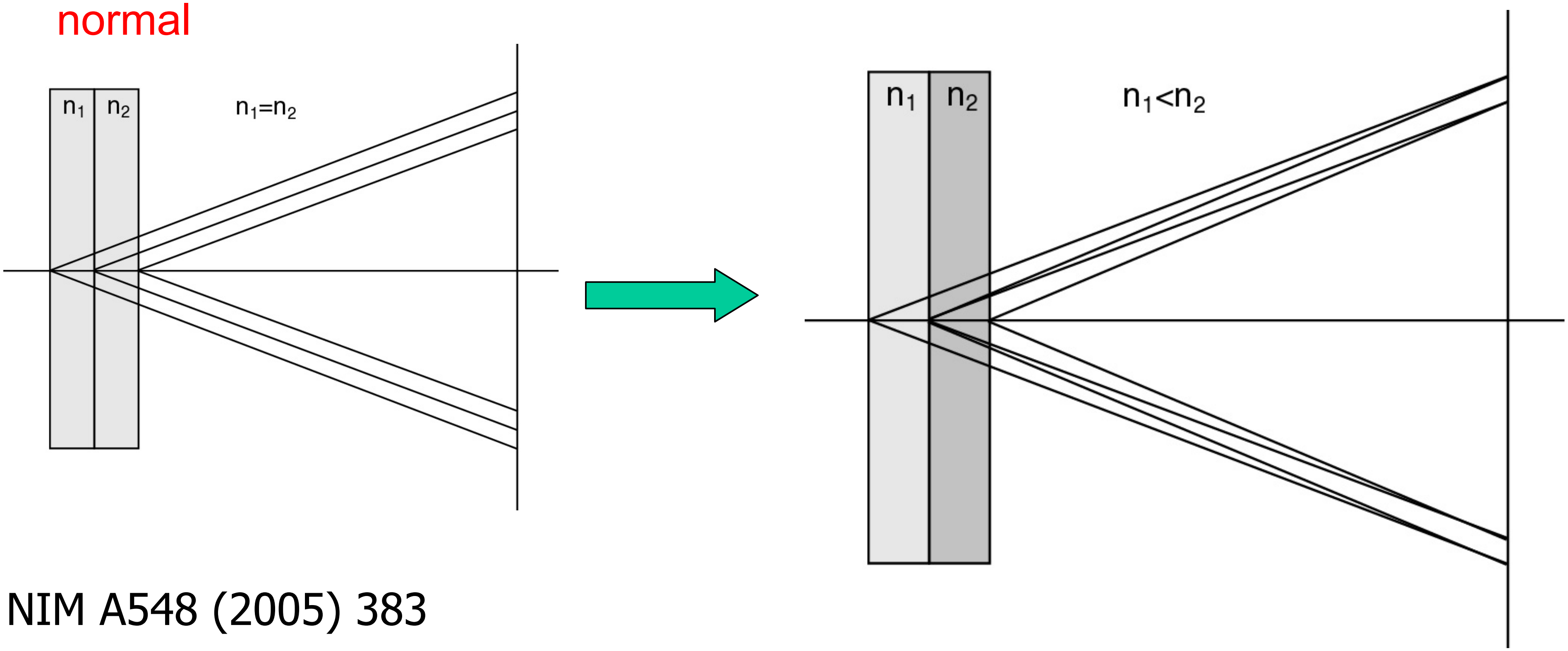
→ Optimum is close to 2 cm

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



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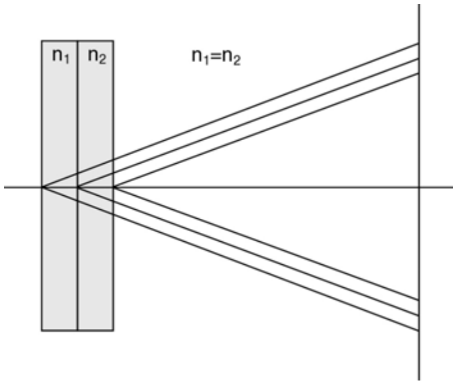
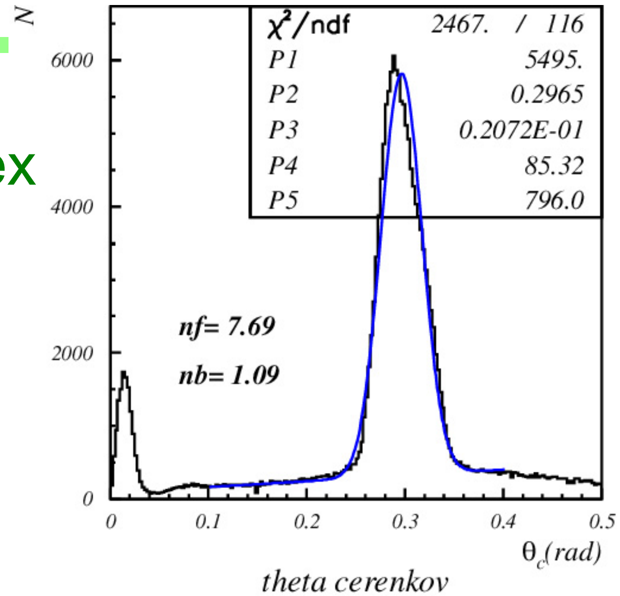
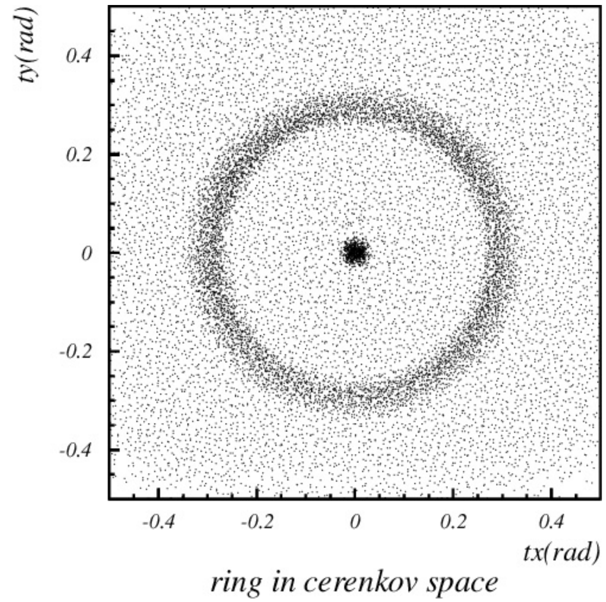
Focusing configuration – data

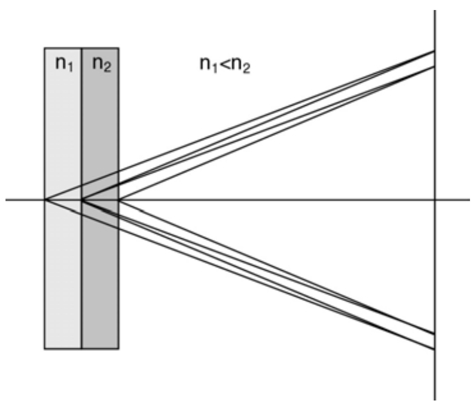
4cm aerogel single index

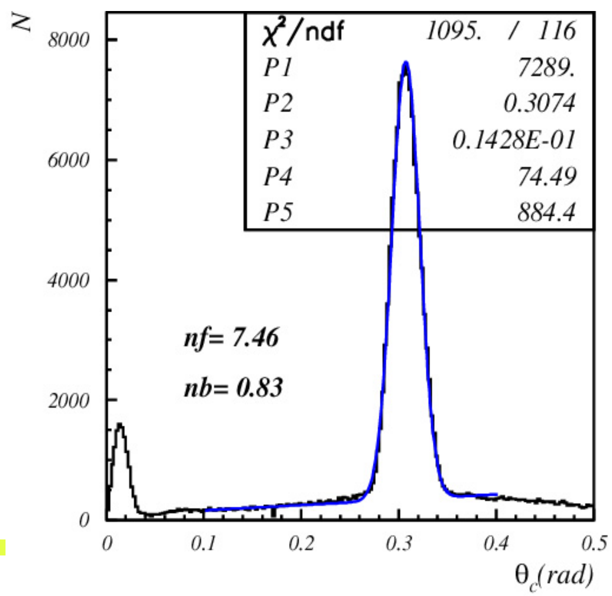


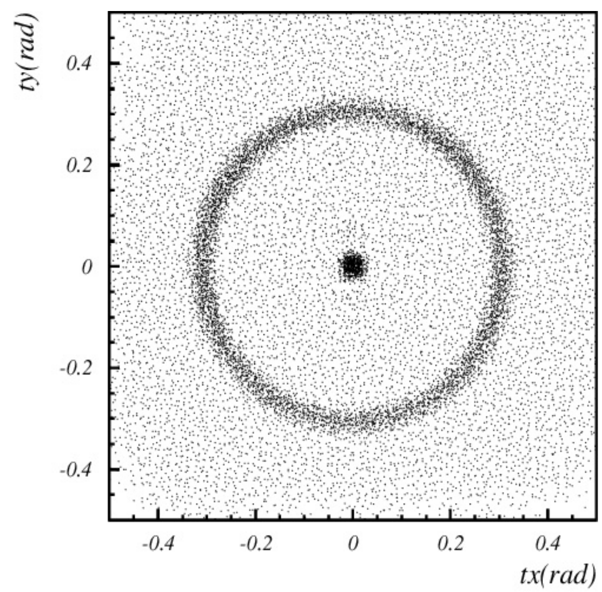




2+2cm aerogel

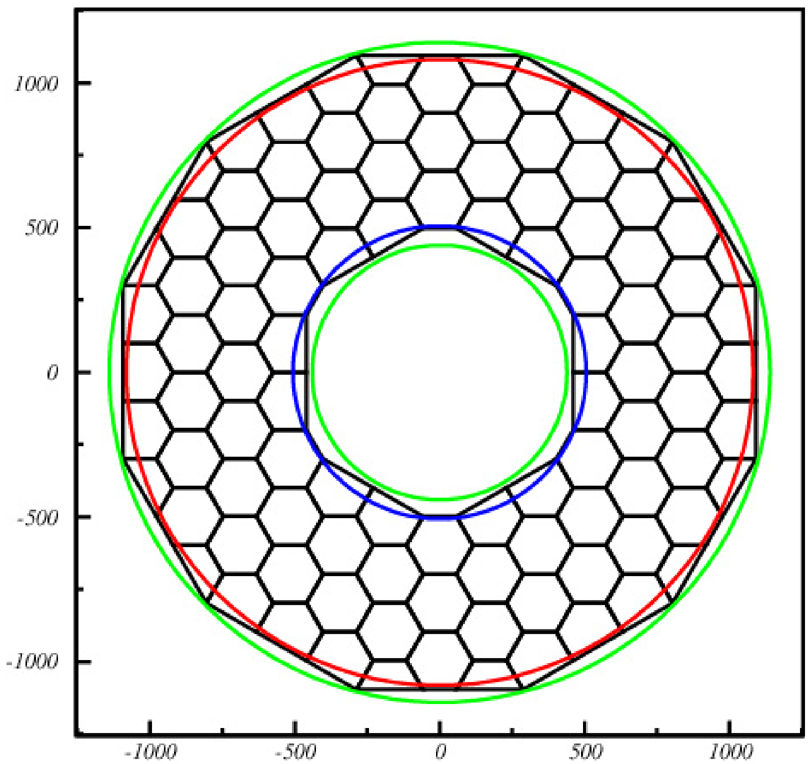






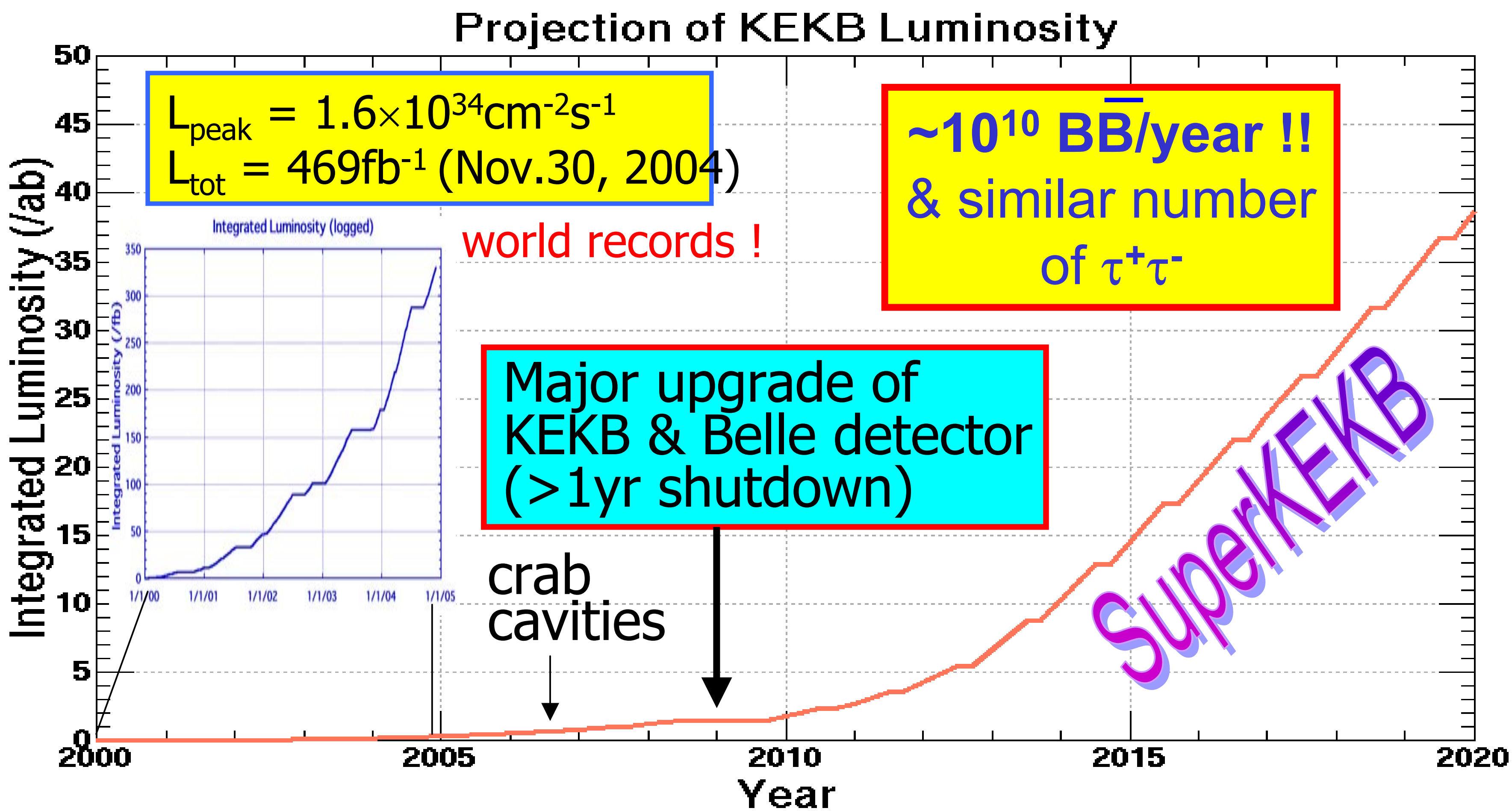
Tiling of the radiator

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

KEKB Collider Upgrade Scenario

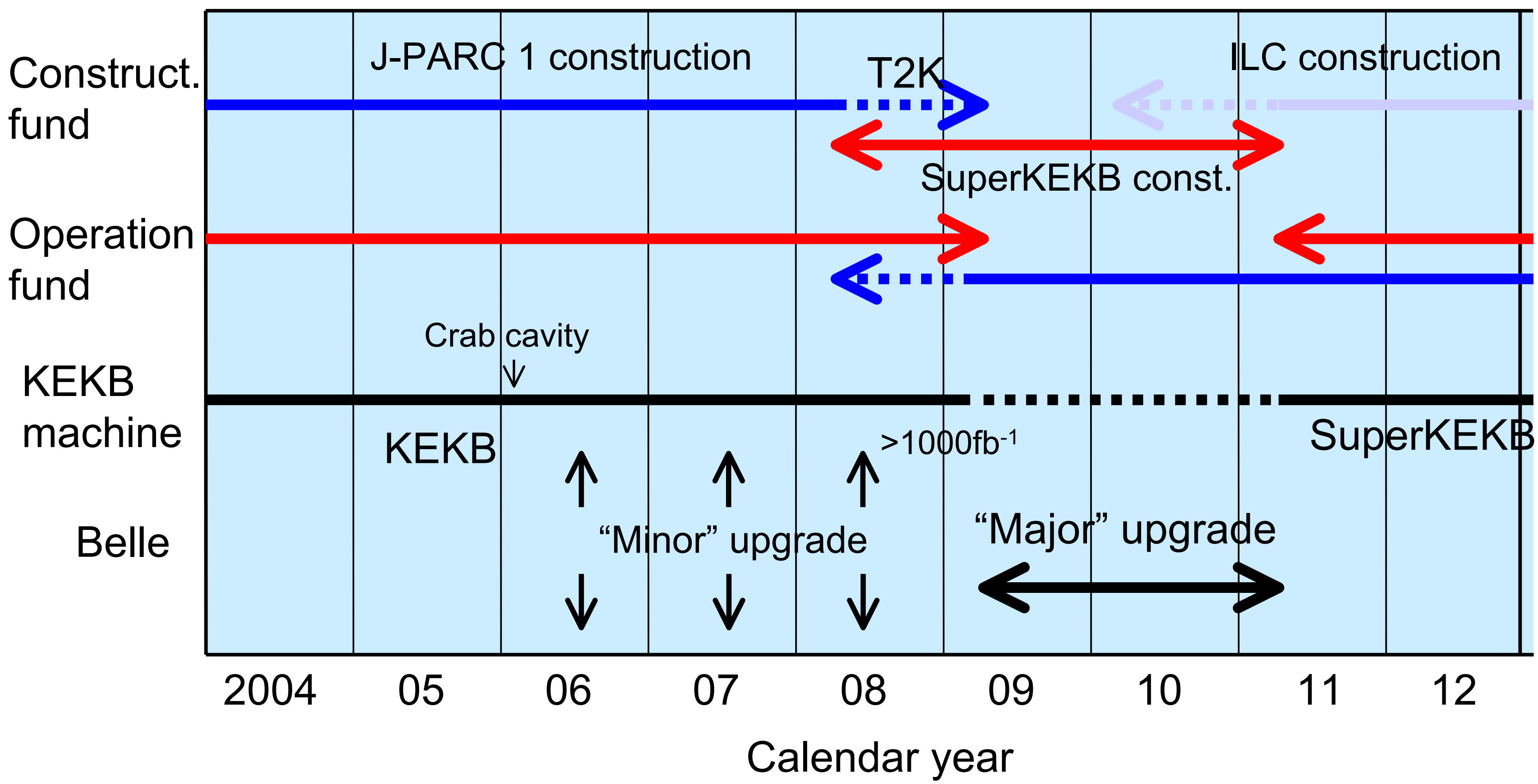


L_{peak} (cm^{-2}s^{-1})	1.6x10^{34}	5x10^{34}	5x10^{35}
L_{int}	469 fb^{-1}	~1 ab^{-1}	~10 ab^{-1}

Possible 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



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 bellow SM expectation, but statistically limited.
- Forward-backward asymmetry (A_{FB}) in $b \rightarrow sl^+l^-$ 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...