Inclusive rare B decays

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Flavour and the Fourth Family, Durham, September 14-16, 2011

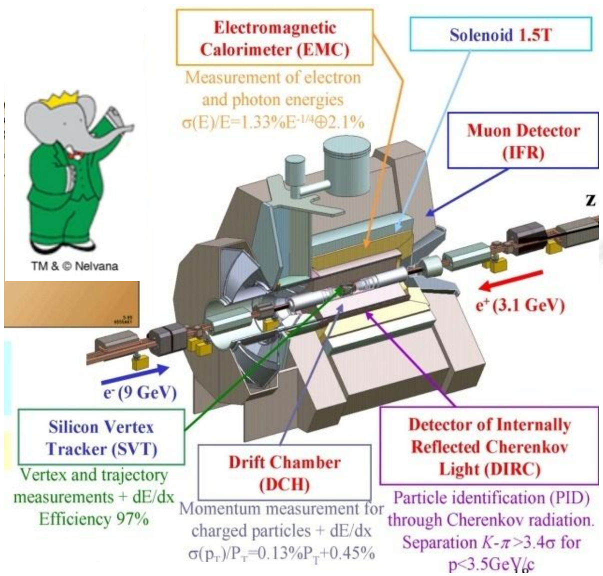
- $b \to s\gamma$
  $\mathcal{B}$, A_{CP}
- $b \to s\ell\ell$
  $\mathcal{B}$, A_{FB}, A_{CP}
- $b \to s\nu\nu$
  $\mathcal{B}$

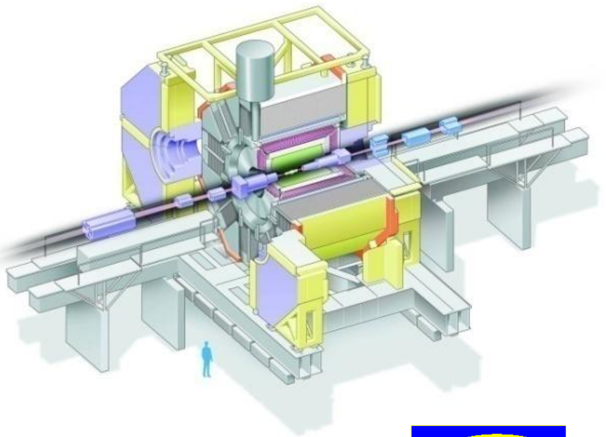
Experiments

B-Factories

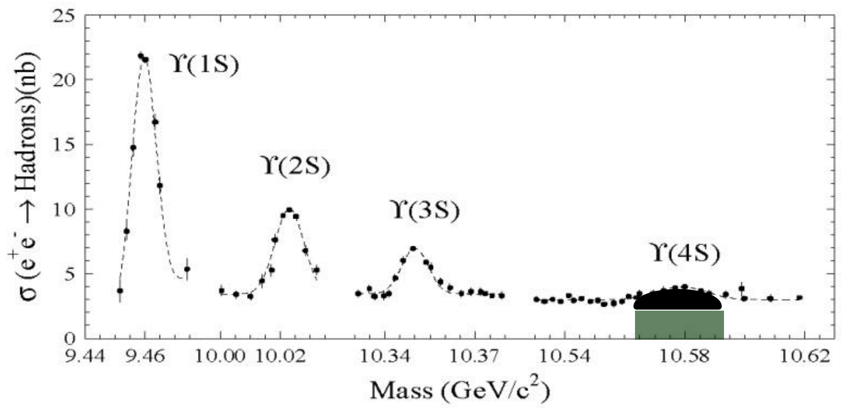
BaBar @ PEPII
SLAC

Belle @ KEKB
KEK





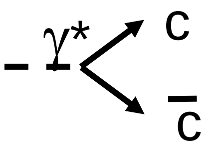
BELLE



on resonance production
$e^+e^- \to \Upsilon(4S) \to B^0\bar{B}^0, B^+B^-$
$\sigma(B\bar{B}) \approx 1.1$ nb (~10^9 $B\bar{B}$ pairs)

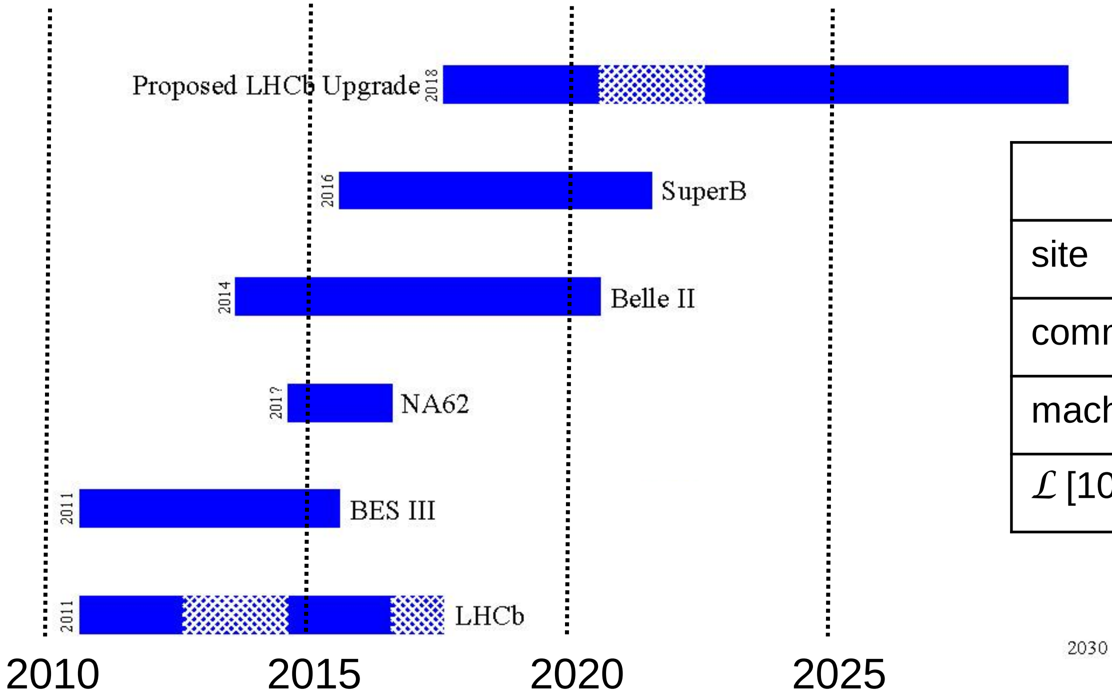
continuum production

$\sigma(c\bar{c}) \approx 1.3$ nb (~1.3×10^9 $X_c\bar{Y}_c$ pairs)
$N_{rec}(D^{*+} \to D^0 \pi^+ \to K^- \pi^+ \pi^+) \approx 2.5\times10^6$



Experiments

LHCb, super B factories



approved super B factories projects:

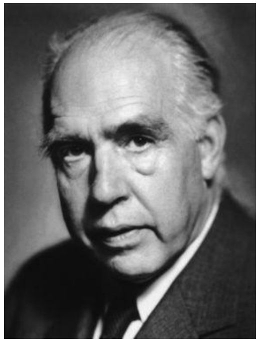
	SuperB	SuperKEKB
site	Tor Vergata	Tsukuba
commissioning	Early 2016	Spring 2015
machine cost	360 M€*	320 M€
$\mathcal{L}$ [10^{36}cm^{-2}s^{-1}]	1.0 (75ab^{-1})	0.8 (50ab^{-1})

* estimate provided for LP2011 by SuperB management

Disclaimer:

Prediction is very difficult, especially if it's about the future.

Niels Bohr (1885-1962)



$B \to s\gamma$

branching fraction

inclusive decays $B \to X_s \gamma$
experimentally difficult

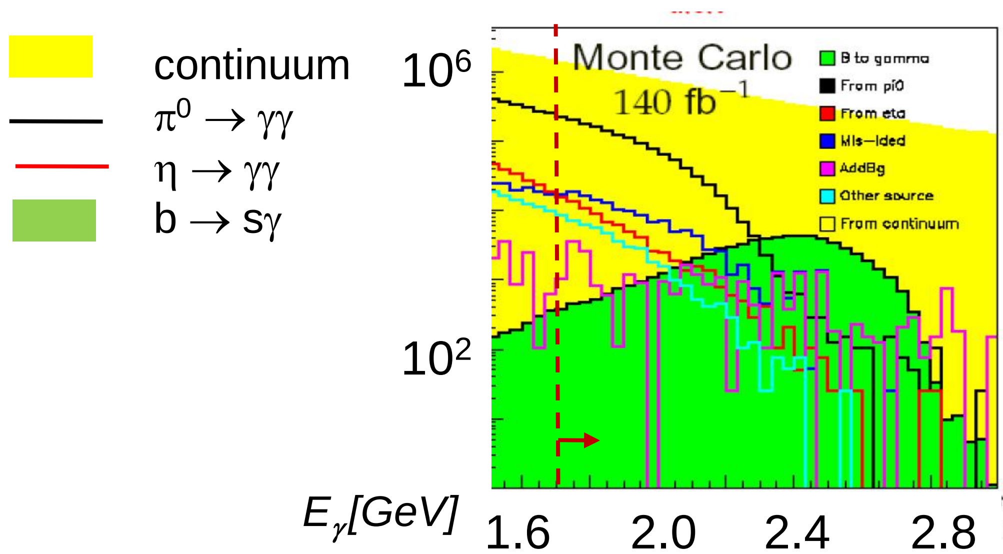
experiment:

measure low E_γ
$\Rightarrow$ huge bkg. $\Rightarrow E_\gamma > E_{cut}$

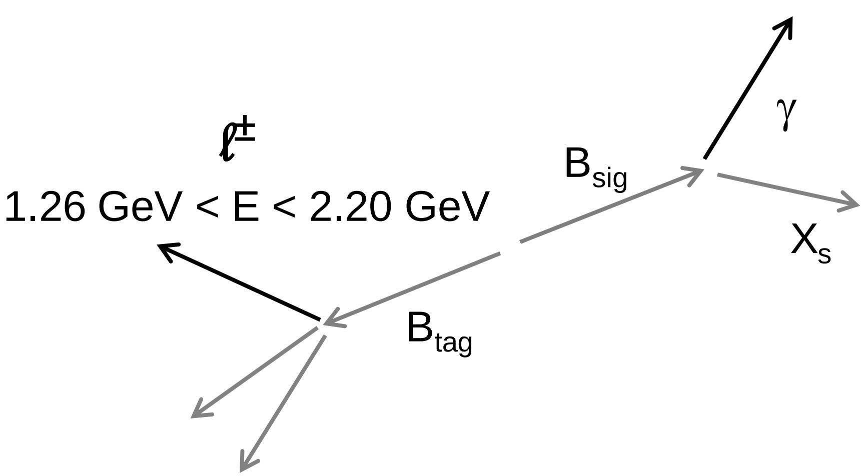
theory:

parameter extraction from partial Br($E_\gamma > E_{cut}$) $\Rightarrow$ extrapolation needed;

only γ on signal side reconstructed;
samples: tagged/untagged;
e.g. leptonic tag
$E_\gamma > 1.7$ GeV



Belle, PRL103, 241801(2009),605 fb-1



B → sγ

branching fraction

Background treatment

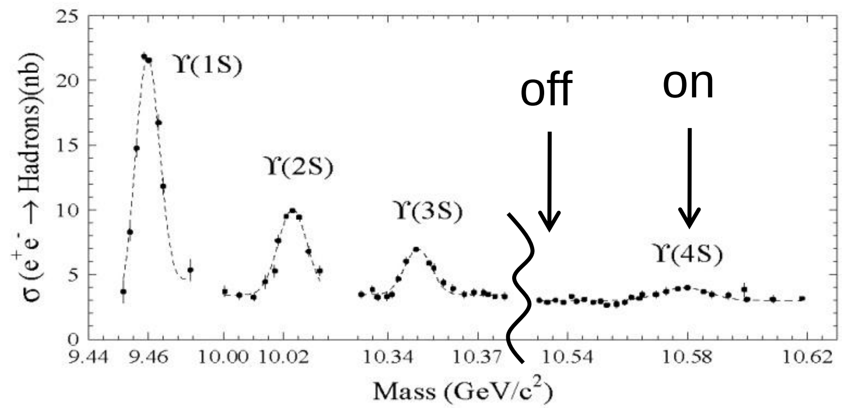
subtract luminosity scaled E_γ distribution for off-data from on-data (continuum bkg.);

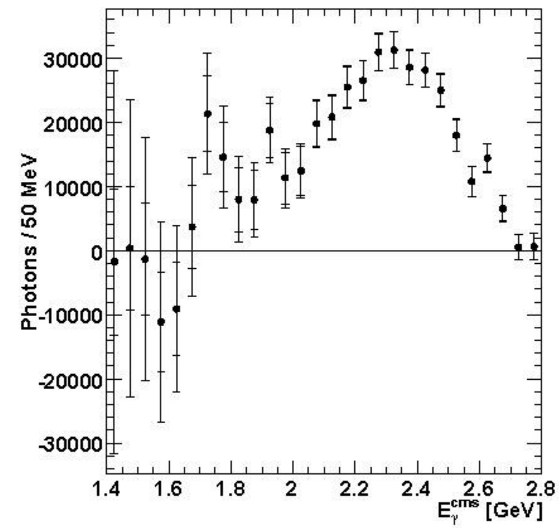
explicit veto π^0, $\eta \to \gamma\gamma$;

- individual remaining bkg. categories taken from MC;
- shape and yield corrected by data control samples;

Corrections

- select. eff. ($\varepsilon_{untag} \sim 15\%$, $\varepsilon_{tag} \sim 2.5\%$);
- unfolding $E_\gamma^{meas} \to E_\gamma^{true}$;
- $B \to X_d\gamma$ ($R_{d/s}$=4.5% ± 0.3%);
- boost to B meson rest frame





E_γ[GeV]

Belle, PRL103, 241801(2009),605 fb^{-1}

$$\mathcal{B}(B \to X_s\gamma; 1.7\,GeV < E_\gamma < 2.8\,GeV) =$$
$$= (3.47 \pm 0.15 \pm 0.40)\cdot 10^{-4}$$

$B \to s\gamma$

branching fraction

World average

$$\mathcal{B}(B \to X_s\gamma; E_\gamma > 1.6\,GeV) =$$
$$= (3.55 \pm 0.24(stat.+syst.) \pm 0.09(shape\ f.) \cdot 10^{-4}$$

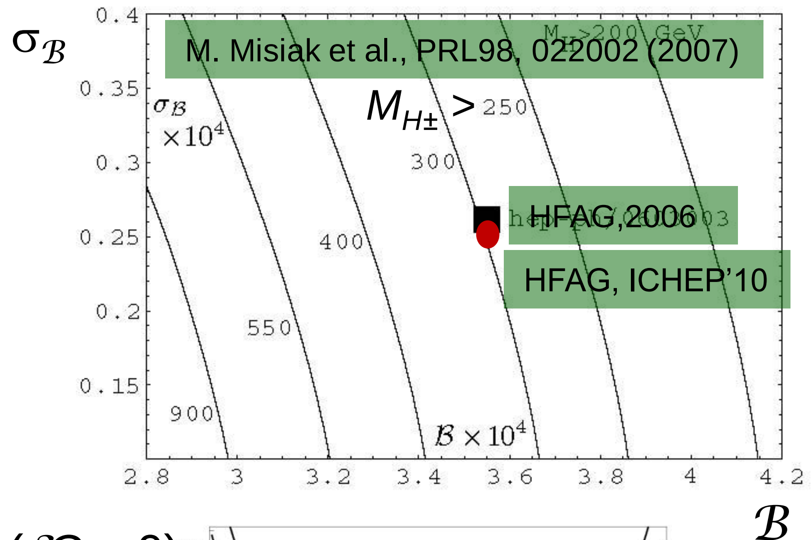
HFAG, ICHEP'10

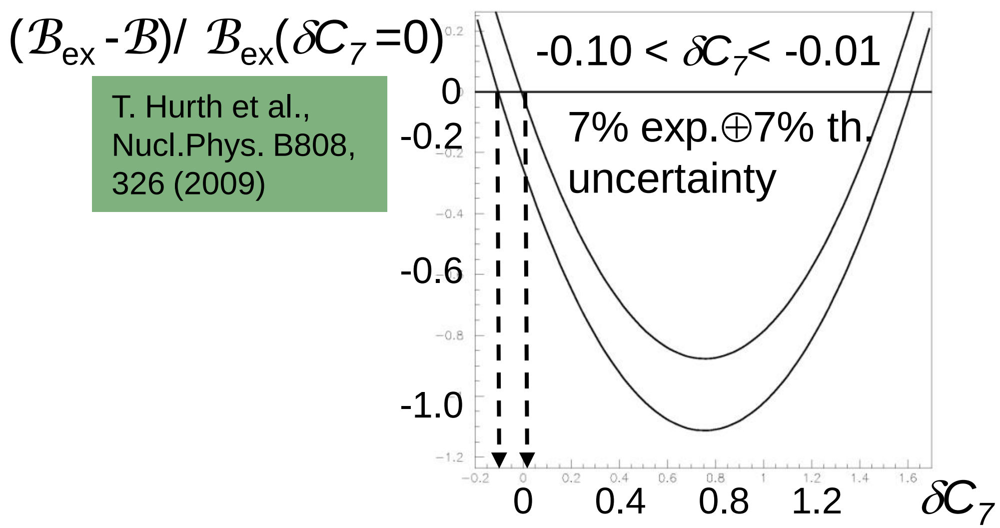
measurements systematics dominated;

Belle, PRL103, 241801(2009),605 fb^{-1}

has 0.01 $\cdot 10^{-4}$ th. error (E_γ>1.7 GeV);

systematics can be reduced by more strict tagging
(e.g. full reconstruction of other B,
BaBar, PRD77, 051103(2008),210 fb^{-1})
on the account of stat. uncertainty
$\Rightarrow$ SuperB factories





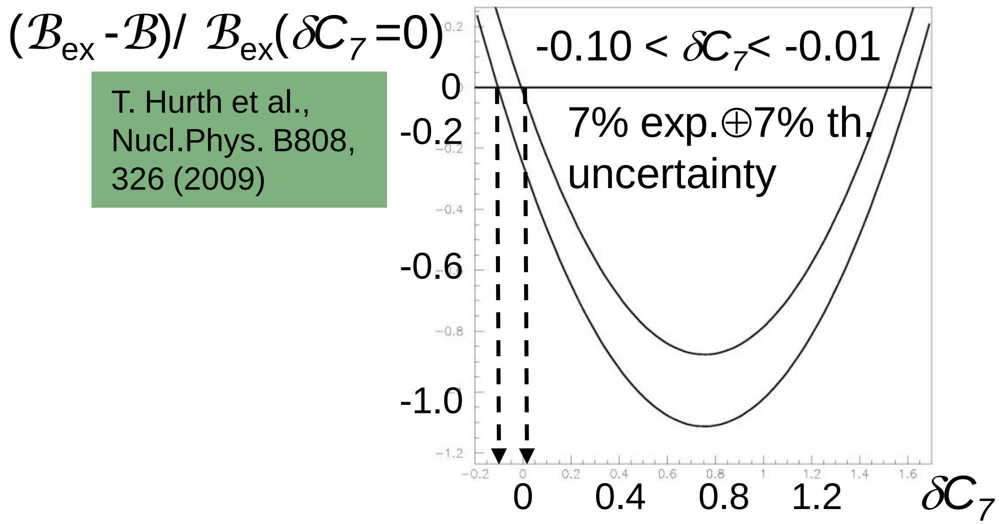
B → sγ

branching fraction

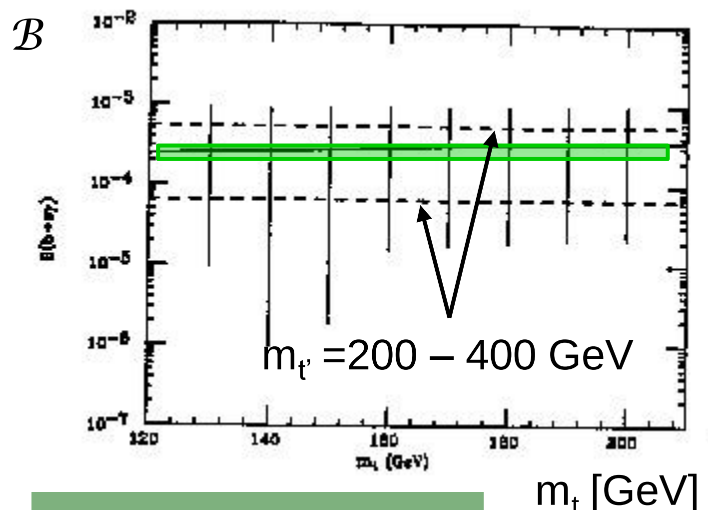
Expectations

full reconstruction of accompanying B
$\varepsilon_{had} \sim 5 \cdot 10^{-3}$; $\mathcal{L}=50\ ab^{-1}$;
current selection can probably be relaxed;
$N_{sig} \sim$ same as for L=0.6 ab^{-1}
2 exp's with 50 ab^{-1} → exp. error 4%

semileptonic tagging (D and ℓ):
according to Belle, PRD82, 071101(2010),605 fb^{-1}
(B → τν)
$\varepsilon_{semil} \sim 5\ \varepsilon_{had}$
$P_{semil} \sim 0.5\ P_{had}$
$\sigma/\mathcal{B} \propto 1/\sqrt{\varepsilon}\ P$
measurement with semil. tag
of similar accuracy as with fullrec. tag
3% combined exp. accuracy



T. Hurth et al., Nucl.Phys. B808, 326 (2009)



J.L. Hewett, hep-ph/9406302

$B \to s\gamma$
direct CPV

Semi-inclusive, sum of many exclusive states:

BaBar, PRL101, 171804(2008),350 fb^{-1}

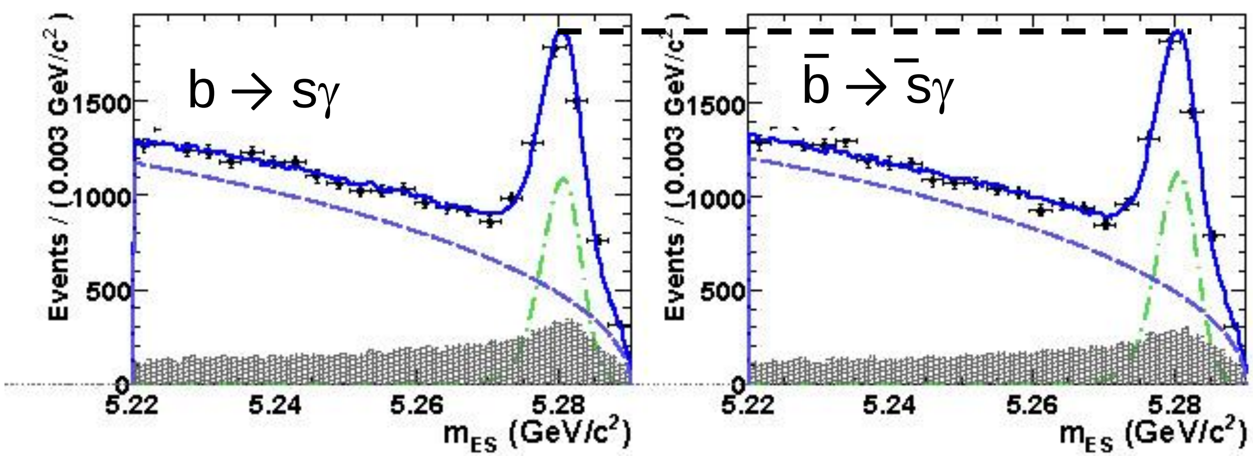
$$B^- \to K^0_S\pi^-\gamma, K^-\pi^0\gamma, K^-\pi^+\pi^-\gamma, K^0_S\pi^-\pi^0\gamma, K^-\pi^0\pi^0\gamma, K^0_S\pi^+\pi^-\pi^-\gamma, K^-\pi^+\pi^-\pi^0\gamma, K^0_S\pi^-\pi^0\pi^0\gamma, K^-\eta\gamma, K^+K^-K^-\gamma,$$

$$\overline{B}^0 \to K^-\pi^+\gamma, K^-\pi^+\pi^0\gamma, K^-\pi^+\pi^-\pi^+\gamma, K^-\pi^+\pi^0\pi^0\gamma, K^-\pi^+\eta\gamma, K^+K^-K^-\pi^+\gamma,$$

all flavor specific final states;
0.6 GeV $\leq M_s \leq$ 2.8 GeV, $E_\gamma \geq$ 1.9 GeV;
topological continuum event suppression;
explicit π^0, η veto;

$$\frac{N_b - N_{\bar{b}}}{N_b + N_{\bar{b}}} = \langle D \rangle A_{CP} + \Delta D + A_{\rm det}$$

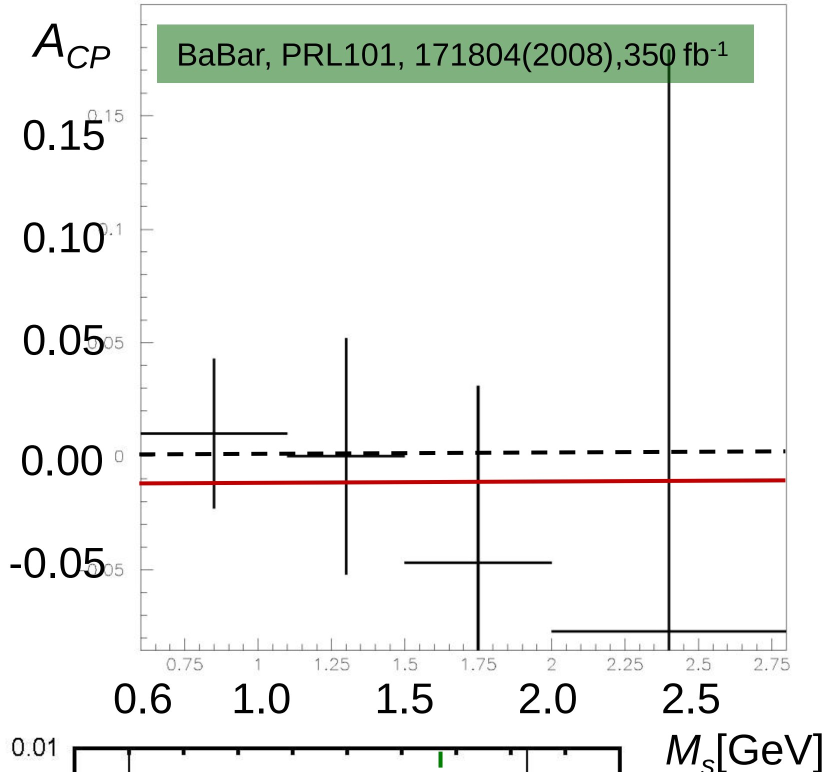
$<D>$: average dilution due to flavour mistag, ~1
ΔD: difference between flavour mistag for b and $\bar{b}$, << 1
A_{det}: detector induced asymmetry



$B \to s\gamma$
direct CPV

A_{det}: detector induced asymmetry;
m_{ES} sideband, mainly continuum events, no CPV expected (D?)
m_{ES} sidebands, γ replaced by π^0

A_{det} = - 0.007 ± 0.005



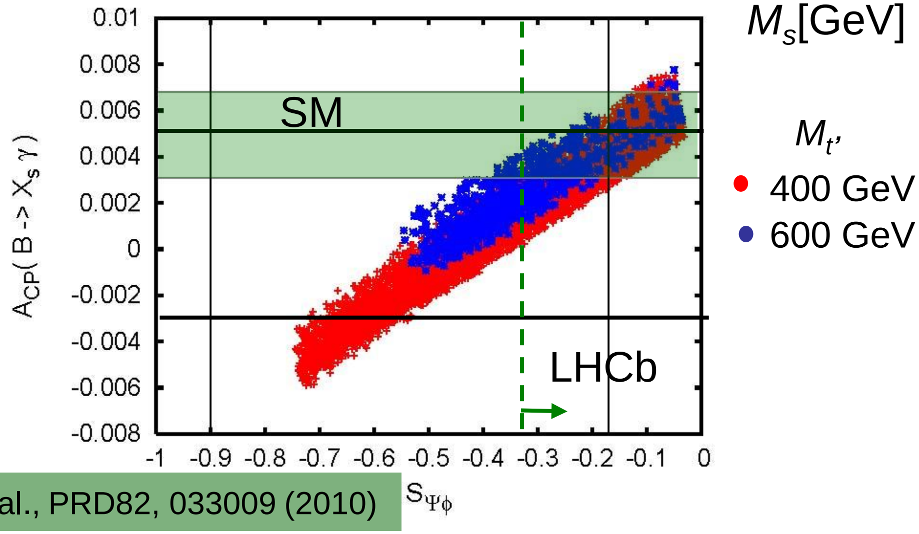
$A_{CP} = (-1.2 \pm 2.8)\%$ HFAG, ICHEP'10

SM: T. Hurth et al., Nucl.Phys.B704, 56 (2005)

LHCb: t-dependent CPV
(SM: $\Delta\Gamma_s$ ~ 0.1 ps^{-1}, $\Phi_s = -2\beta_s \sim 0.04$)

$\Phi_s = (0.13 \pm 0.18 \pm 0.07)\ rad$

G. Raven, LP 2011, 337 pb^{-1}



A. Soni et al., PRD82, 033009 (2010)

$B \to s\gamma$
direct CPV
Expectations

$M_{t'}$,
- 400 GeV
- 600 GeV

A_{det} = - 0.007 ± 0.005
A_{det}: careful study of K/π asymmetries in (p, θ_{lab}) using D decays or inclusive tracks from fragmentation;

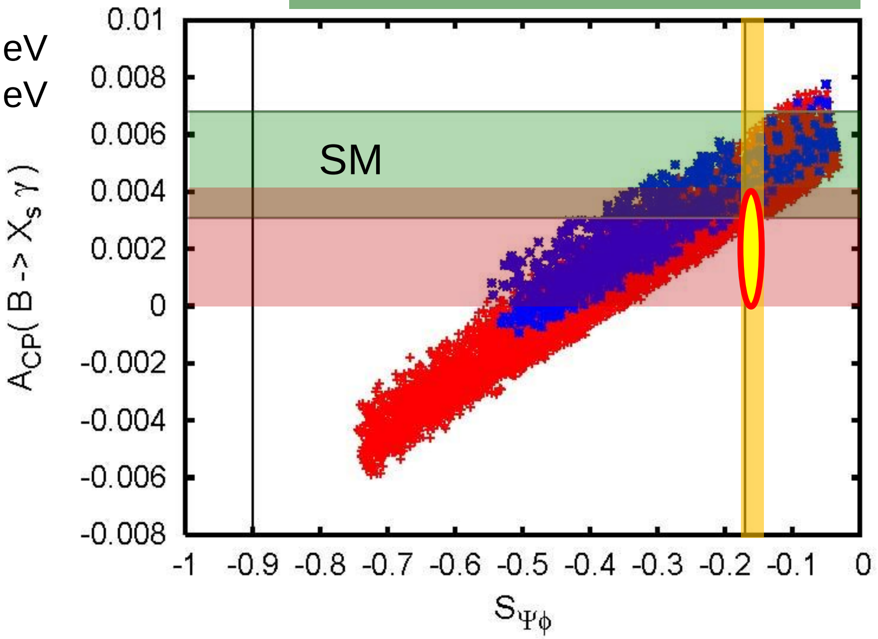
$B\bar{B}$, cross-feed background: comparison data control samples/MC; JETSET fragment. from meas.;

lots of work, few 10^{-3} single exp. sensitivity

LHCb, 5 fb^{-1} : $\sigma(S(\psi\phi))$ ~0.02 LHCb, arXiv:0912.4179

extrap. from 337 pb^{-1}: ±0.05
(syst. @ 337 pb^{-1} ± 0.07)

A. Soni et al., PRD82, 033009 (2010)



combined super B fact. sensitivity
LHCb sensitivity 5 fb^{-1}
example of overlap region

B → sℓℓ

branching fraction

$$Br(B \rightarrow X_s \ell\ell) = (3.33 \pm 0.80 \pm {}^{0.19}_{0.24}) \cdot 10^{-6}$$

Belle LP2009, 605 fb^{-1}

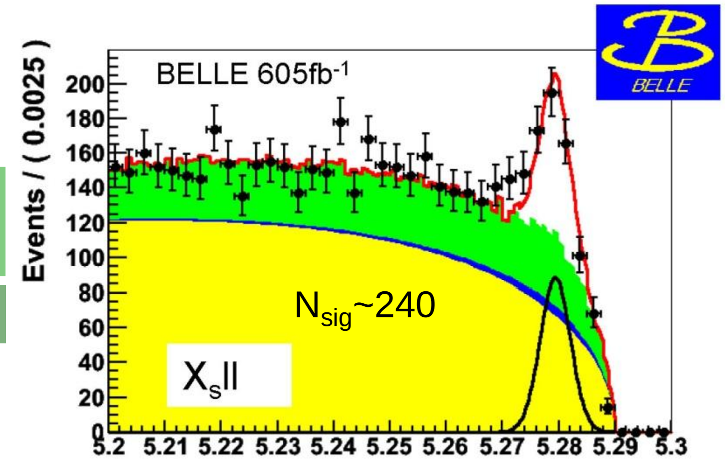
semi-inclusive
- similar as b $\rightarrow s\gamma$;
- e^+e^-, $\mu^+\mu^-$; $K^-/K_s+(0\text{-}4)\pi$;
- ~18% missing modes;
- charmonium sample provides cross-check of bkg.;

improvements
- measure $d\mathcal{B}/dM_s$
- fit with more free param. (smaller syst., larger stat.)

comparison to excl. $K^*\ell\ell$
- smaller ε, signal yield ~ same in incl. and excl.;
- slightly worse resolution on X_s (needed for A_{FB})

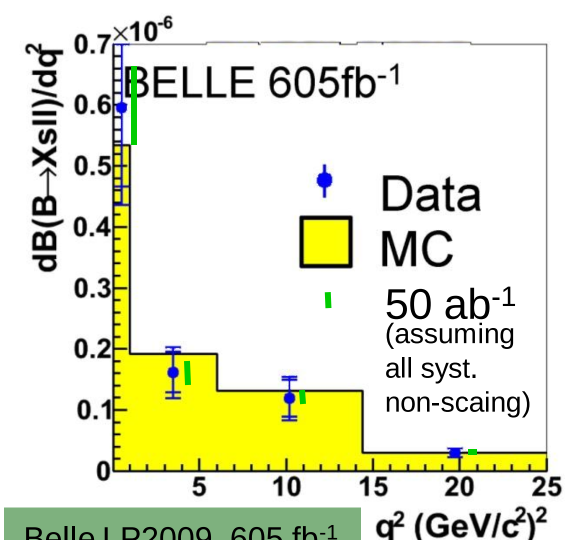
signal yield in q^2 bins completely stat. dominated

$$\sigma(\mathcal{B}; 0 \leq q^2 \leq 6) \sim 0.1 \cdot 10^{-6} \text{ @ } 50 \text{ ab}^{-1}$$



$$Br(B \rightarrow X_s \ell\ell) = (3.66 \pm 0.77) \cdot 10^{-6}$$

HFAG, ICHEP'10



Belle LP2009, 605 fb^{-1}

$B \to s\ell\ell$

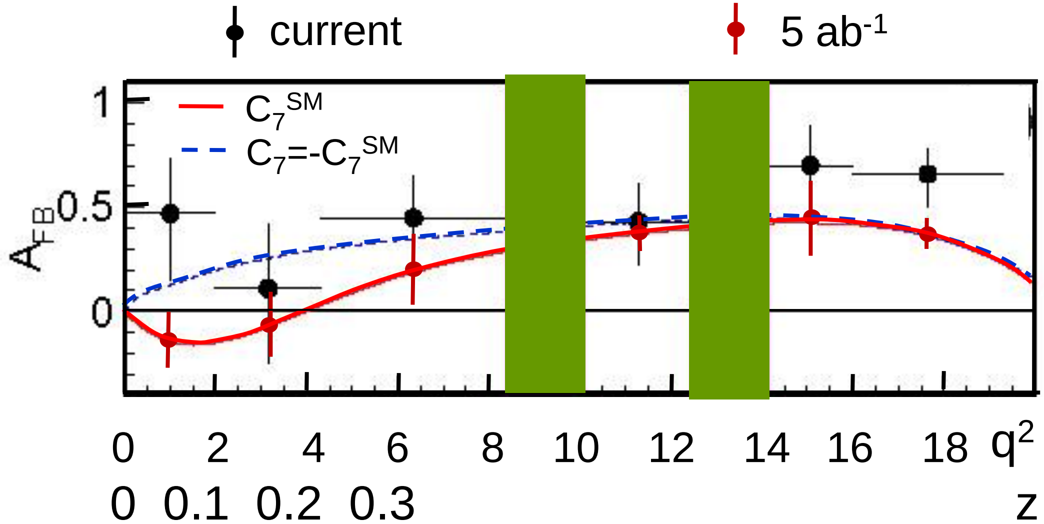
$B \to s\ell\ell$

forward-backward asymmetry

excl. $K^* \ell\ell$ (~ same signal yield as incl.)

$\sigma(A_{FB}; 0 \leq q^2 \leq 4.3) \sim 0.03$ @ 50 ab^{-1}

Belle, PRL103, 171801 (2009), 657M BB



number of reconstr. exclusive events:

Super B factories, 50 ab^{-1}:

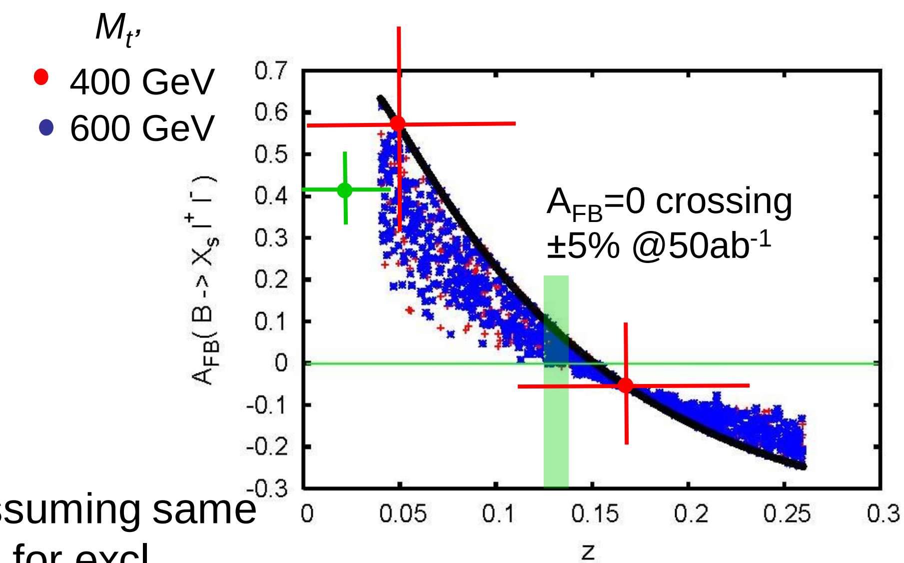
$(7 - 10) \cdot 10^3$ each K^*ee, $K^*\mu\mu$

LHCb, 5 fb^{-1}:

$5 \cdot 10^3$ $K^*\mu\mu$, 400 K^*ee

LHCb, 50 fb^{-1}:

$65 \cdot 10^3$ $K^*\mu\mu$, $5 \cdot 10^3$ K^*ee



5 ab^{-1} assuming same sens. as for excl.

50 ab^{-1} from incl.

A. Soni et al., PRD82, 033009 (2010)

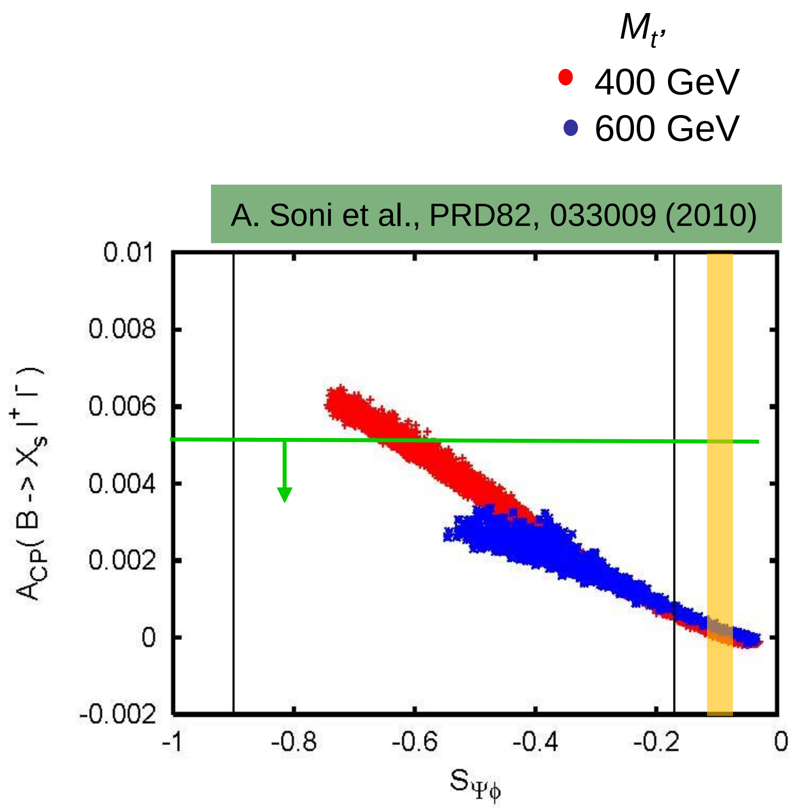
$B \to s\ell\ell$

direct CPV

A_{CP} can be measured using semi-inclusive method, with flavor specific final states (no K_s final states)

$\mathcal{B}$'s covered by semi-inclusive analysis:
~40% of K modes, ~20% of K_s modes
$\varepsilon_{Ks} \sim 0.7\ \varepsilon_K \Rightarrow$ 25% of signal yield with K_s's

N_{sig} @50 $ab^{-1} \sim 15 \cdot 10^3$
assuming same purity as for all modes
$\sigma(A_{CP}) \sim 8 \cdot 10^{-3}$
single exp. sensitivity @50 ab^{-1}



B → sνν

branching fraction

$B_{sig}B_{tag} \to (h\,\nu\nu)(X\ell\nu)$ semil. tag

$\to (h\,\nu\nu)(X)$ hadr. tag

fully (partially) reconstruct B_{tag};
reconstruct h from $B_{sig} \to h\,\nu\nu$;
no additional energy in EM calorim.; signal at E_{ECL}~0;

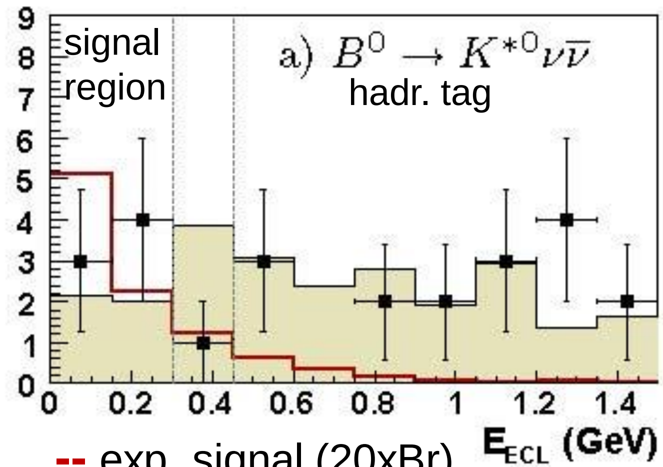
B_{tag} full reconstruction: NeuroBayes;
TOP detector $\varepsilon_{PID}^{K,\pi}$ x1.1-1.15/track;
ECL, increased background;
together: N_{sig}: x1.8; N_{bkg}: x0.9

$B^0 \to K^{*0}\nu\nu$

$\int\mathcal{L}dt$=50 ab^{-1}, semil.+hadr. tag:

N_{sig} ~240; N_{bkg} ~4600
$\mathcal{B}(B^0 \to K^{*0}\nu\nu)$ can be measured to ±(25-30)%;
similar precision for $\mathcal{B}(B^0 \to K_S\nu\nu)$;

Belle, PRL99, 221802 (2007), 490 fb^{-1}



-- exp. signal (20xBr)
exp. bkg. (scaled to sideband)

N_{bkg}^{exp}=4.2 ±1.4
(stat. of MC and sidebands,
ECL distr. checked with wrong-sign)
N_{sig}^{exp}=0.34
($\mathcal{B}(B^0 \to K^{*0}\nu\nu)$ = 1.3x10^{-5}
G. Buchalla et al., PRD63, 014015 (2001))

$B \to s\nu\nu$

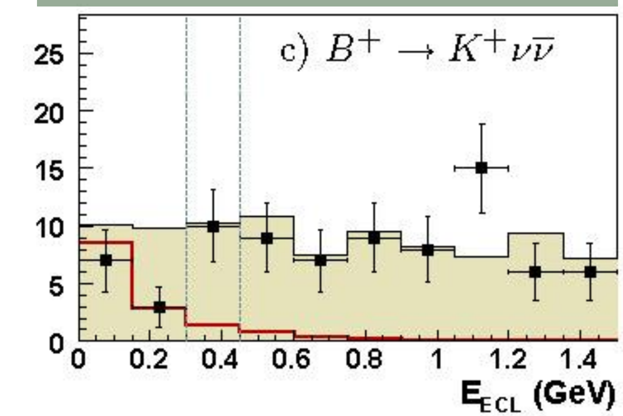
branching fraction
$B^+ \to K^+ \nu\nu$

includes irreducible background from
$B^+ \to \tau\nu \;\; \tau \to K^+\nu$;
$\mathcal{B}(B^+ \to \tau\nu)\, \mathcal{B}(\tau \to K^+\nu) / \mathcal{B}(B^+ \to K\nu\nu) / \sim 30\%$;
if $\mathcal{B}(B^+ \to \tau\nu)$ known to $\pm 5\% \Rightarrow$
negligible contribution to uncertainty;

$B^+ \to K^+\nu\nu$ suffers from larger bkg. than $B^0 \to K^{*0}\nu\nu$
need to use NeuroBayes with larger purity
and smaller eff. (P x2, ε_{had}^{full} x1.6)

N_{sig} ~500; N_{bkg} ~17.5×10^3
$\mathcal{B}(B^+ \to K^+\nu\nu)$ can be measured to ±(25-30)%;

Belle, PRL99, 221802 (2007), 490 fb^{-1}



-- exp. signal (20xBr)
exp. bkg. (scaled to sideband)

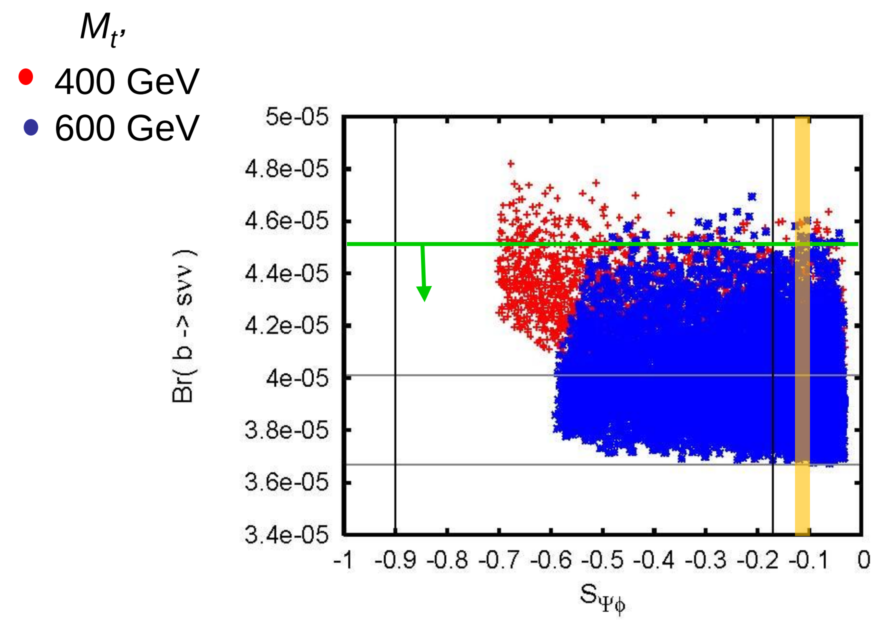
N_{bkg}^{exp}=20.0 ±4.0
N_{sig}^{exp}=0.52
($\mathcal{B}(B^+ \to K^+\nu\nu) = 3.6 \times 10^{-6}$
G. Buchalla et al., PRD63, 014015 (2001))

B → sνν

branching fraction

if B(K*νν)/B(sνν) ~ 50%
B(Kνν)/B(sνν) ~ 10%
(like for B → sℓℓ)

probably possible to measure
$\mathcal{B}$(B → sνν) with accuracy 25%,
two exp's 18%



A. Soni et al., PRD82, 033009 (2010)

Conclusions

- some measurements of inclusive rare B meson decays provide constraints on SM4

- super B factories needed to perform measurements with accuracy needed

observable	accuracy	comment	sensitivity to SM4
$\mathcal{B}(b \to s\gamma)$	3%		**
$A_{CP}(b \to s\gamma)$	0.2%		****
$\mathcal{B}(b \to s\ell\ell)$	10^{-7}	$0 < q^2 < 6$ GeV^2	?
$A_{FB}(b \to s\ell\ell)$	0.03	$0 < q^2 < 4$ GeV^2	***
$A_{CP}(b \to s\ell\ell)$	$5 \cdot 10^{-3}$		*
$\mathcal{B}(b \to s\nu\nu)$	25%		

n.b.: approximate expected accuracies for two super B factories @ 50 ab^{-1}