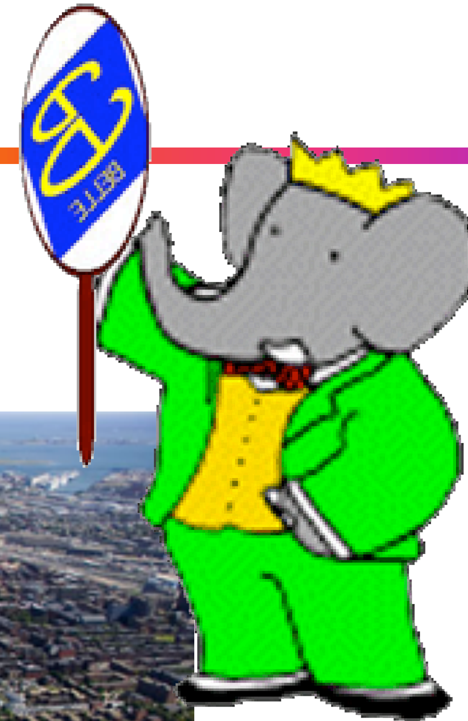
New Physics Searches at the B-Factories II:



Examining the loops

SUSY09
June 5-10, 2009
Northeastern U

Kay Kinoshita
University of Cincinnati
Belle Collaboration

B-factories: early history

First goal: establish unitarity & complex phase of CKM matrix

Kobayashi & Maskawa (1973)

- proposed 3[rd] generation of particles
- could explain CP violation in K (& predict for B)

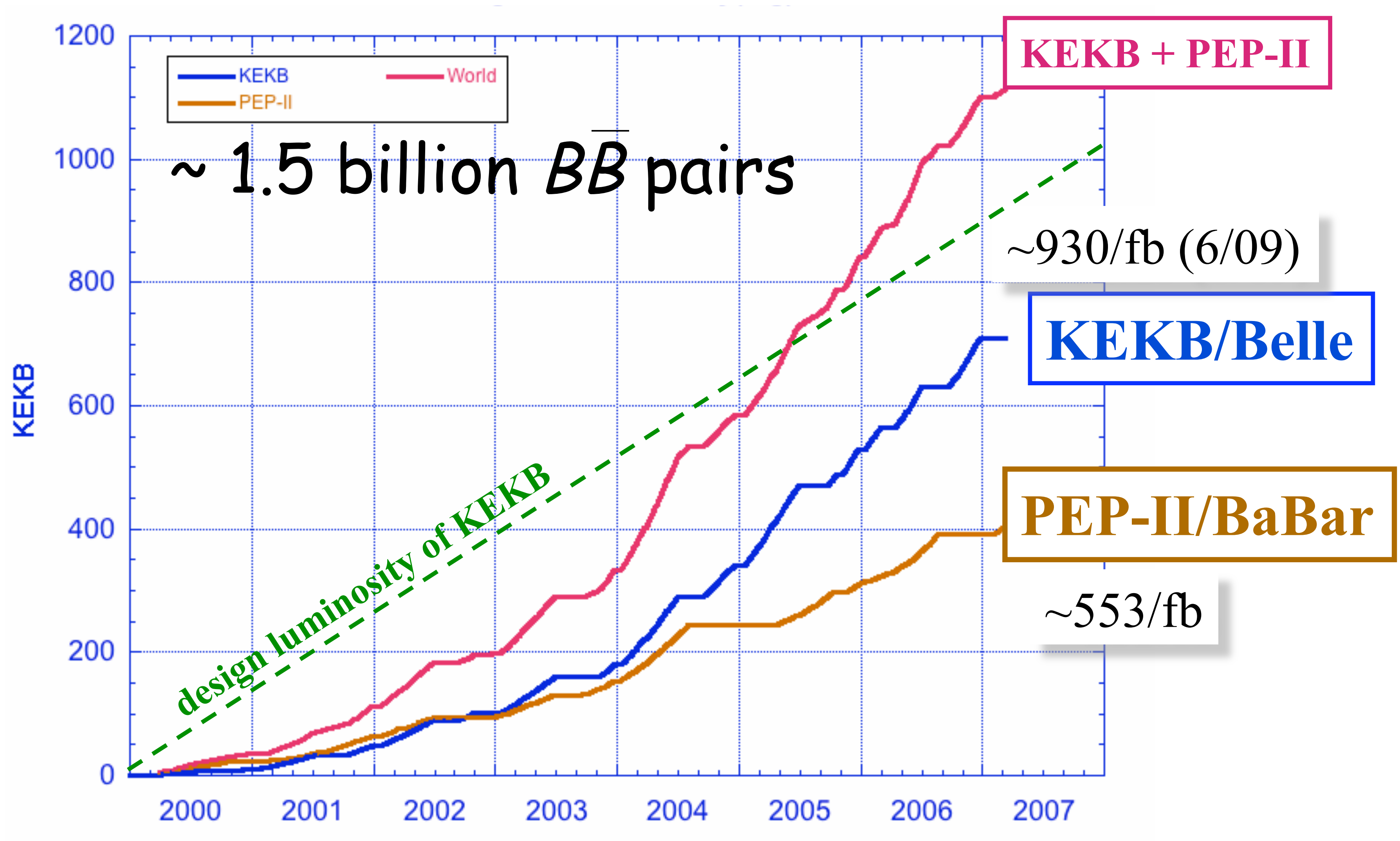
B-Factories (1999-2009)

- CP asymmetry observed in diverse processes in B decay

-> many measurements, (over)constrain CKM, confirm unitarity

2008
Nobel Prize

B factories: data



variations on $\sin 2\phi_1$ ($\sin 2\beta$)

cf parallel talk:
P. Biassoni

Standard Model: "golden" $\sin 2\varphi_1$ ($\sin 2\beta$)

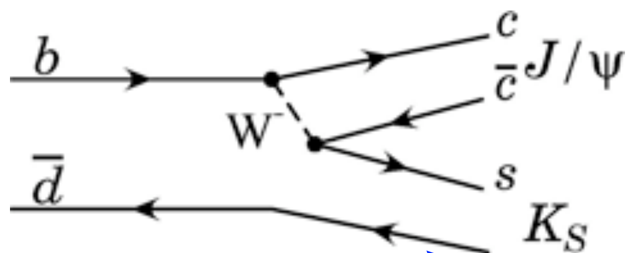
for $B \to J/\psi\ K_s$

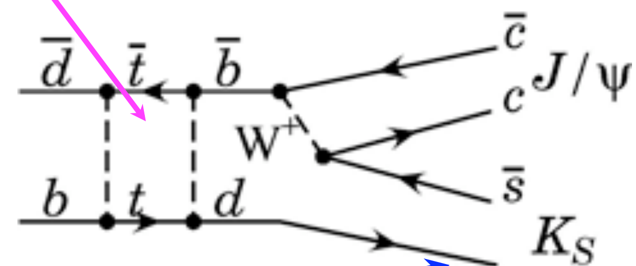
tree (real V_{ij}) $\propto V_{cb}^{*}V_{cs}$

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

well-measured rate

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





identical hadronic processes -> same |Amplitude|

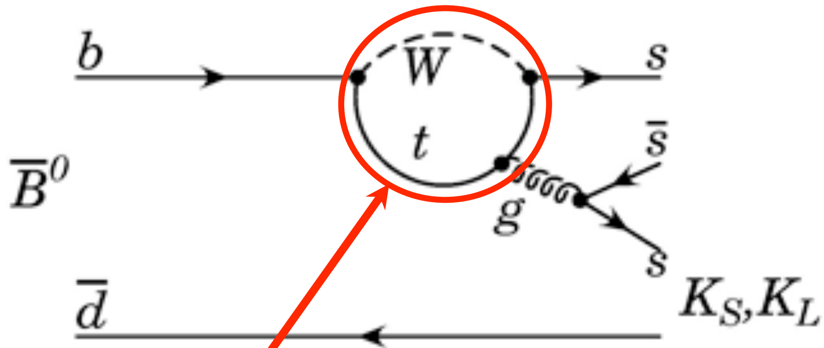
$V_{cb}^{*}V_{cs}$ real => zero phase difference

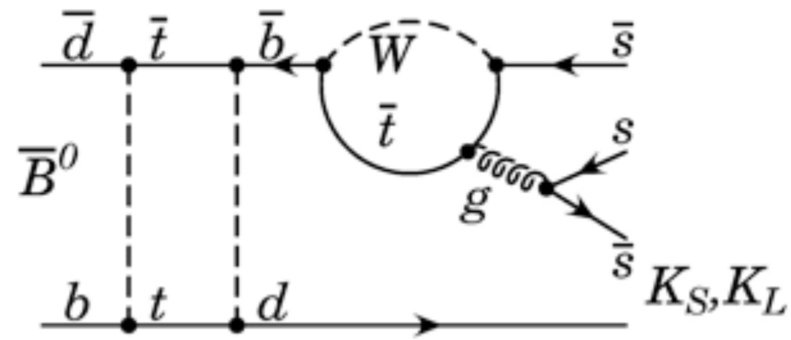
=> relative phase = $2\varphi_1$, CP asymmetry ~ $\sin 2\varphi_1$

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

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

penguin (real V_{ij}) $\propto V_{tb}^{*}V_{ts}$ mixing+penguin $\propto V_{tb}^{*2}V_{td}^{2}V_{tb}V_{ts}^{*}$





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

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

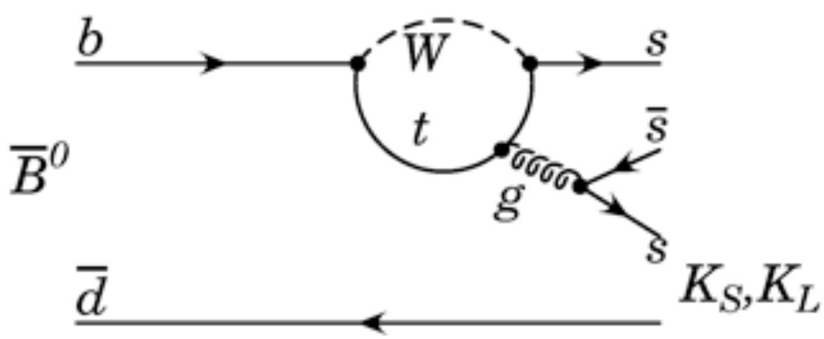
"New Physics" w complex phase φ_{new}

---> CP asymmetry ≠ $\sin(2\varphi_1)$

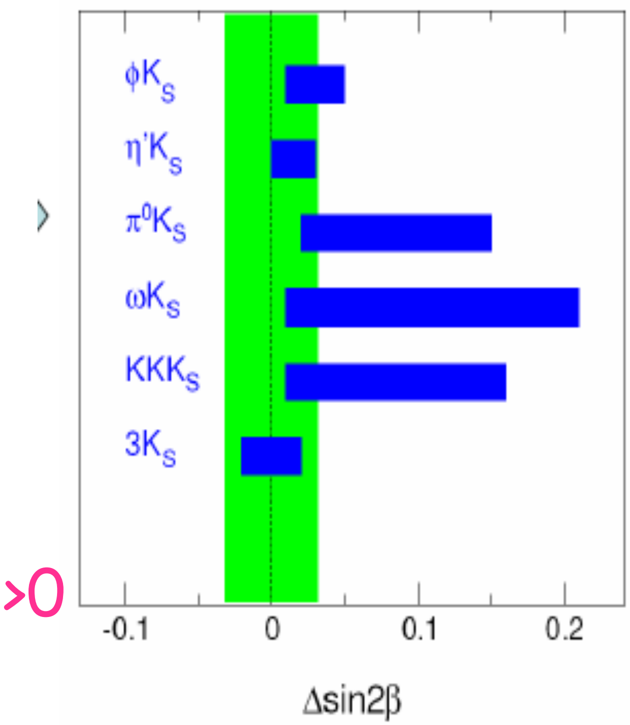
Standard Model: "other" $\sin 2\varphi_1$

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

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



some of recent QCDF estimates
$\sin 2\beta^{f}_{eff} - \sin 2\beta$



caveat:
(small) theory correction -> mostly >0

Average "sin2φ_1" from $b \to s$ penguins

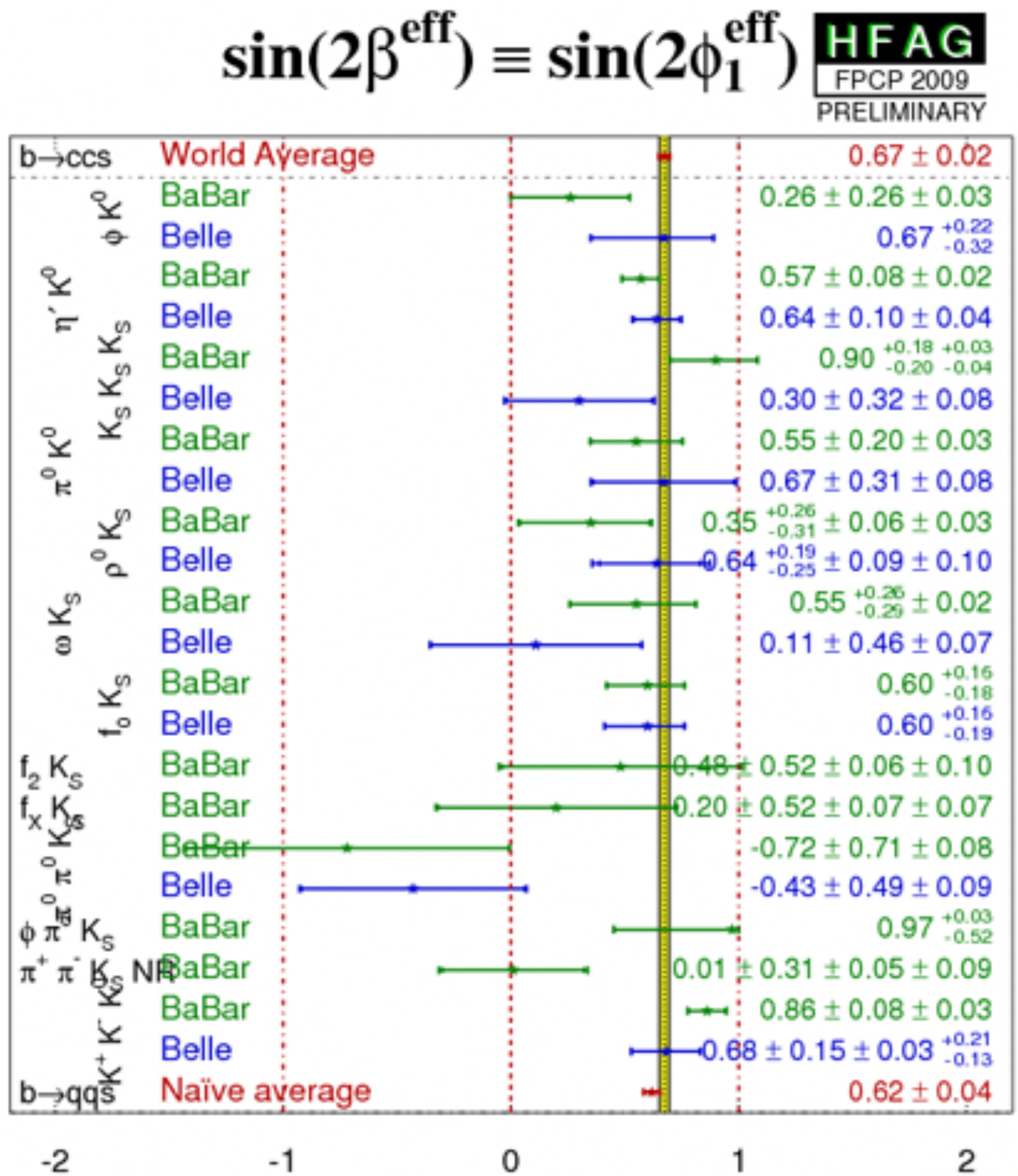
Naïve World Average
$\sin 2\varphi_1(b \to sq\bar{q}) = 0.62 \pm 0.04$

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

$CL = 0.19\ (1.3\sigma)$

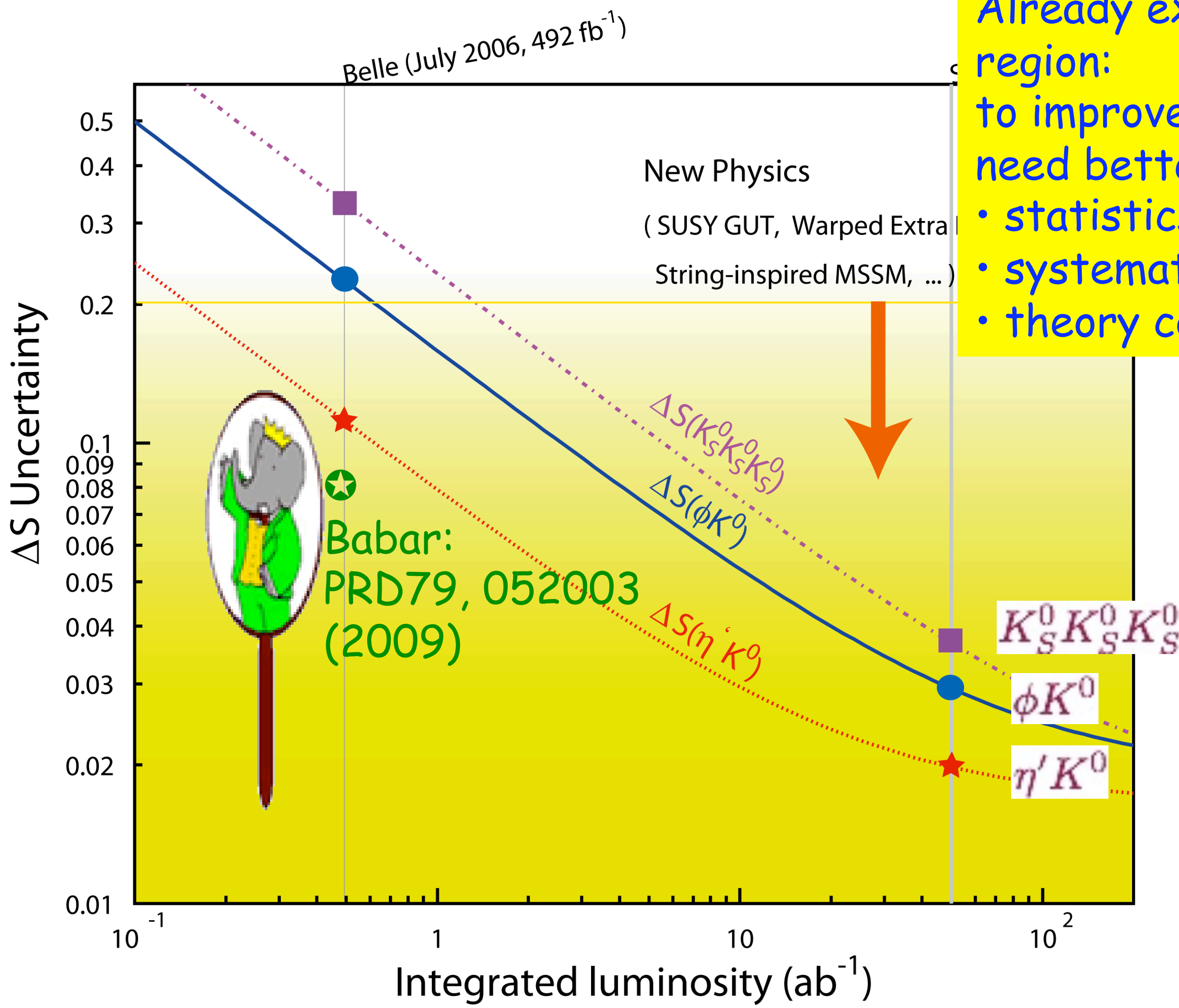
difference is < 0
(theory corrections mostly >0)

Heavy Flavor Averaging Group



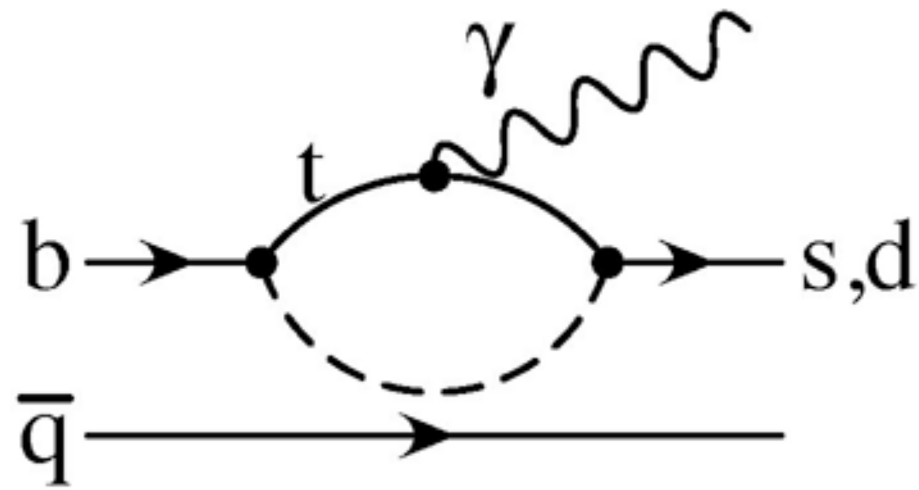
"sin2φ$_1$" sensitivity to New Physics

(Projections for SuperKEKB)



Already exploring "New" region:
to improve sensitivity, need better
- statistics
- systematics
- theory corrections

Radiative decays

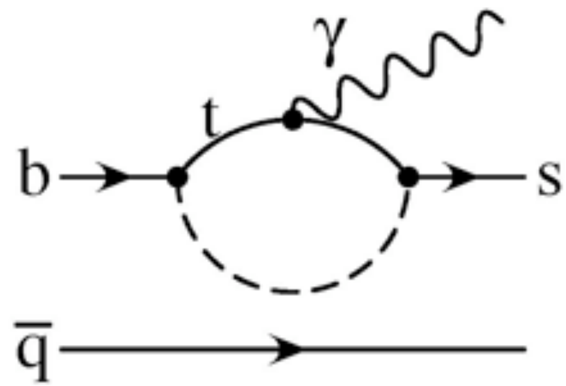


cf parallel talks:
K. Yarritu [K* γ]
H. Hyun
K. Yarritu [d γ]

Inclusive $b \to s\gamma$

Rate is well-defined at quark level

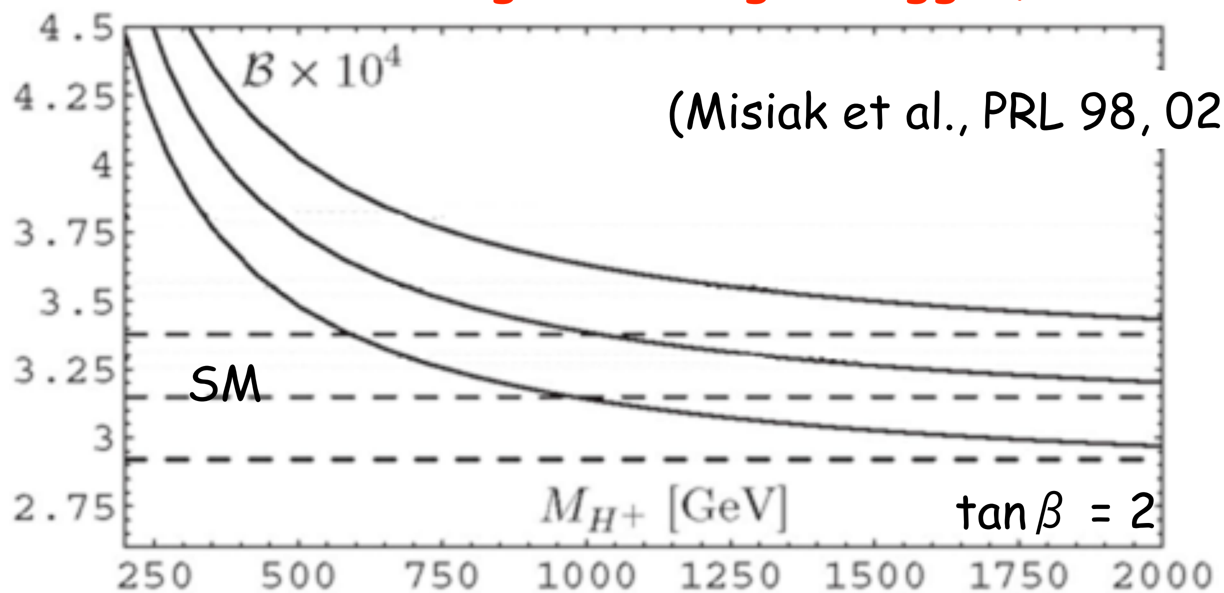
in SM, $|V_{ts}| = |V_{cb}|$



calculated to $O(\alpha^2)$:

$$\mathcal{B}(\bar{B} \to X_s\gamma) = (3.15 \pm 0.23) \times 10^{-4} \ (E_\gamma > 1.6 \text{ GeV})$$

Deviations from SM, e.g. via charged Higgs (2HDM II)



(Misiak et al., PRL 98, 022002 (2007))

Inclusive $b \to s\gamma$

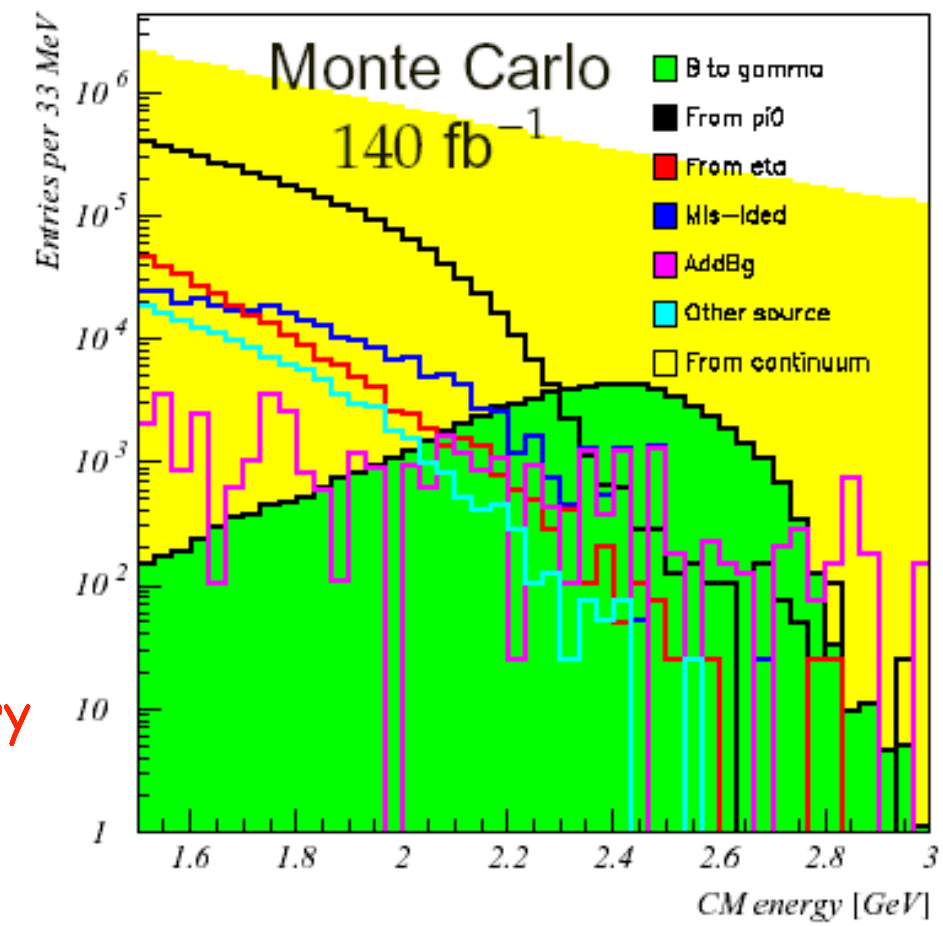
Experimental measurement

in Principle:

- primary γ spectrum
  ~ monochromatic

in Practice:

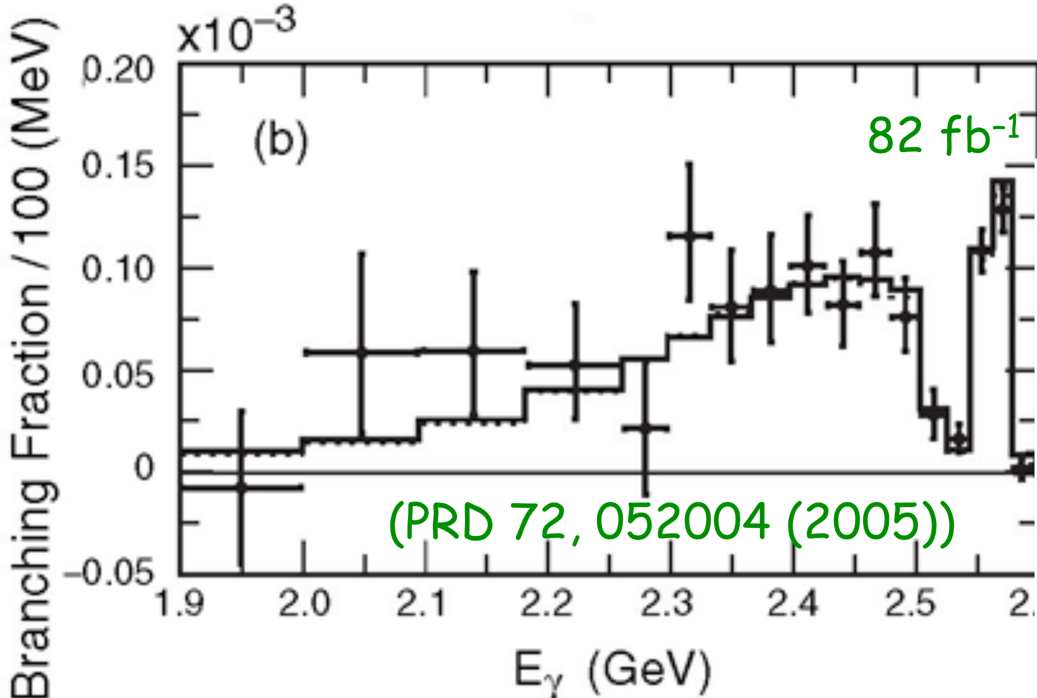
- HUGE background
  continuum
  $\pi^0 \to \gamma\gamma$
- not so monochromatic
- bg worst at low E_γ but need full spectrum to limit theory error

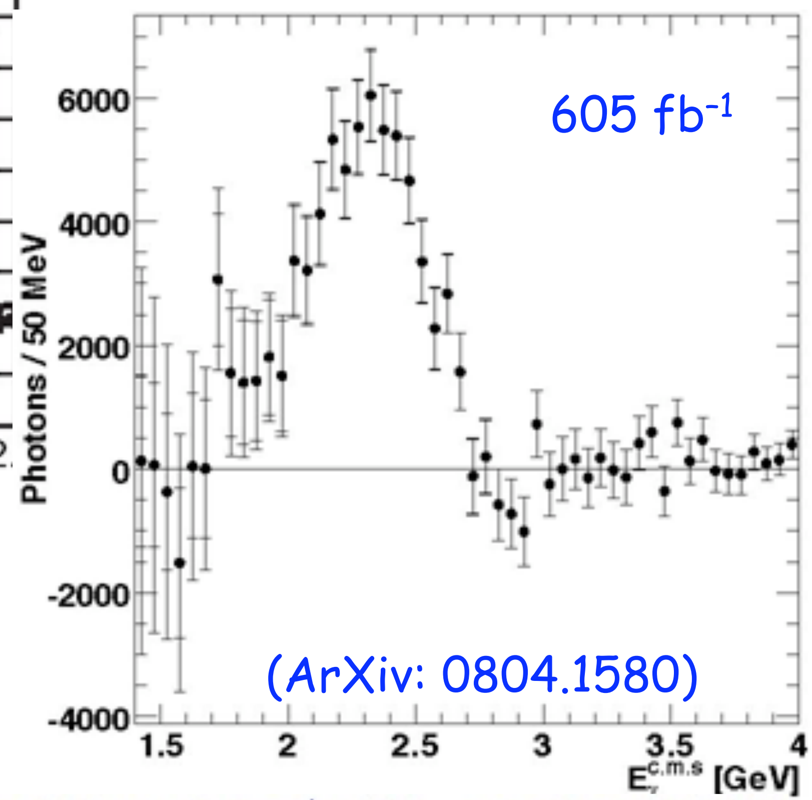


Inclusive $b \to s\gamma$

$$\mathcal{B}(\bar{B} \to X_s\gamma) =$$

$$(3.27 \pm 0.18^{+0.55}_{-0.44}) \times 10^{-4} \ (E_\gamma > 1.9 \text{ GeV})$$

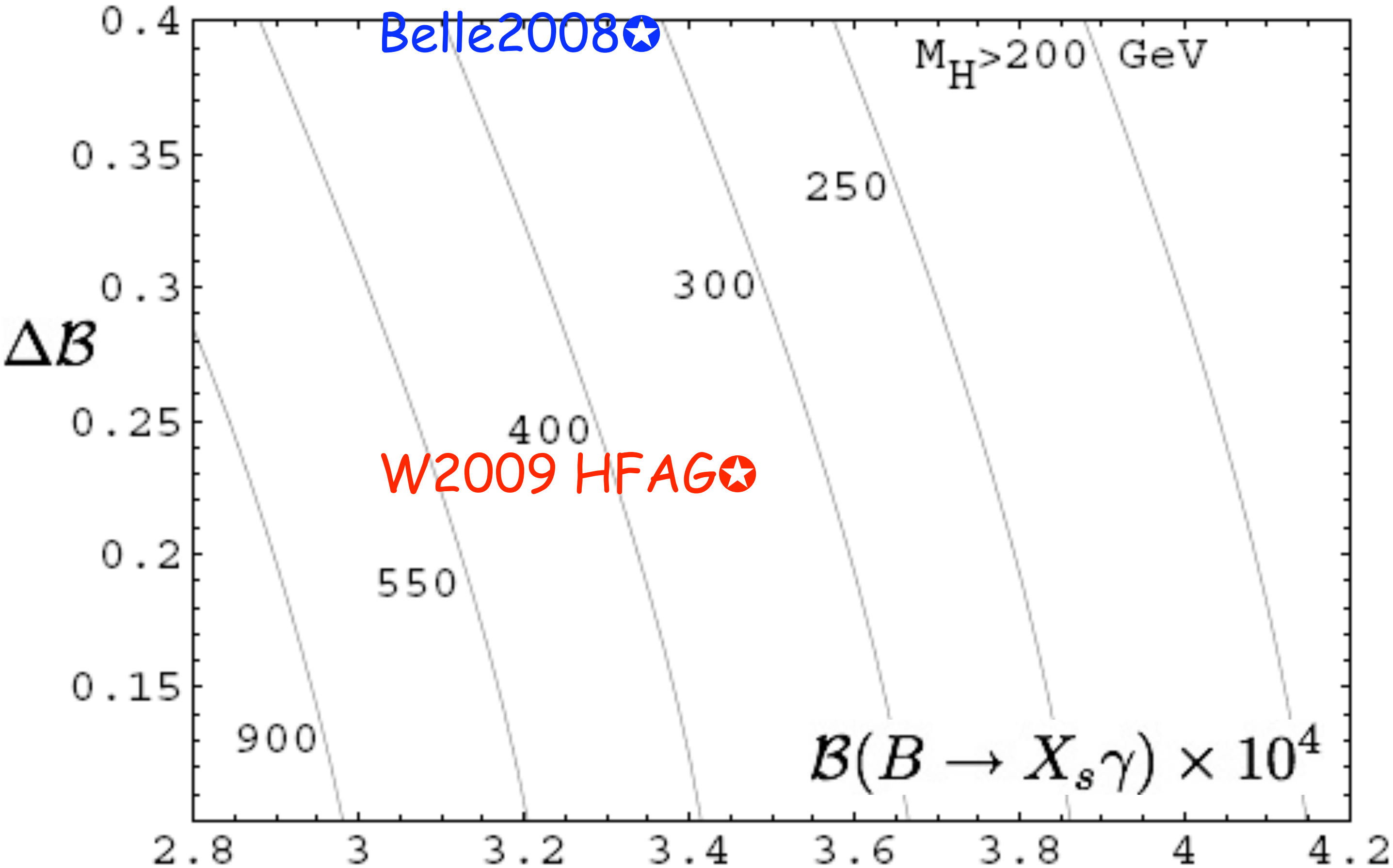




$$(3.47 \pm 0.15 \pm 0.40) \times 10^{-4} \ (E_\gamma > 1.7 \text{ GeV})$$

Inclusive $b \to s\gamma$

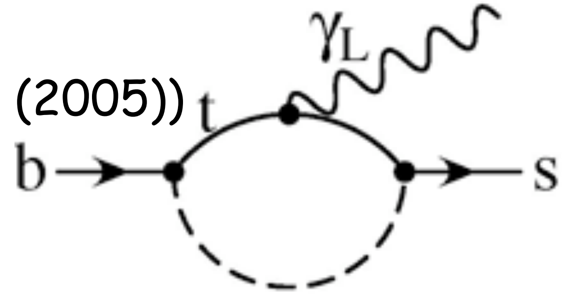
(from Misiak et al., PRL 98, 022002 (2007))



95% CL limit on M_{H+} for all $\tan\beta$

Right-handed currents

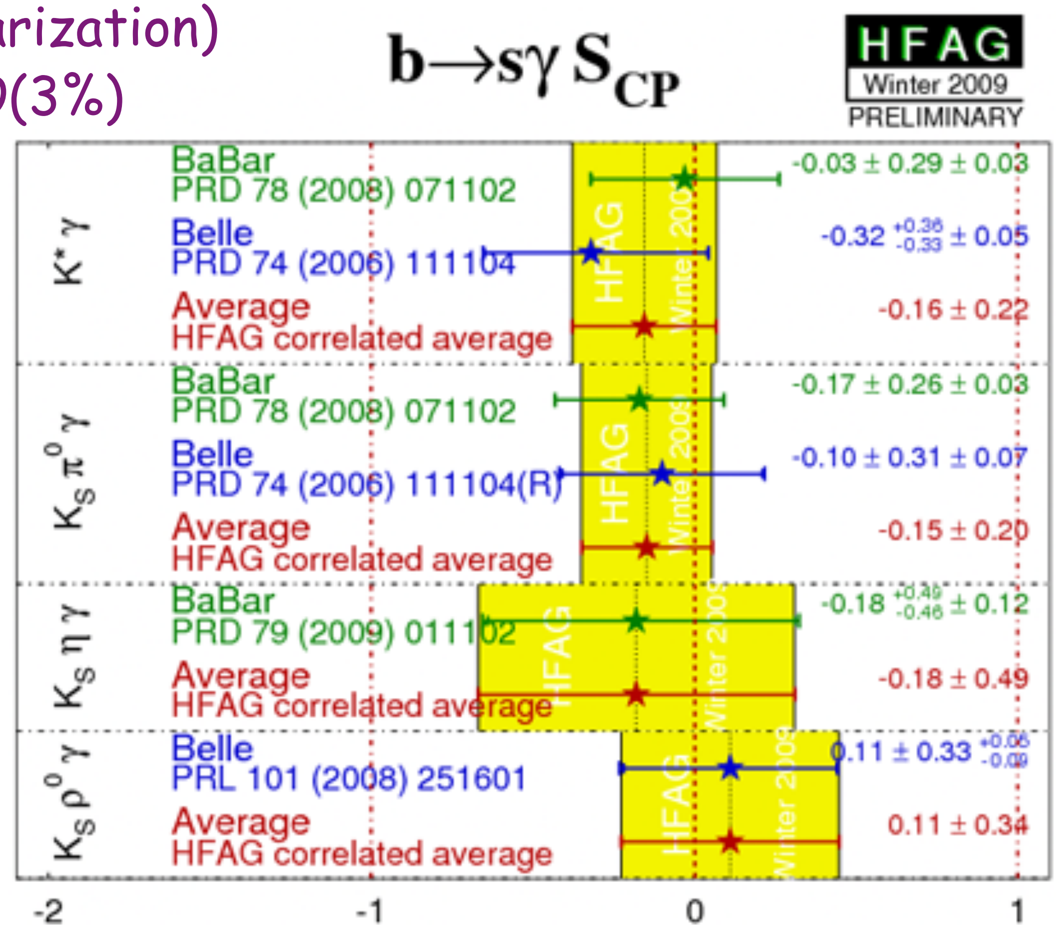
Atwood, Gronau, Soni (PRL 79, 185 (1997))
Atwood, Gershon, Hazumi, Soni (PRD 71, 076003 (2005))



in SM
$B^0 \to X_s^{CP}\gamma$ is
~flavor-specific (γ polarization)
-> low CP-asymmetry, O(3%)

large asymmetry
<->
right-handed current

Current results:
consistent with no
RH currents
(but need more data for
good sensitivity...)



$b \to d\gamma$

Physics issues: similar to b->sγ

-> branching fractions, time-dependent asymmetry, direct CP, isospin

Experimental challenge:

Branching fractions suppressed over b->sγ by $(|V_{td}|/|V_{ts}|)^2 \sim 0.04$

b->sγ constitutes large "physics background"

-> mainly exclusive modes

First seen in 2005 at Belle: $B^0 \to \rho^0\gamma$

PRL 96, 221601 (2006)

$b \rightarrow d\gamma$

branching fraction ratio

$$\frac{\mathcal{B}(B \rightarrow \{d\}\gamma)}{\mathcal{B}(B \rightarrow \{s\}\gamma)}$$

is a measure of

$$\frac{|V_{td}|}{|V_{ts}|}$$

w low model-dependence

exclusive modes

Babar: PRD 78, 112001 (2008) 465M $B\bar{B}$

Belle: PRL 101, 111801 (2008) 657M $B\bar{B}$

h_d	$R \equiv \frac{\mathcal{B}(B \to h_d \gamma)}{\mathcal{B}(B \to K^* \gamma)}$
ρ^+	$0.030^{+0.012}_{-0.011}$
ρ^0	0.024 ± 0.006
	$0.0206^{+0.0045}_{-0.0043}{}^{+0.0014}_{-0.0016}$
ω^0	$0.012^{+0.007}_{-0.006}$
ρ/ω	0.039 ± 0.008
	$0.0284 \pm 0.0050^{+0.0027}_{-0.0029}$

semi-inclusive method

Babar: arXiv:0807.4975 383M $B\bar{B}$

$$R \equiv \frac{\mathcal{B}(B \rightarrow \{d\}\gamma)}{\mathcal{B}(B \rightarrow \{s\}\gamma)} = 0.033 \pm 0.013 \pm 0.009$$

$b \to d\gamma$

branching fraction ratio

$$\frac{\mathcal{B}(B \to \{d\}\gamma)}{\mathcal{B}(B \to \{s\}\gamma)}$$

is a measure of

$$\frac{|V_{td}|}{|V_{ts}|}$$

w low model-dependence

exclusive modes

Babar: PRD 78, 112001 (2008) 465M $B\bar{B}$

Belle: PRL 101, 111801 (2008) 657M $B\bar{B}$

$$\frac{|V_{td}|}{|V_{ts}|} = 0.195^{+0.020}_{-0.019} \pm 0.015(\mathrm{th})$$

$$\frac{|V_{td}|}{|V_{ts}|} = 0.233^{+0.025+0.022}_{-0.024-0.021}$$

semi-inclusive method

Babar: arXiv:0807.4975 383M $B\bar{B}$

$$= 0.177 \pm 0.043 \pm 0.001(\mathrm{th})$$

B-factory average

$$0.203 \pm 0.020$$

compare w result from mixing (PDG2008)

$$0.208 \pm 0.002(\mathrm{exp})^{+0.008}_{-0.006}(\mathrm{th})$$

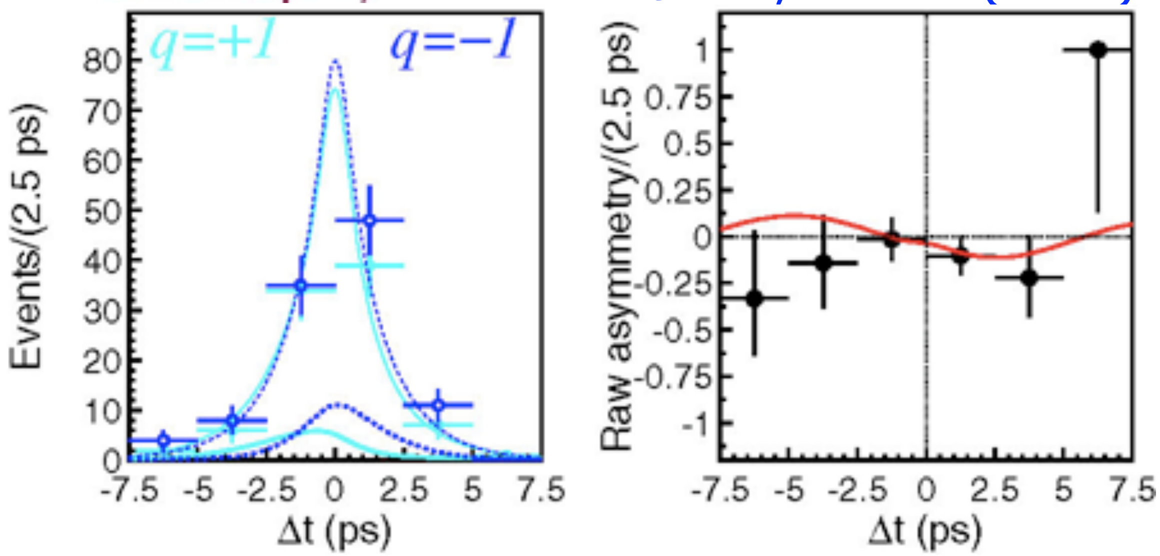
$b \to d\gamma$

CP asymmetry

SM: time-dependent S = 0, direct A ~ –0.1

$B^0 \to \rho^0\gamma$

Belle: PRL 100, 021602 (2008)



$$S_{\rho^0\gamma} = -0.83 \pm 0.65 \pm 0.18$$

$$\mathcal{A}_{\rho^0\gamma} = -0.44 \pm 0.49 \pm 0.14$$

consistent with zero asymmetry

semileptonic FCNC decays

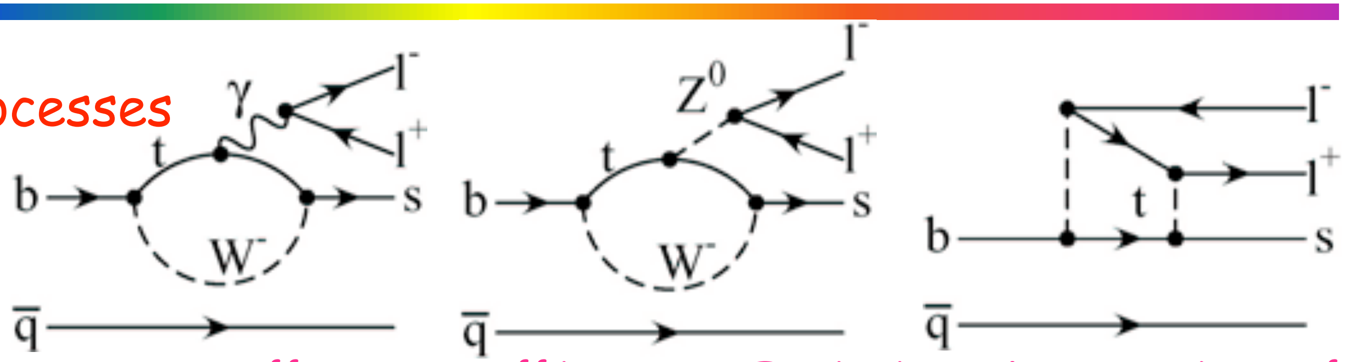
$$b \to s\ell^+\ell^-$$

$$b \to d\ell^+\ell^-$$

cf parallel talks:
J. Watson
H. Hyun

$B \to K^* \ell\ell$

- 3 dominant processes



C_7^{eff} C_9^{eff}(vector EW), (axial vector) C_{10}^{eff}

"effective Wilson coefficients:" short distance part of amplitude (calculated in SM to NNLO)

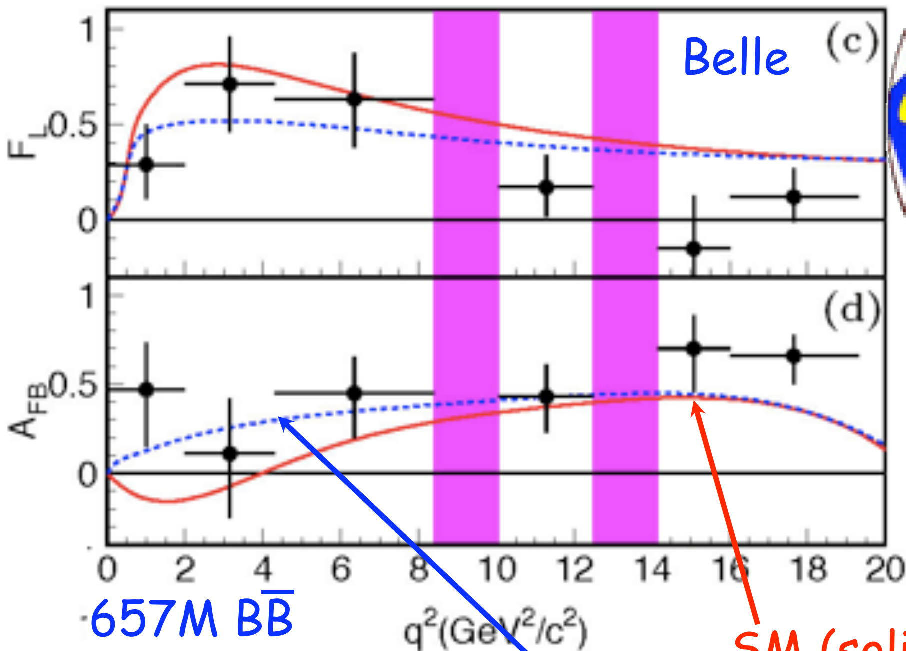
{$|C_7^{eff}|$ from B(B->$X_s\gamma$), constraints from B(B->$K^{(*)}l^+l^-$)}

- Different distributions in
  - q^2
  - θ = "helicity angle" -> polarization, forward-backward asymmetry A_{FB}
  - Direct CP asymmetry

$$PDF(\cos\theta_K) = \frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K)$$

$$PDF(\cos\theta_\ell) = \frac{3}{4}F_L(1-\cos^2\theta_\ell) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\ell) + \mathcal{A}_{\rm FB}\cos\theta_\ell$$

$B \to K^*\ell\ell$: A_{FB} (of angle θ), F_L vs q^2

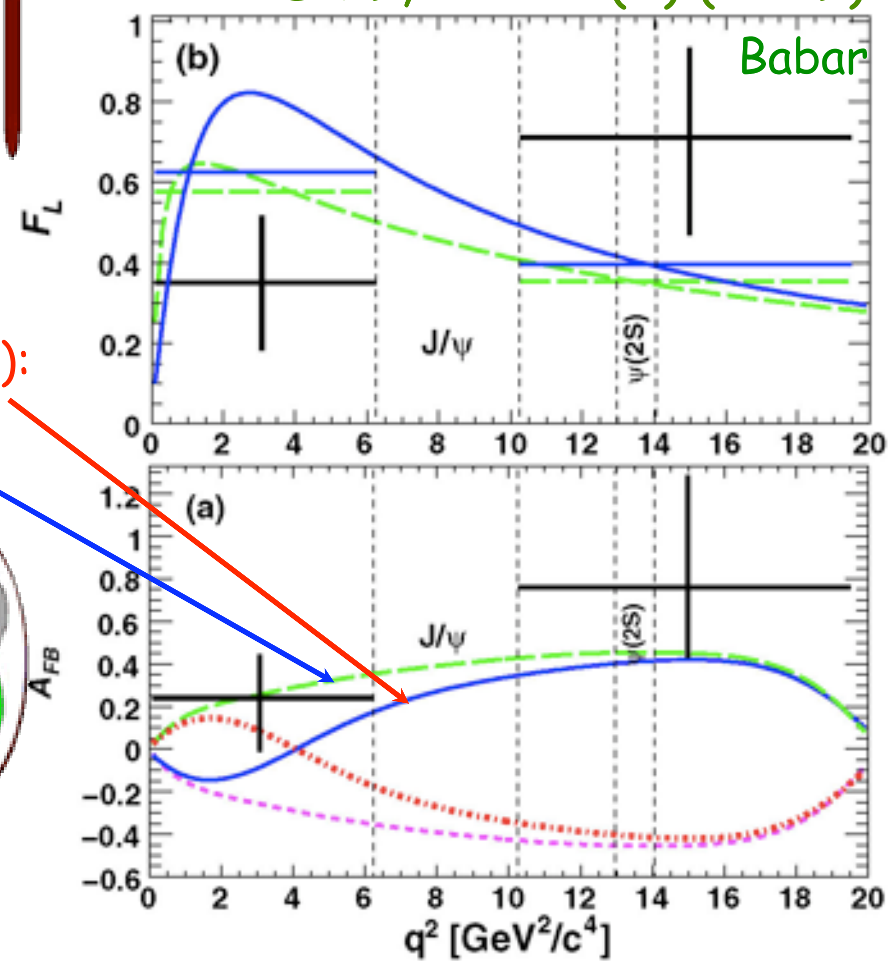


657M $B\bar{B}$

arXiv:0904.0770

384M $B\bar{B}$

PRD 79, 031102(R) (2009)



SM (solid):

$C_7^{eff}=-C_7^{eff,SM}$

Consistent with SM

isospin asymmetry in $B \to K^{(*)}\ell\ell$

$$A_I \equiv \frac{\tau_{B^-}\mathcal{B}(B^0 \to K^{(*)0}\ell^+\ell^-) - \tau_{B^0}\mathcal{B}(B^- \to K^{(*)-}\ell^+\ell^-)}{\tau_{B^-}\mathcal{B}(B^0 \to K^{(*)0}\ell^+\ell^-) + \tau_{B^0}\mathcal{B}(B^- \to K^{(*)-}\ell^+\ell^-)}$$

in SM

A_I ~ 6-13% as q^2->0

$$\boxed{A_I^{K^{(*)}} = -0.64^{+0.15}_{-0.14} \pm 0.03}$$

384M $B\overline{B}$

PRL 102, 091803 (2009)

TABLE III. $A_I^{K^{(*)}}$ results in each q^2 region. The uncertainties are statistical and systematic, respectively. The last table row shows $K^*e^+e^-$ results for the extended regions.

Mode	Combined q^2	Low q^2	High q^2
$K\mu^+\mu^-$	$0.13^{+0.29}_{-0.37} \pm 0.04$	$-0.91^{+1.2}_{-\infty} \pm 0.18$	$0.39^{+0.35}_{-0.46} \pm 0.04$
Ke^+e^-	$-0.73^{+0.39}_{-0.50} \pm 0.04$	$-1.41^{+0.49}_{-0.69} \pm 0.04$	$0.21^{+0.32}_{-0.41} \pm 0.03$
Kl^+l^-	$-0.37^{+0.27}_{-0.34} \pm 0.04$	$-1.43^{+0.56}_{-0.85} \pm 0.05$	$0.28^{+0.24}_{-0.30} \pm 0.03$
$K^*\mu^+\mu^-$	$-0.00^{+0.36}_{-0.26} \pm 0.05$	$-0.26^{+0.50}_{-0.34} \pm 0.05$	$-0.08^{+0.37}_{-0.27} \pm 0.05$
$K^*e^+e^-$	$-0.20^{+0.22}_{-0.20} \pm 0.03$	$-0.66^{+0.19}_{-0.17} \pm 0.02$	$0.32^{+0.75}_{-0.45} \pm 0.03$
$K^*l^+l^-$	$-0.12^{+0.18}_{-0.16} \pm 0.04$	$-0.56^{+0.17}_{-0.15} \pm 0.03$	$0.18^{+0.36}_{-0.28} \pm 0.04$
$K^*e^+e^-$ (ext.)	$-0.27^{+0.21}_{-0.18} \pm 0.03$	$-0.25^{+0.20}_{-0.18} \pm 0.03$	...

isospin asymmetry in $B \to K^{(*)}\ell\ell$

$$A_I \equiv \frac{\tau_{B^-}\mathcal{B}(B^0 \to K^{(*)0}\ell^+\ell^-) - \tau_{B^0}\mathcal{B}(B^- \to K^{(*)-}\ell^+\ell^-)}{\tau_{B^-}\mathcal{B}(B^0 \to K^{(*)0}\ell^+\ell^-) + \tau_{B^0}\mathcal{B}(B^- \to K^{(*)-}\ell^+\ell^-)}$$

in SM

AI ~ 6-13% as q^2->0

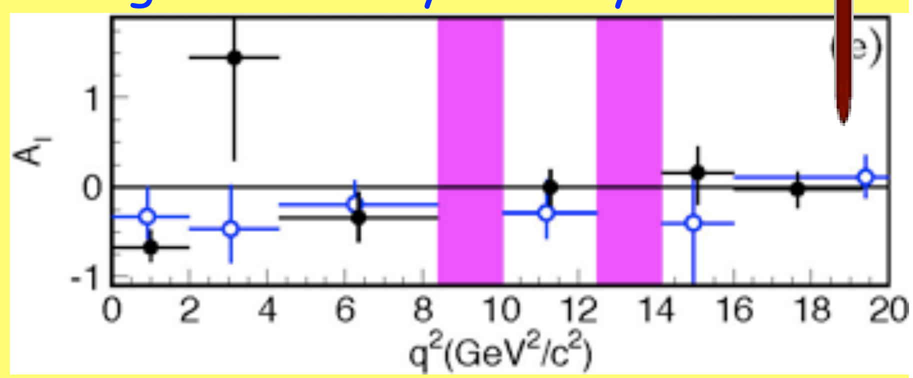
$$\boxed{A_I^{K^{(*)}} = -0.64^{+0.15}_{-0.14} \pm 0.03}$$

384M $B\overline{B}$
PRL 102, 091803 (2009)

657M $B\overline{B}$
arXiv:0904.0770

$$\boxed{A_I^{K^{(*)}} = -0.30^{+0.12}_{-0.11} \pm 0.04}$$

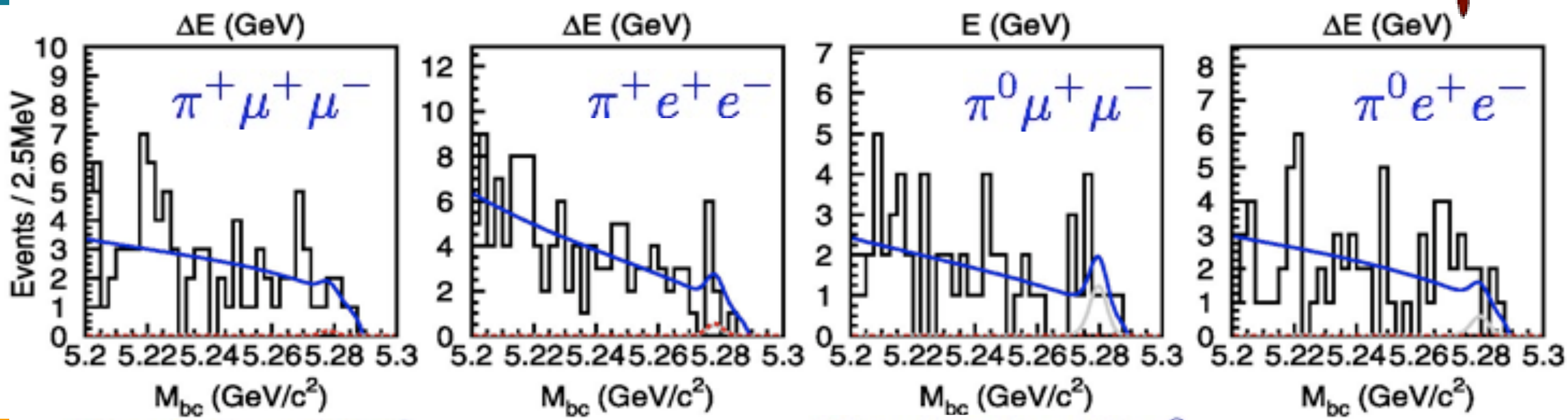
no significant asymmetry



K; K*

$B \to \pi \ell^+ \ell^-$

Belle: PRD 78, 011101 (R) (2008)
657M $B\overline{B}$



$\mathcal{B} < 6.9 \times 10^{-8}$

$\mathcal{B} < 8.0 \times 10^{-8}$

$\mathcal{B} < 18.4 \times 10^{-8}$

$\mathcal{B} < 22.7 \times 10^{-8}$

(90% CL) no evidence, yet

search for $X^0(214)$

History

- observation by HyperCP of 3 events $\Sigma^+ \to p\mu^+\mu^-$
  $M_{\mu\mu}$ clustered at 214.3 MeV/c^2
  [PRL 94, 021801 (2005)]

Interpretations

- Pseudoscalar Sgoldstino
  [D.S.Gorbunov + V.A.Rubakov, PRD 73, 035002 (2006)]
- Low mass Higgs
  [X.-G.He, J.Tandean + G.Valencia, PRL 98, 081802 (2007)]

search for $X^0(214)$

Suggested searches

- $10^{-7} < B(B \to \rho X^0, K^* X^0) < 10^{-6}$
  [S.V.Demidov + D.S.Gorbunov, JETP Letters 84, 479 (2006)]

Belle 657M $B\overline{B}$

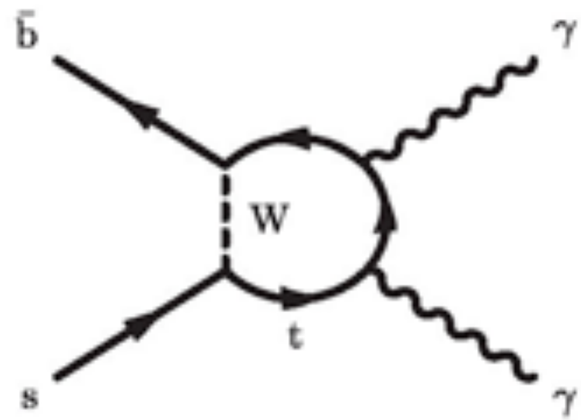
PRELIMINARY

(90% CL)

$$\mathcal{B}(B^0 \to K^{*0} X^0,\ K^{*0} \to K^- \pi^+,\ X^0 \to \mu^+ \mu^-) < 2.01 \times 10^{-8}$$

$$\mathcal{B}(B^0 \to \rho^0 X^0,\ \rho^0 \to \pi^- \pi^+,\ X^0 \to \mu^+ \mu^-) < 1.51 \times 10^{-8}$$

loop annihilation



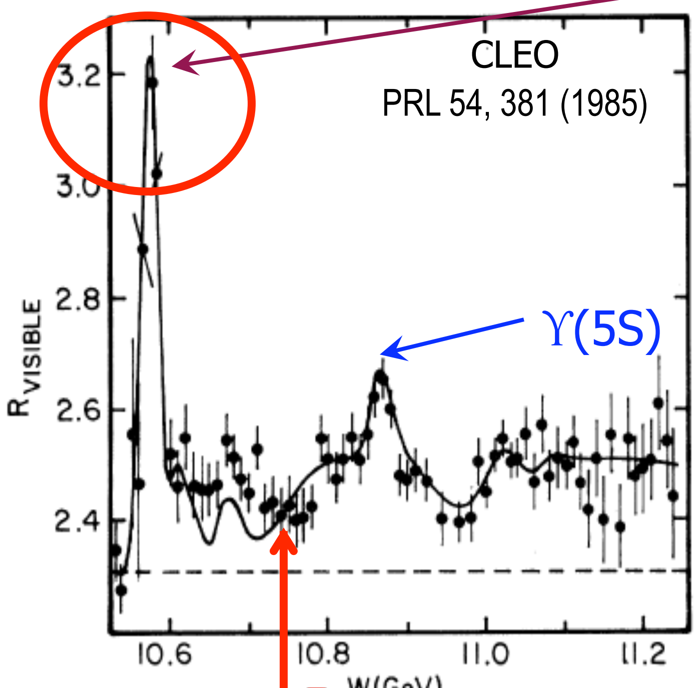
$e^+e^- \rightarrow \Upsilon(5S)$

most B-factory activity is concentrated at the Υ(4S)

$\rightarrow B^+B^-,\ B^0\bar{B}^0$

M=10580±1 MeV/c^2, Γ=20.5±2.5MeV

$B_q = \{B_d^0, B_u^+\}$



$B_s\bar{B}_s$ threshold

Υ(5S) $\rightarrow B_s^{(*)}\bar{B}_s^{(*)},\ B_q^{(*)}\bar{B}_q^{(*)},\ B_q\bar{B}_q^{(*)}\pi,$
$B_q\bar{B}_q\pi\pi$

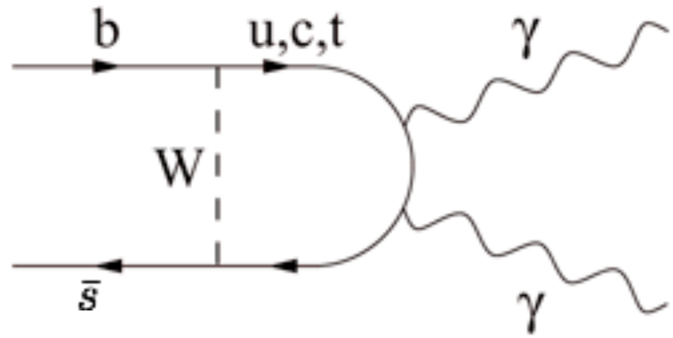
M=10865±8 MeV/c^2, Γ=110±13 MeV

$B_s \to \gamma\gamma$

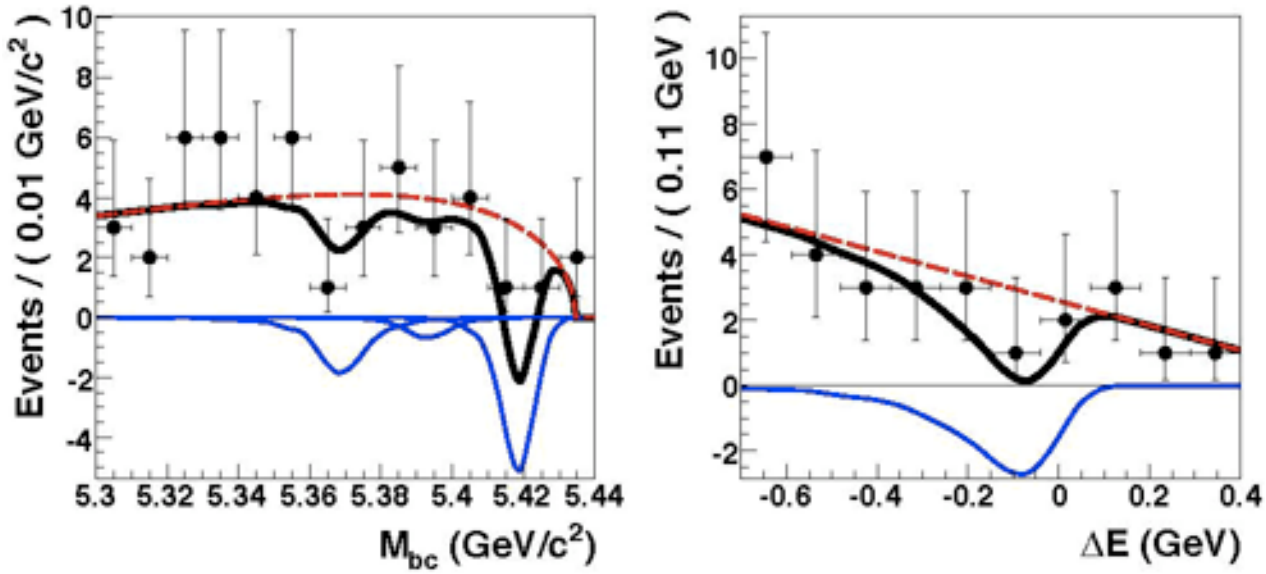
$\gamma\gamma$: difficult for hadron machines

$$\mathcal{B}_{SM} \sim (0.4 - 1.0) \times 10^{-6}$$

beyond SM: up to 5×10^{-6}



23.6 fb^{-1}=1.3M $B_s^{(*)}\bar{B}_s^{(*)}$



$$\mathcal{B} < 8.7 \times 10^{-6} \ (90\% \ CL)$$

PRL 100, 121801 (2008)

Summary

B-factories 1999-2009, >1.5x10^9 B pairs, 1.3M B_s pairs:

- CKM firmly established as main source of CP asymmetry in weak interaction

  multiple measurements on CKM with increasing precision
- -> probe New Physics

  in loops: b->{s,d} hadronic/radiative/leptonic

  rates,

  CP asymmetry (via mixing or direct),

  isospin asymmetry,

  FB asymmetry, polarization ...
- methods are complementary to LHC

Future

- Belle run 9/2008 -> ~100 fb^{-1} at Υ(5S)
- "Super-B-Factories" – X10^2 luminosity