BaBar results on Radiative and Leptonic B Decays

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- Constraints on new physics from $b \to s\gamma$
- Measurements of $B \to \rho\gamma$ and V_{td}/V_{ts}
- Status and prospects for $b \to s\ell^+\ell^-$
- Decays to lepton pairs $B^0 \to \ell^+\ell^-$
- Progress towards a measurement of $B \to \tau\nu$
- Searches for $B \to K\nu\bar{\nu}$ and $B \to$invisible

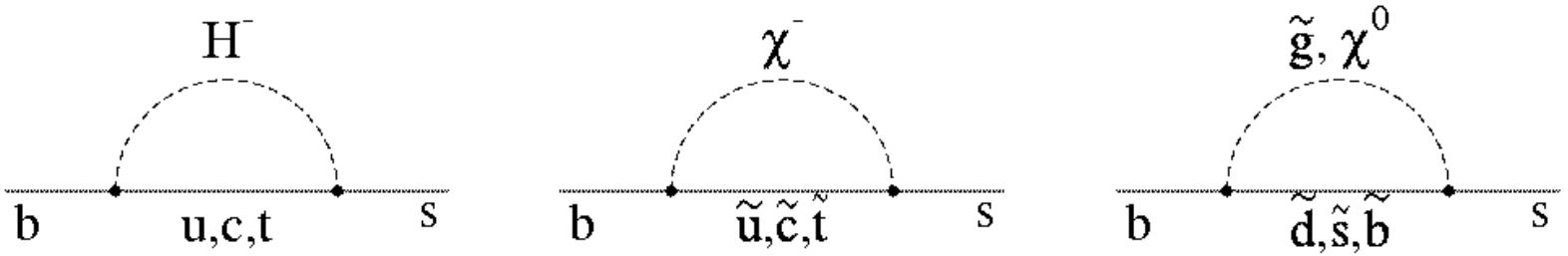
All results are from 230M $B\bar{B}$ pairs unless stated otherwise

This is 20-25% of the anticipated sample in 2008

Workshop on Flavour in the LHC era CERN, November 7/10th 2005

$b \to s\gamma$ as a probe of New Physics

Can replace the W and t quark in the "penguin" diagram with new particles in the loop:



Additional contributions could change the rate of $b \to s\gamma$

$$BF(b \to s\gamma) = (3.6 \pm 0.3) \times 10^{-4} \quad \text{SM} \qquad (E_\gamma > 1.6GeV)$$

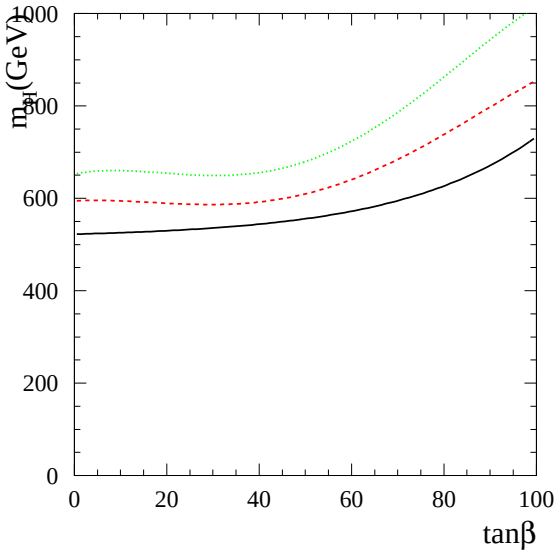
$$BF(b \to s\gamma) = (3.5 \pm 0.3) \times 10^{-4} \quad \text{HFAG} \qquad (E_\gamma > 1.6GeV)$$

This agreement gives important constraints on New Physics

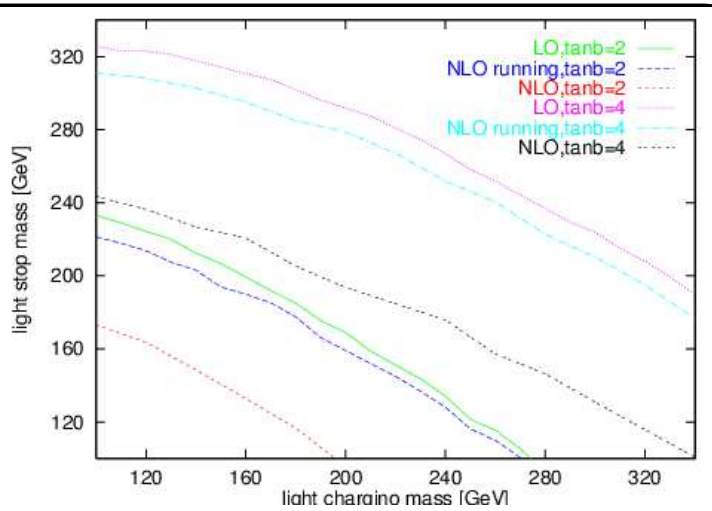
Experimental error can be reduced to 5% with more data

Theory error can be reduced with NNLO calculations

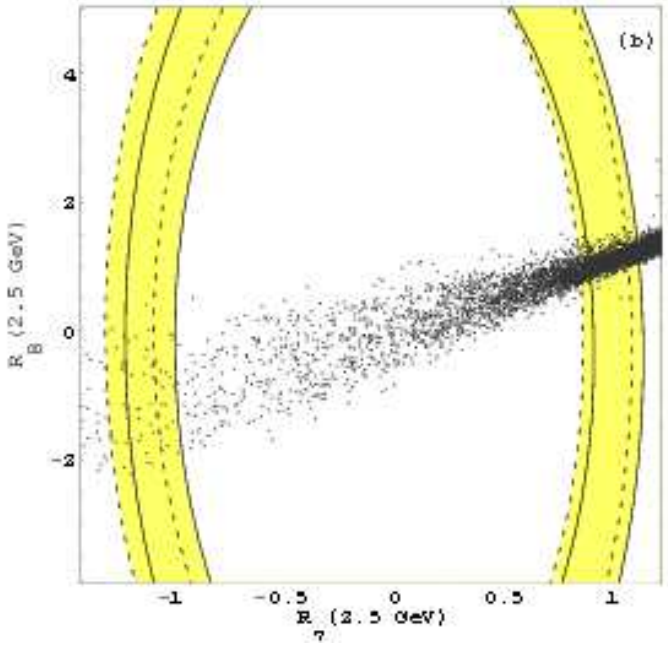
Charged Higgs mass constraint from $b \to s\gamma$ and $B \to \tau\nu$ (for 500/1000/2000 fb^{-1} of data)



Constraints on Wilson coefficients $C7$ and $C8$:
Yellow bands from $BF(b \to s\gamma)$
Dots from a scan of Minimal Flavor Violating SUSY models
T.Hurth, RMP 75:1159 (2003)



Chargino and stop mass from $b \to s\gamma$



Methods of measuring $b \to s\gamma$

There are several different approaches:

- Fully inclusive measurements of gamma spectrum
  - Without a tag from the other B
  - With a lepton tag from the other B
  - Recoiling against a reconstructed B
- Semi-inclusive sum of exclusive final states
  - $(K + n\pi)\gamma$ where $n \leq 4$ is $\approx 50\%$ of the rate
  - Can also include $3K\gamma$, $K\eta\gamma$, $\bar{\Lambda}p\gamma$...

The methods are complementary:

$\Rightarrow$ *Small overlap between event samples (can be combined easily)*

$\Rightarrow$ *Different sources of systematic errors*

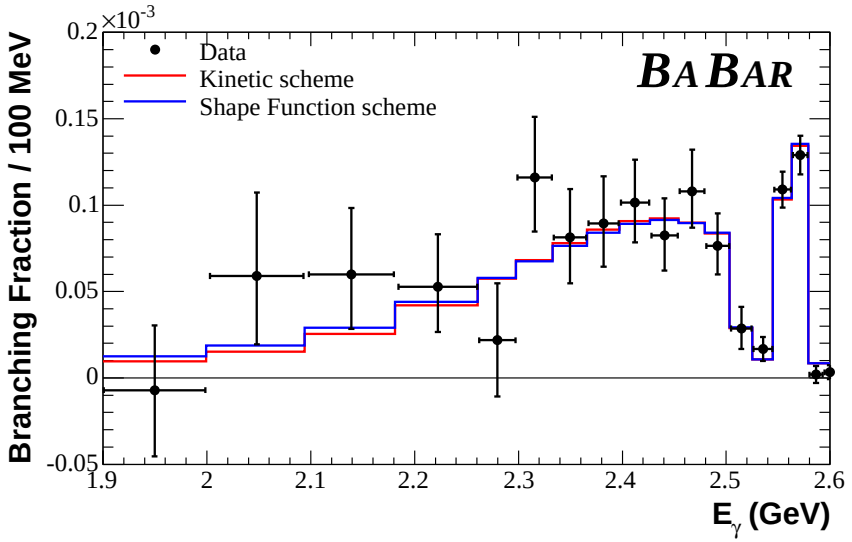
BaBar results for $BF(b \to s\gamma)$ with $E_\gamma > 1.9GeV$

Sum of exclusive modes

PRD 72, 052004 (2005)

89M $B\bar{B}$ pairs

Photon spectrum in B rest frame

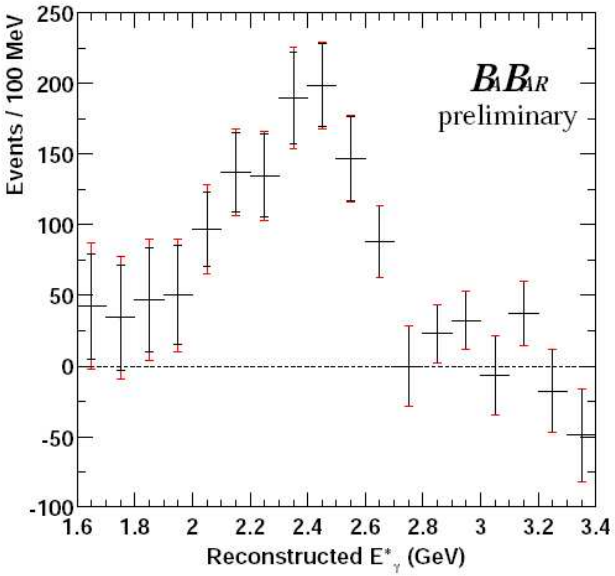


$$BF = (3.29 \pm 0.18^{+0.63}_{-0.40} \pm 0.07) \times 10^{-4}$$

Lepton-tagged inclusive

hep-ex/0507001

Background-subtracted photons in $\Upsilon(4S)$ frame



$$BF = (3.67 \pm 0.29 \pm 0.34 \pm 0.29) \times 10^{-4}$$

Errors are statistical, systematic, theoretical respectively

systematic errors can be reduced with more data

Time-Dependent CP Violation in $B \to K^*\gamma$

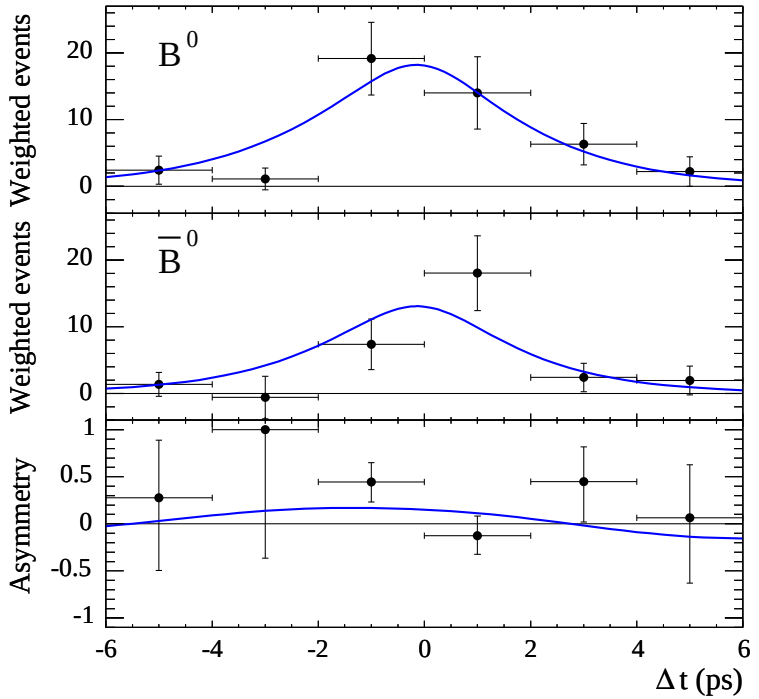
The dominant couplings in the Standard Model (SM) are left-handed (right-handed) for $b \to s\gamma$ ($\bar{b} \to \bar{s}\gamma$)

hep-ex/0507038 (*Preliminary*)

Method uses $K^{*0} \to K_s\pi^0$

B decay vertex reconstructed by extrapolating K_s to beam axis

Δt resolution depends on radius at which K_s decays



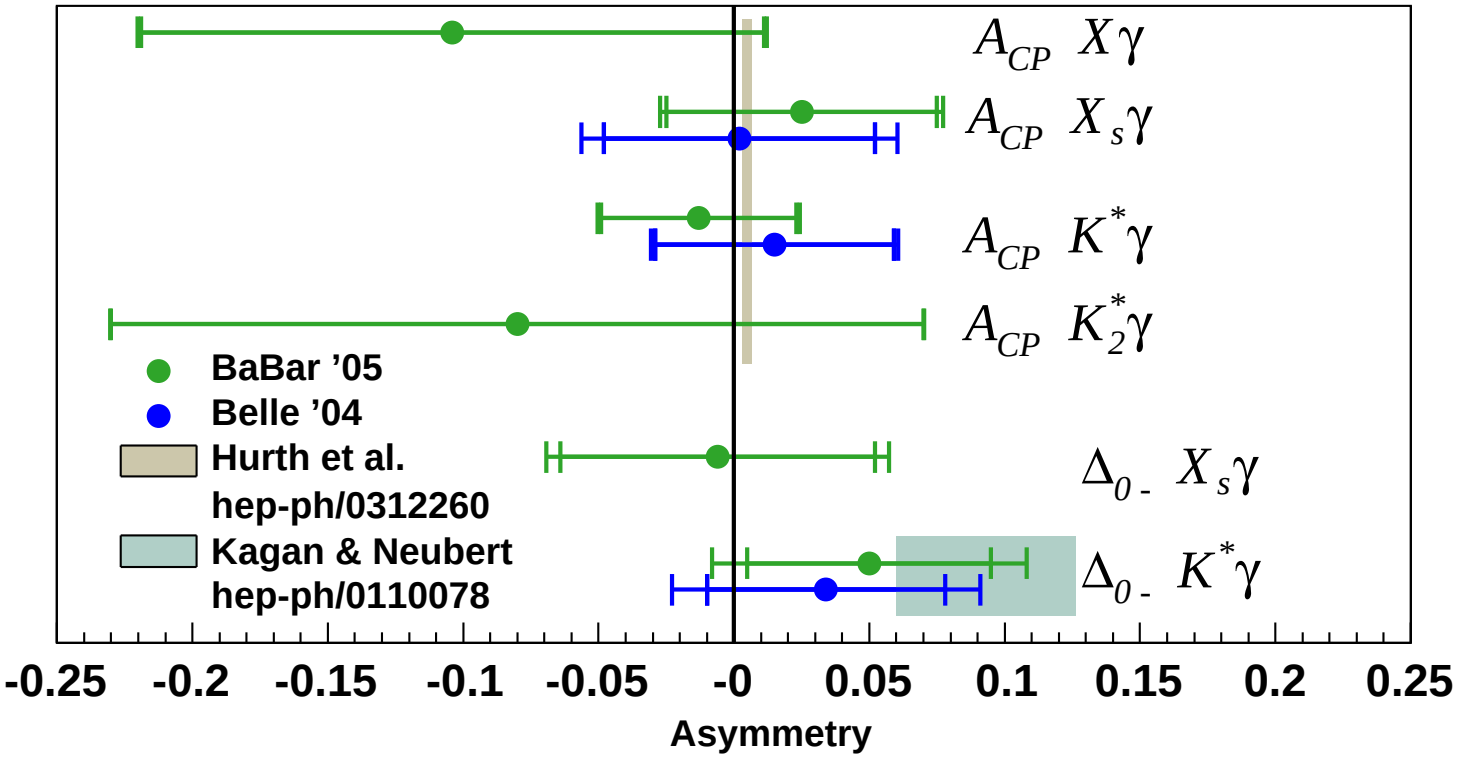
Not enough data to test SM

$$S_{K^*\gamma} \propto \frac{m_s}{m_b} \sin 2\beta = 0.07 \pm 0.03 \qquad C_{K^*\gamma} \approx 0.01 \qquad \text{(SM)}$$

$$S_{K^*\gamma} = -0.21 \pm 0.40 \pm 0.05 \qquad C_{K^*\gamma} = -0.40 \pm 0.23 \pm 0.03$$

Direct CP and Isospin asymmetries in $b \to s\gamma$

These asymmetries are small in the Standard Model because there is only the penguin contribution to the amplitude.



All measurements are statistics limited - need more data!

In Supersymmetric models asymmetries could be enhanced

$B \to \rho(\omega)\gamma$ at BaBar

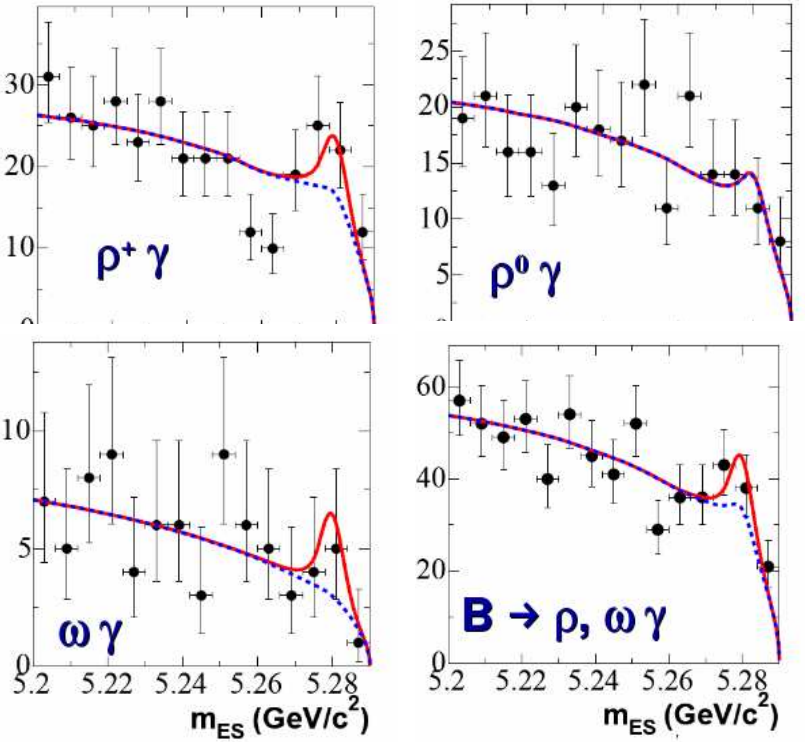
PRL 94, 011801 (2005)

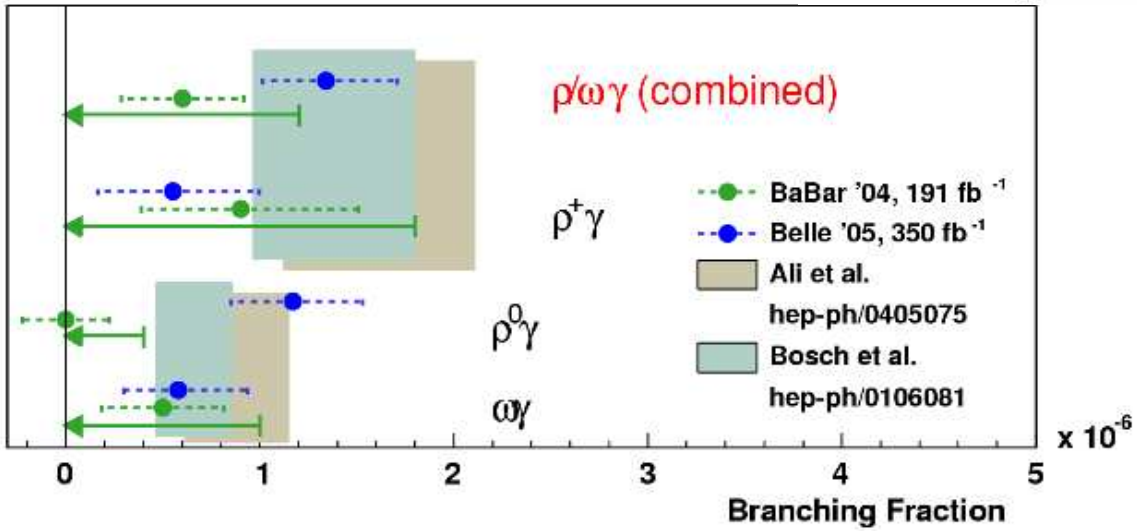
(210 million $B\bar{B}$ pairs)

BaBar sees 2σ excesses in $B^+ \to \rho^+\gamma$, $B^0 \to \omega\gamma$

Combined 90% C.L. upper limit:

$BF(B \to \rho(\omega)\gamma) < 1.2 \times 10^{-6}$





For $B^0 \to \rho^0\gamma$ Belle and BaBar differ by $\approx 3\sigma$!

Measuring V_{td}/V_{ts} with $b \to d\gamma$ penguins

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

$\zeta = 0.85 \pm 0.10$ allows for SU(3) breaking in the form factor

$\Delta R = 0.1 \pm 0.1$ allows for weak annihilation ($B^+ \to \rho^+\gamma$ only!)

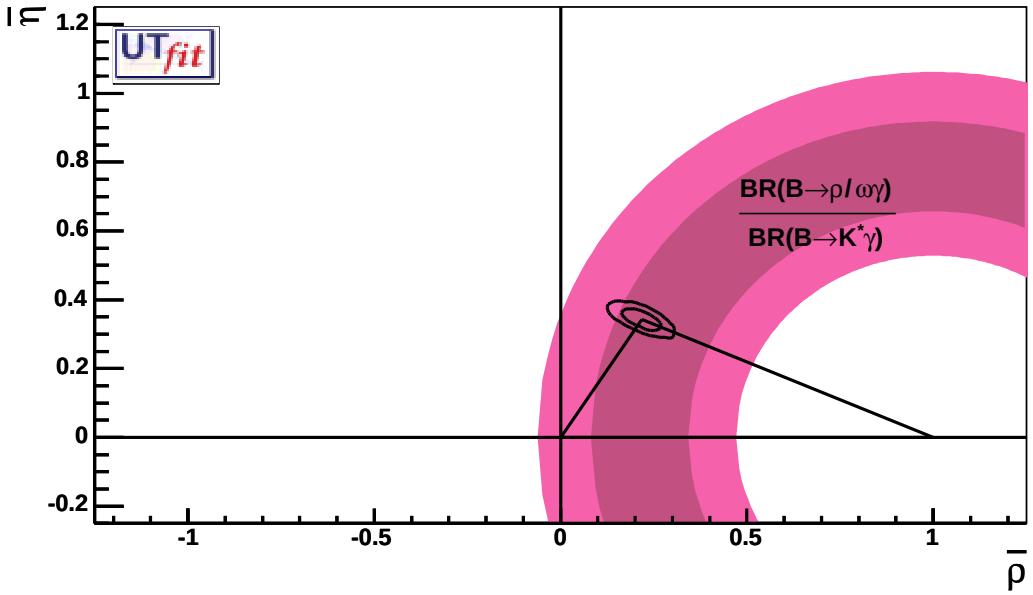
BaBar (95% CL)

$|V_{td}/V_{ts}| < 0.21$

Belle (95% CL)

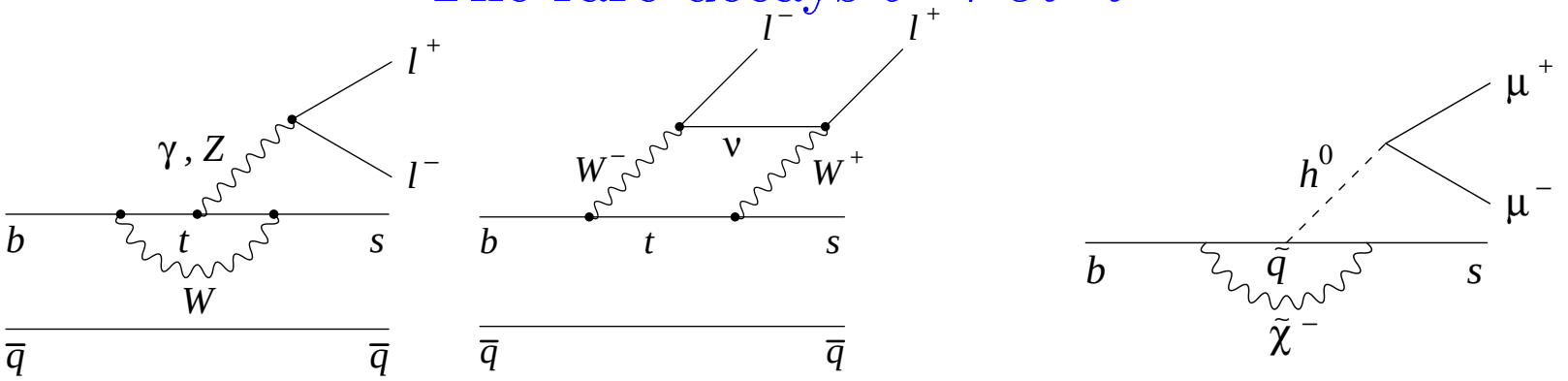
$|V_{td}/V_{ts}| > 0.14$

Currently better than B_s mixing!



Is an inclusive measurement of $b \to d\gamma$ also possible?

The rare decays $b \to s\ell^+\ell^-$



Wilson coefficients C_7, C_9 and C_{10} (sensitive to New Physics) from:

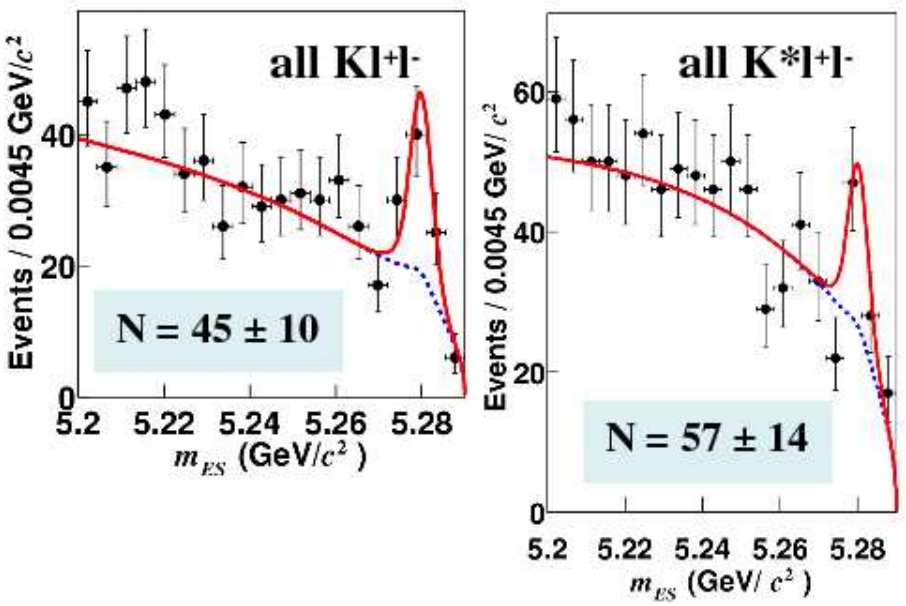
- Inclusive and exclusive (K, K^*) Branching Fractions as a function of q^2 of the leptons
- Forward-Backward lepton asymmetry as a function of q^2 (note that this is zero for $K\ell^+\ell^-$)
- The ratio of $se^+e^-/s\mu^+\mu^-$
- Direct CP asymmetries
- Eventually $b \to d\ell^+\ell^-$ (using $B \to \pi\ell^+\ell^-$)

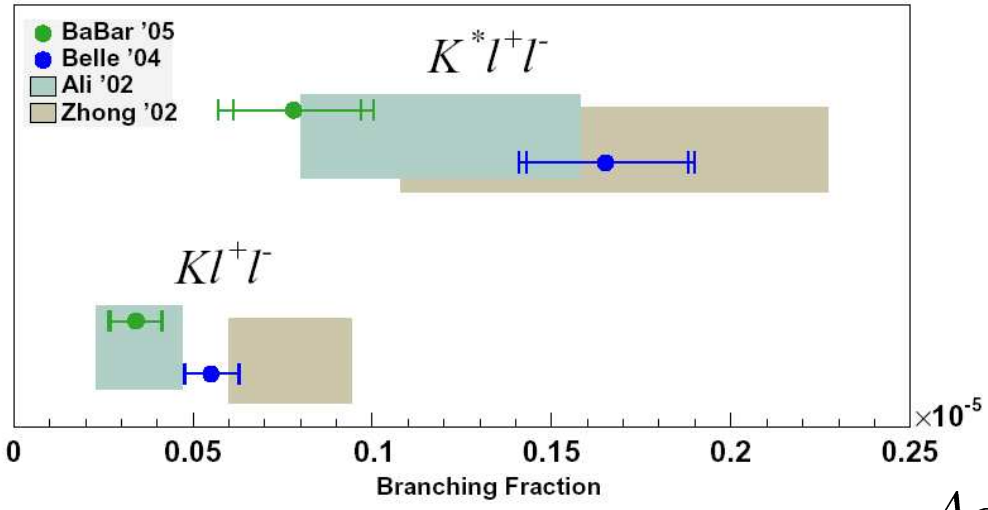
Exclusive $B \to K^{(*)}\ell^+\ell^-$

hep-ex/0507005 (*Preliminary*)

Very low event yields!

$B \to K\ell^+\ell^-$ is rarest B decay ever observed





BFs uncertain by x2
(experiment and theory!)

Direct CP asymmetries:

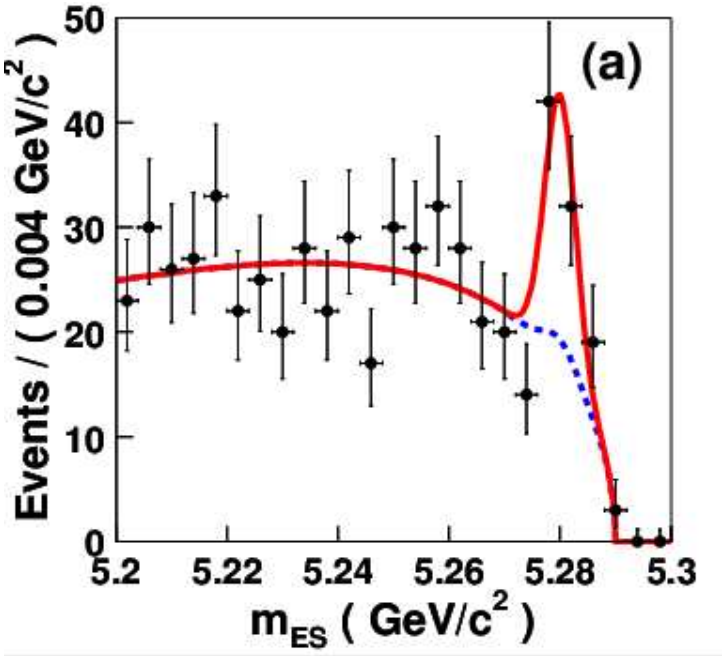
$$A_{CP}(K\ell\ell) = 0.08 \pm 0.22 \pm 0.11$$

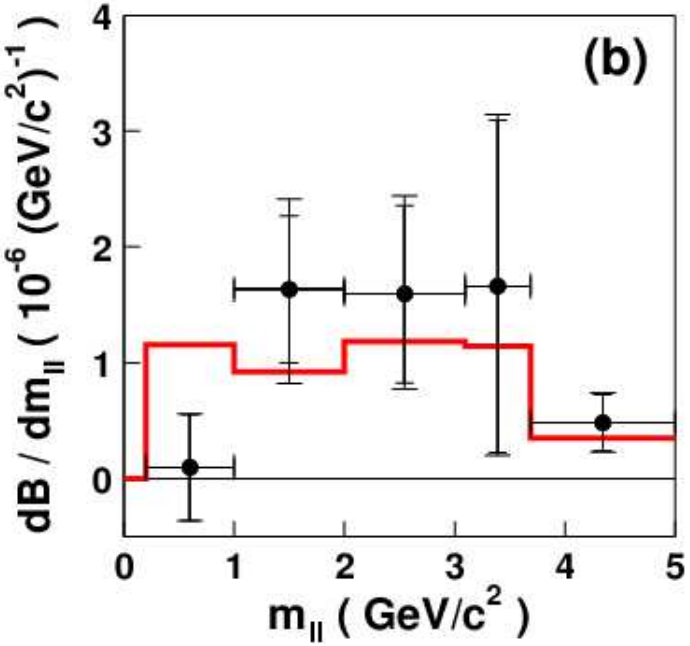
$$A_{CP}(K^*\ell\ell) = -0.03 \pm 0.23 \pm 0.12$$

Inclusive $b \to s\ell^+\ell^-$ at BaBar

Measured with sum of exclusive final states

PRL 93 081802 (2004) - only 89M $B\bar{B}$ pairs used!



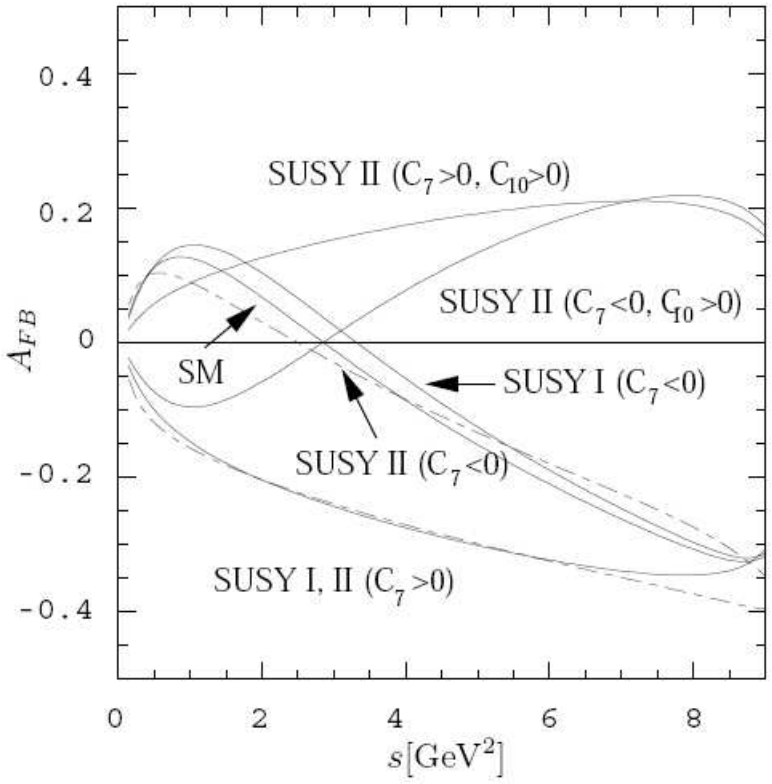


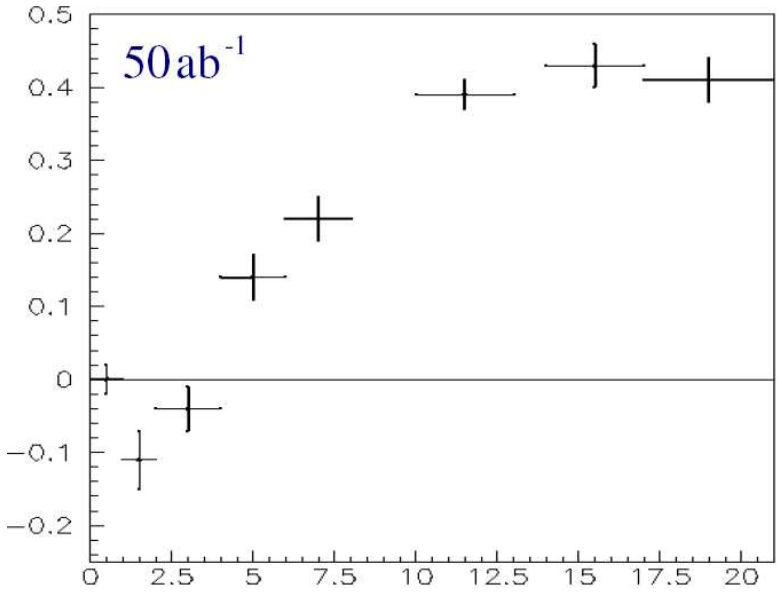
BF is in good agreement with Standard Model

$$BF(b \to s\ell^+\ell^-) = (4.5 \pm 1.0) \times 10^{-6}$$

Forward-Backward Asymmetry in $B \to K^* \ell^+ \ell^-$

Theory (SM and SUSY)





$-A_{FB}$ vs q^2

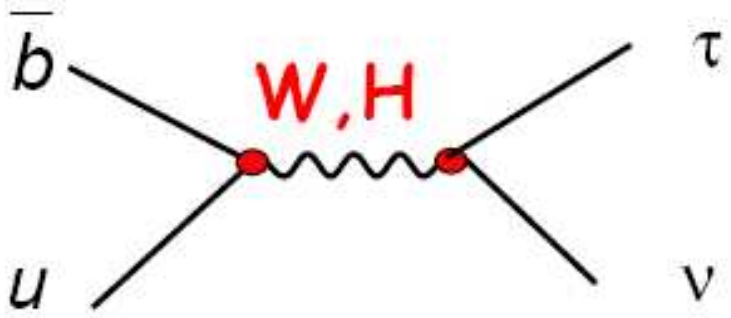
SuperB factory with $50/ab$

$\Rightarrow$ Can measure for both $K^* e^+ e^-$ and $K^* \mu^+ \mu^-$

$\Rightarrow$ Inclusive $s\ell^+\ell^-$ by sum of exclusive modes

Purely leptonic B decays

$B \to \ell\nu$ proceeds via a weak annihilation diagram:



Standard Model prediction:

$$BF(B^+ \to \tau^+\nu_\tau) = 1.2 \times 10^{-4} \left(\frac{f_B}{200MeV}\right)^2 \left(\frac{V_{ub}}{0.004}\right)^2$$

can be modified by an H^+ at large $\tan\beta$

The decays $B^+ \to \mu^+\nu_\mu$ and $B^+ \to e^+\nu_e$ are helicity suppressed

$$\tau\nu : \mu\nu : e\nu = 1 : 4 \times 10^{-3} : 1 \times 10^{-7}$$

Progress towards measuring $B \to \tau\nu$ (hep-ex/0507069)

A tag B^- is reconstructed as:

$\Rightarrow$ semileptonic $B^- \to D^{*0}\ell^-\nu$

$\Rightarrow$ hadronic final states

τ^+ decays to:

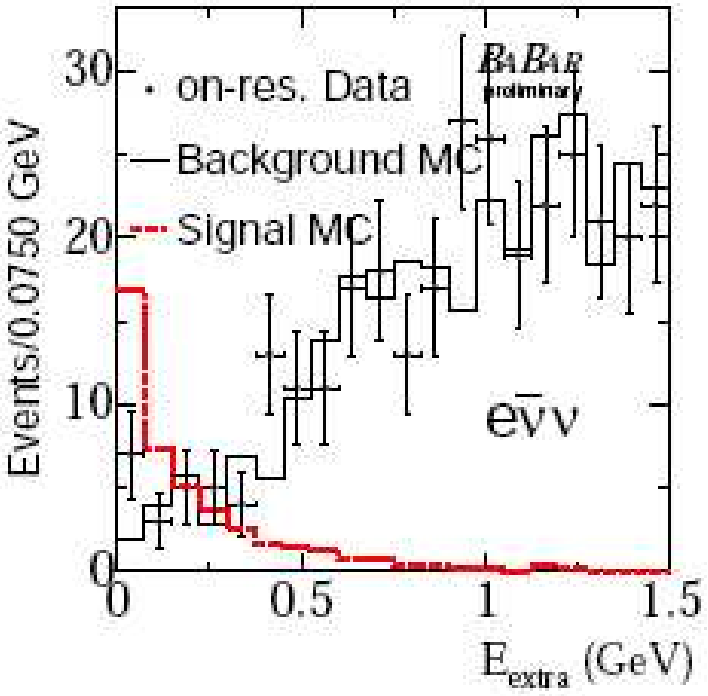
e^+, μ^+, π^+, ρ^+, a_1^+

(81% of τ decays)

Plot of extra energy in event

Semileptonic tags

$\tau \to e$ decays

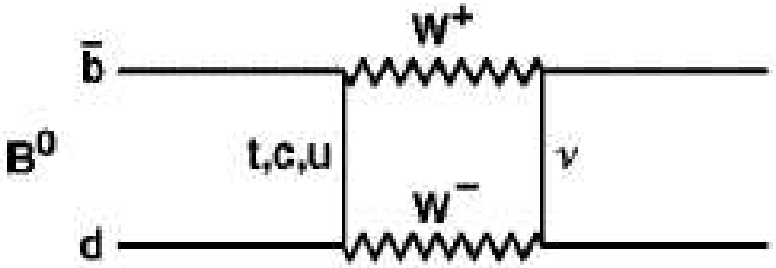


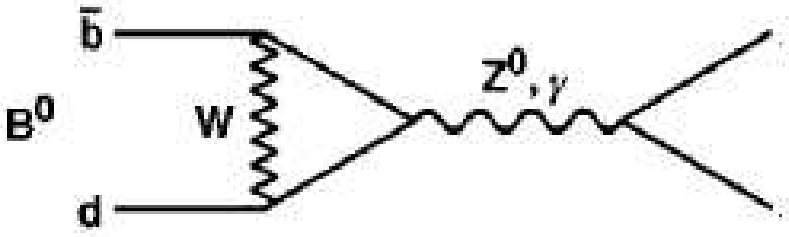
Combined result from all tags and decays is close to expected BF:

$BF(B^+ \to \tau^+\nu_\tau) = 1.3^{+1.0}_{-0.9} \times 10^{-4}$ $\quad (< 2.6 \times 10^{-4}$ at 90% C.L.)

Decays to lepton pairs

$B^0 \to \ell^+\ell^-$ is a very rare weak process (enhanced by SUSY H^0?)





The decays $B^0 \to \mu^+\mu^-$ and $B^0 \to e^+e^-$ are again helicity suppressed

$$\tau^+\tau^- : \mu^+\mu^- : e^+e^-$$
$$1 : 4 \times 10^{-3} : 1 \times 10^{-7}$$

$$BF(B^0 \to \tau^+\tau^-) = 1.3 \times 10^{-7} \left(\frac{f_B}{200MeV}\right)^2 \left(\frac{V_{td}}{0.007}\right)^2 \quad \text{(SM)}$$

$BF(B^0 \to \tau^+\tau^-) < 3.2 \times 10^{-3}$ (PRL in preparation)

$BF(B^0 \to \mu^+\mu^-) < 8.3 \times 10^{-8}$

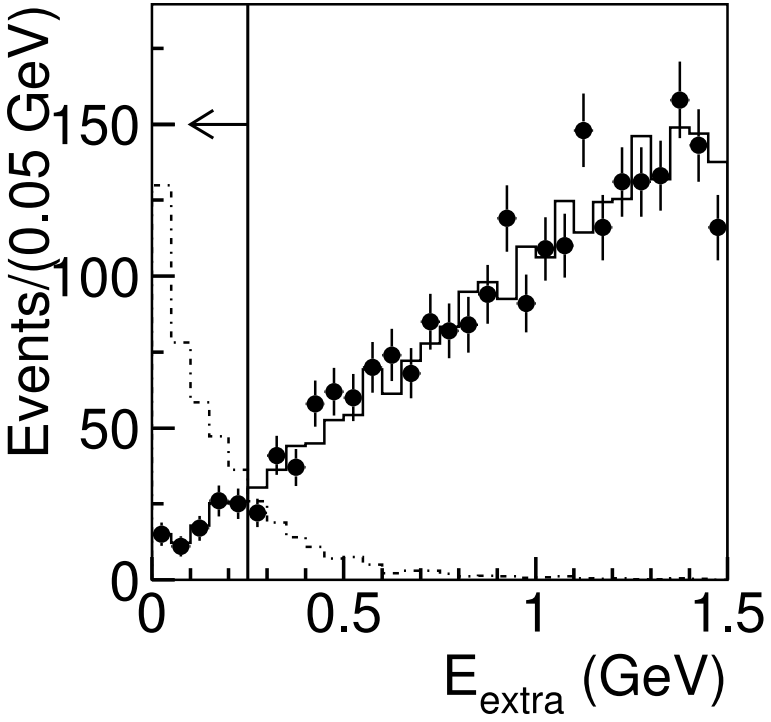
$BF(B^0 \to e^+e^-) < 6.1 \times 10^{-8}$

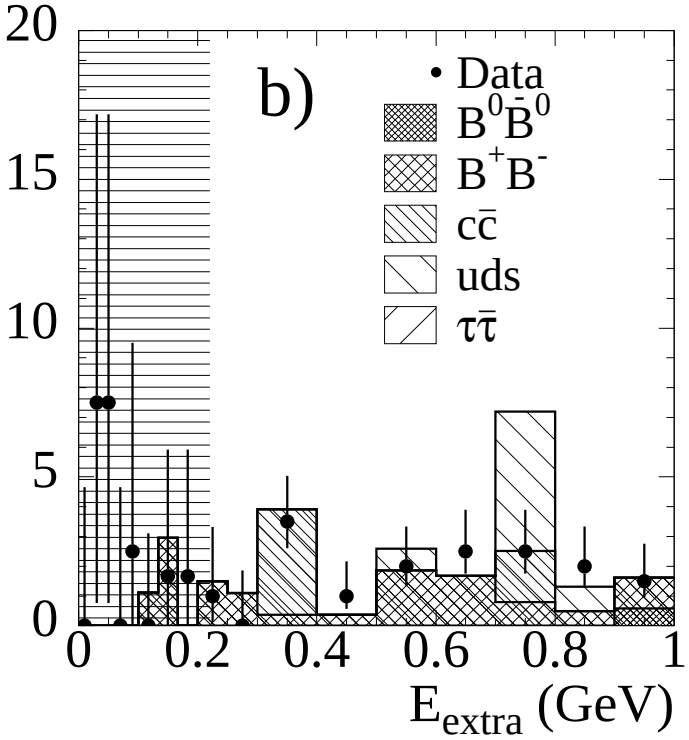
$BF(B^0 \to e^\pm\mu^\mp) < 18.4 \times 10^{-8}$ (lepton-flavour violating)

$B \to K\nu\bar{\nu}$ and $B \to (\gamma)\nu\bar{\nu}$

PRL 94, 101801 (2005) and PRL 93, 091802 (2004) - 89M $B\bar{B}$ pairs

These analyses use the same B tagging methods as $B \to \tau\nu$





$BF(B^+ \to K^+\nu\bar{\nu}) < 5.2 \times 10^{-5}$

(SM predicts 4×10^{-6})

$BF(B^0 \to \gamma\nu\bar{\nu}) < 4.7 \times 10^{-5}$

$BF(B^0 \to \nu\bar{\nu}) < 2.2 \times 10^{-4}$

Conclusions

- Precise measurements of $BF(b \to s\gamma)$ agree with SM
- CP asymmetries in $b \to s\gamma$ are small (statistics limited)
- $B \to \rho\gamma$ is a significant constraint on $|V_{td}/V_{ts}|$
- $B \to K^{(*)}\ell^+\ell^-$ and $s\ell^+\ell^-$ have been observed
  (but need more statistics to measure interesting quantities)
- $B \to \tau\nu$ is close to being observable
- Interesting new limits on $B \to \tau\tau$, $B \to K\nu\bar{\nu}$ and $B \to (\gamma)\nu\bar{\nu}$

$B \to K^{(*)}\ell^+\ell^-$ and $B_{(s)} \to \mu^+\mu^-$ will be well-measured at the LHC

All the other decays need a Super B factory after 2008