Radiative and Electroweak B Decays

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KEK

Belle Collaboration

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Contents

The experimental results are from BaBar and Belle.

Special thanks to Jeff Richman and Jeff Berryhill (BaBar).

Introduction

- $b \to s\gamma$ ($b \to d\gamma$) and $b \to s\ell^+\ell^-$: FCNC process
- Lowest diagram: one loop penguin (or box) diagram.
- Sensitive probe to New Physics.

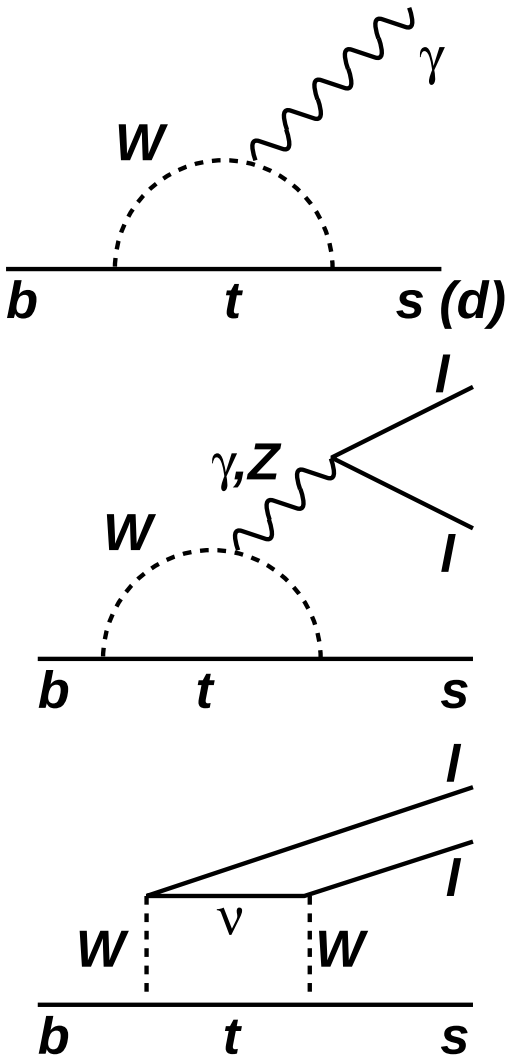
The effective Hamiltonian in terms of Wilson coefficients C_i:

$$\mathcal{H}^{\rm eff} = -\frac{4G_F}{\sqrt{2}}|V_{ts}^* V_{tb}| \sum_{i=1}^{8} C_i(\mu) O_i(\mu).$$

- $b \to s\gamma$: $|C_7|$
- $b \to s\ell^+\ell^-$: C_9, C_{10}, sign of C_7

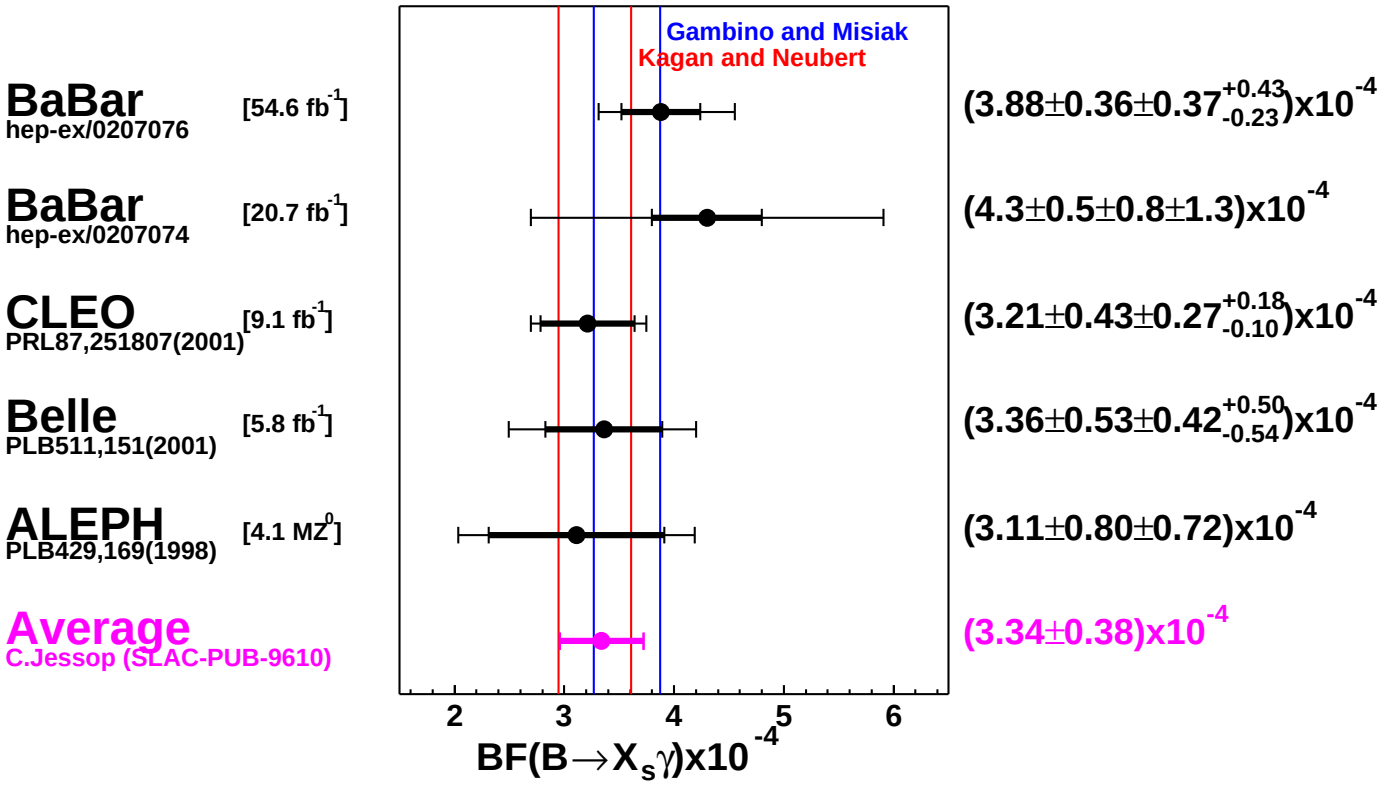
$b \to d\gamma$ not covered this talk (no update this summer).
Best upper limit by BaBar:

$$\mathcal{B}(B^+ \to \rho^+\gamma) < 2.1 \times 10^{-6} \quad [\text{SM: } \sim 1 \times 10^{-6}]$$
$$\mathcal{B}(B^0 \to \rho^0\gamma) < 1.2 \times 10^{-6} \quad [\text{SM: } \sim 0.5 \times 10^{-6}]$$
$$\mathcal{B}(B^0 \to \omega\gamma) < 1.0 \times 10^{-6} \quad [\text{SM: } \sim 0.5 \times 10^{-6}]$$



Radiative B Decays

Inclusive $b \to s\gamma$ Branching Fraction



- Both theoretical predictions and experimental measurements have $\sim 10\%$ uncertainty.
- Measurements are consistent with the SM expectation.

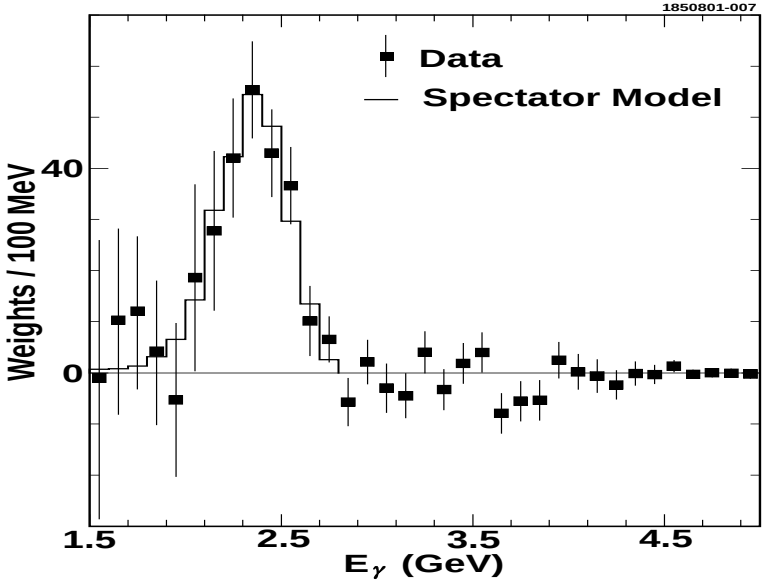
Radiative B Decays

Interests in radiative B decays

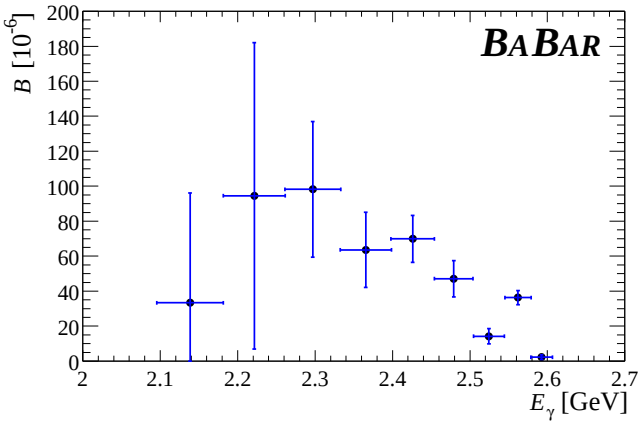
- Inclusive branching fraction.
- ★ Direct CP asymmetry in $b \to s\gamma$.
- Photon polarization (left-handed in the SM).
  - $B \to K^*\gamma \to K^* e^+ e^-$ (conversion at beam pipe etc).
  - $B^+ \to K_1(1400)^+\gamma$
- Mixed induced CP asymmetry.
  - $B^0 \to K^{*0}\gamma \to K^0_S \pi^0 \gamma$
  - $B^0 \to K_1(1270)^0\gamma \to K^0_S \rho^0 \gamma$
- E^*_γ spectrum (for $|V_{ub}|$ measurement).
- ★ Exclusive decays ($B \to K^*_2(1430)\gamma$ etc).

★ : topic in this talk

CLEO $9.1\ \mathrm{fb}^{-1}$
[PRL 87, 251807 (2000)]

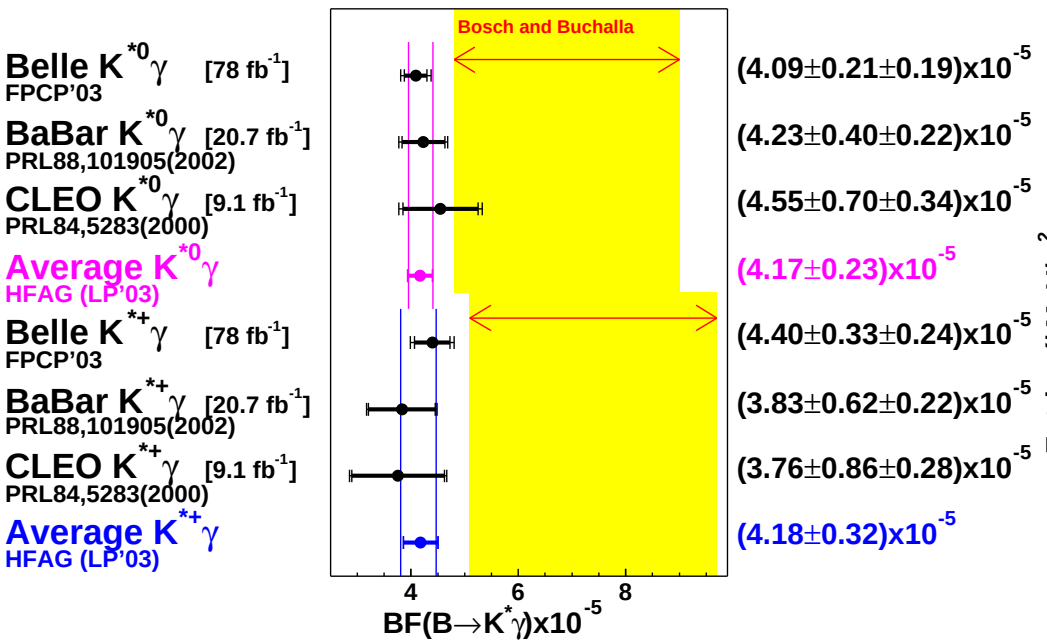


BaBar $21\ \mathrm{fb}^{-1}$ [hep-ex/0207074]

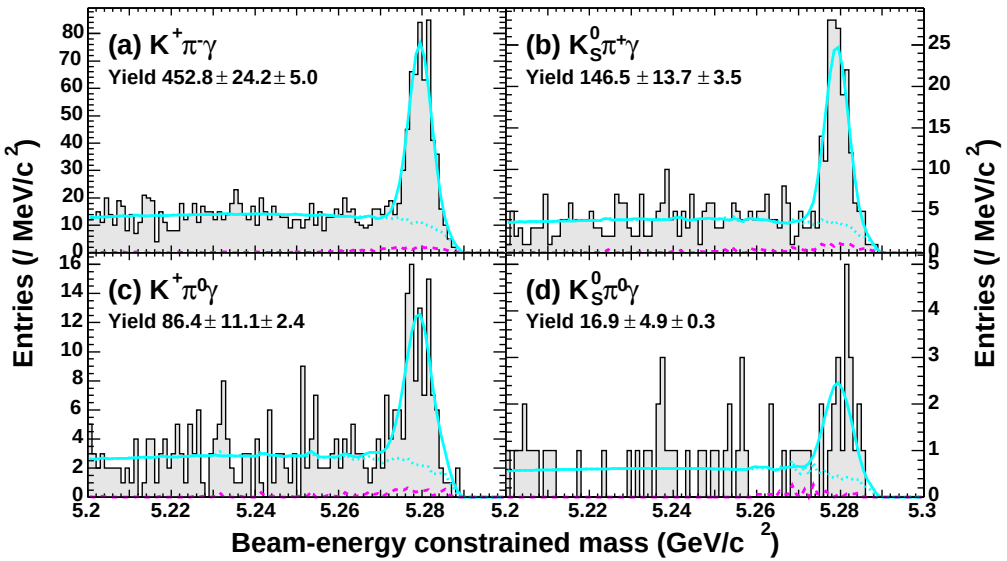


Exclusive modes of radiative B decays

$B \to K^*(892)\gamma$



Belle $78\ \mathrm{fb}^{-1}$ [FPCP]

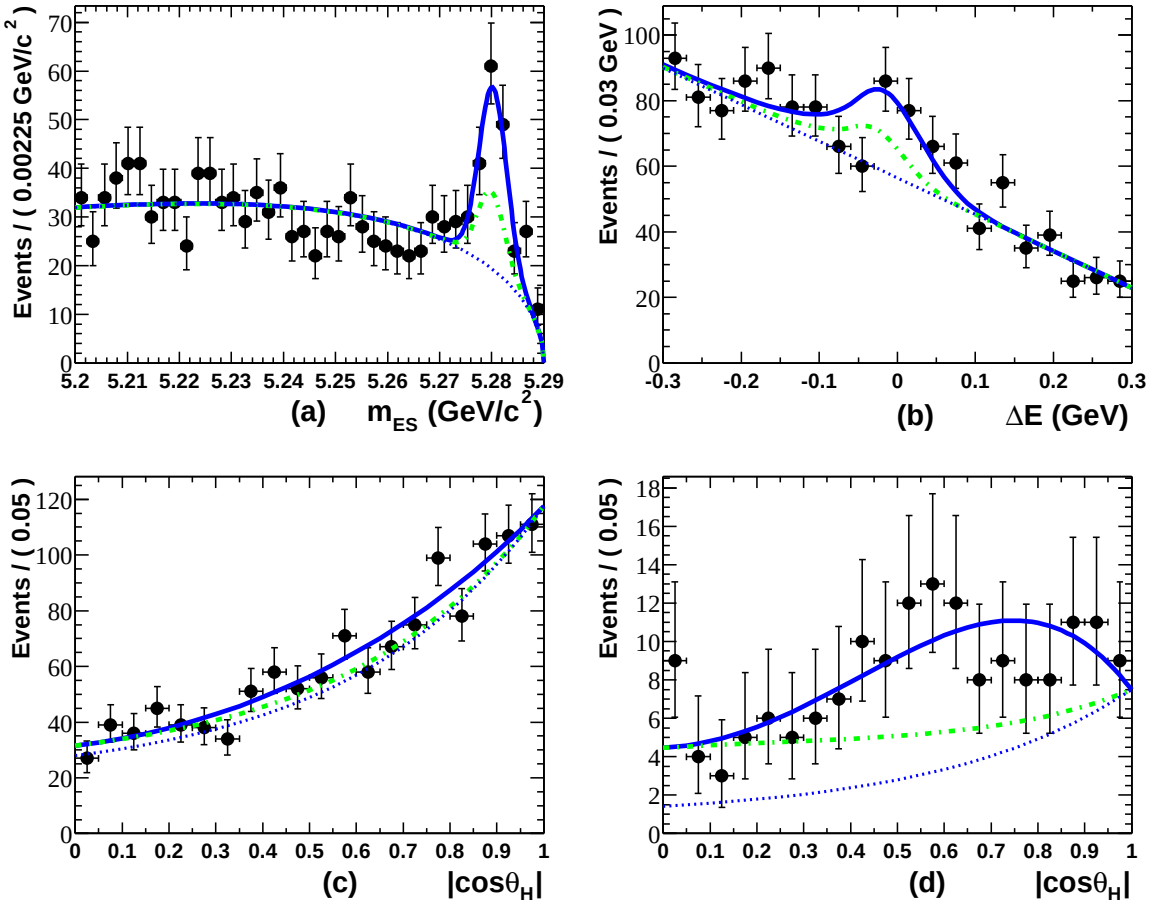


- $\sim 15\%$ of the $b \to s\gamma$ process.
- Difficult theoretical prediction due to the form factor
- Asymmetry of BF in charged and neutral mode $\Longrightarrow$ consistent with zero.
- $A_{\mathrm{CP}}(K^*\gamma) = (-0.5 \pm 3.7)\%$ (averaged).

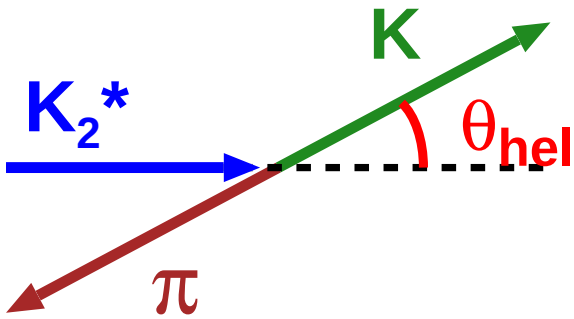
Exclusive modes of radiative B decays

$B \to K_2^*(1430)\gamma$

- CLEO, Belle observed $B \to K_2^*(1430)\gamma$.
- New result from BaBar!!



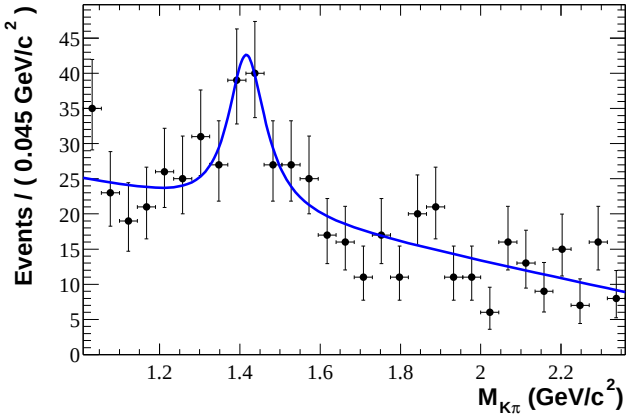
- $K_2^*(1430) \to K\pi$ (50%)
- Helicity angle distribution: $\cos^2\theta_{\rm H} - \cos^4\theta_{\rm H}$



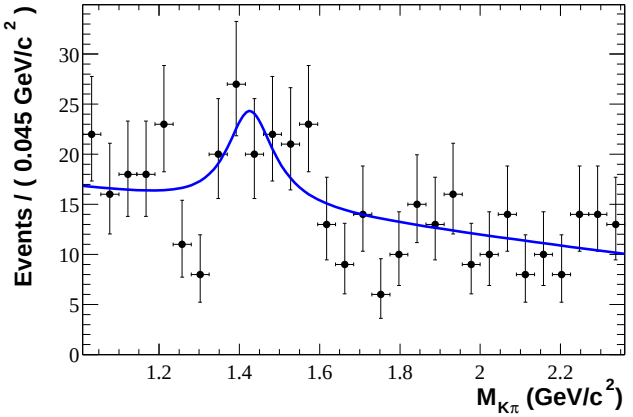
- Separately for the neutral mode and charged mode.
- Maximum likelihood fit for $m_{\rm ES}$, ΔE, $\cos\theta_{\rm H}$

Exclusive modes of radiative B decays

Neutral Mode



Charged Mode

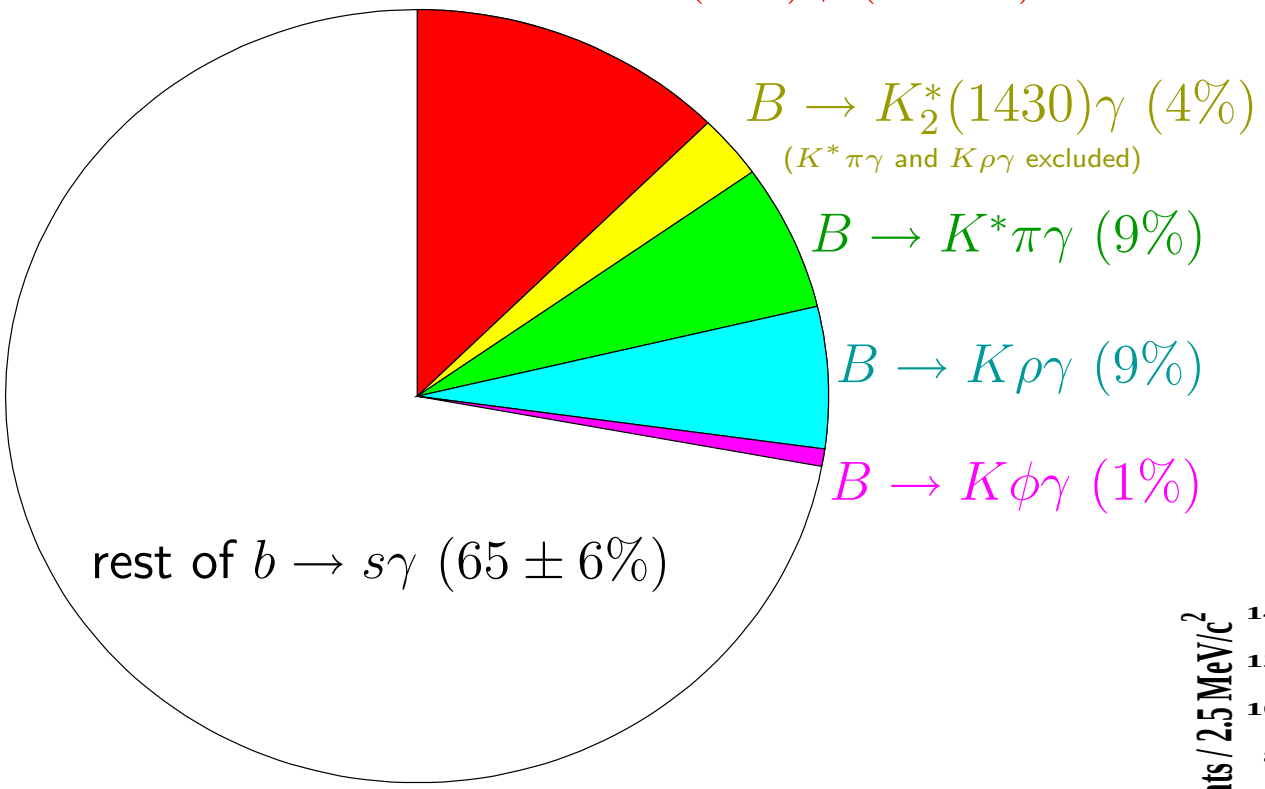


	$\mathcal{B}(B^0 \to K_2^*(1430)^0\gamma)$	$\mathcal{B}(B^0 \to K_2^*(1430)^0\gamma)$	
CLEO	$(16.6^{+5.9}_{-5.3} \pm 1.3) \times 10^{-6}$	(combined)	[PRL84,5283(2000)]
Belle	$(13 \pm 5 \pm 1) \times 10^{-6}$	—	[PRL89,231801(2002)]
BaBar	$(12.2 \pm 2.5 \pm 1.1) \times 10^{-6}$	$(14.4 \pm 4.0 \pm 1.3) \times 10^{-6}$	[LP03]

[SM: e.g. $\mathcal{B}(B \to K_2^*(1430)\gamma) = (17.3 \pm 8.0) \times 10^{-6}$, Veseli-Olsson PLB367,309(1996)]

Exclusive modes of radiative B decays

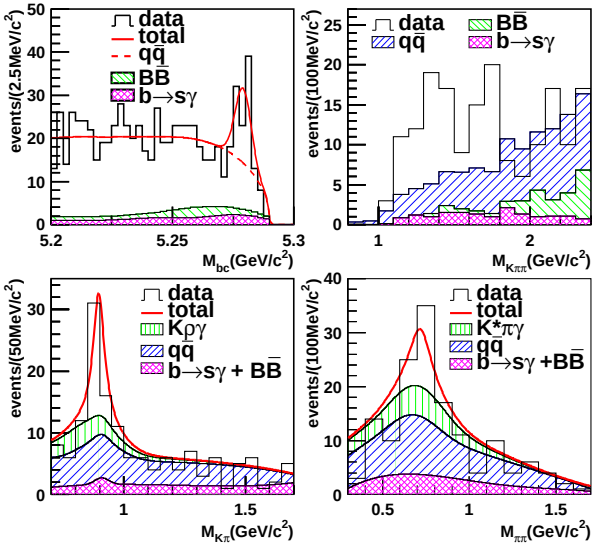
Exclusive mode summary



- $(35 \pm 6)\%$ has been measured.
- What is the rest?

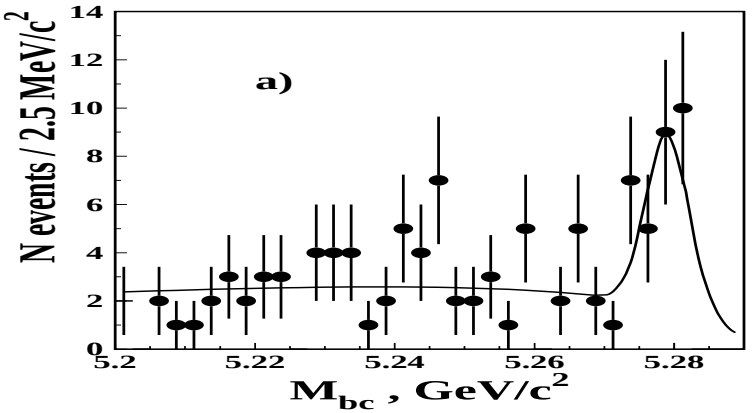
$B^+ \to K^+\pi^-\pi^+\gamma$ (Belle)

[PRL89,231801(2002)]



$B^+ \to K^+\phi\gamma$ (Belle)

[hep-ex/0309006]



$A_{\rm CP}(B \to X_s\gamma)$

$A_{\rm CP}(B \to X_s\gamma)$

- SM predicts small CP asymmetry (less than 0.6%) in the $b \to s\gamma$ process.
  Large CP asymmetry ($\sim 40\%$) is possible for the $b \to d\gamma$ process.
- Some models beyond the SM allow large CP asymmetry.
- Past measurement by CLEO [PRL86, 5661 (2001)]:

$$A_{\rm CP} \equiv 0.965 A_{\rm CP}(B \to X_s\gamma) + 0.02 A_{\rm CP}(B \to X_d\gamma)$$
$$= (-0.079 \pm 0.108 \pm 0.022)(1.0 \pm 0.030)$$
$$-0.27 < A_{\rm CP} < 0.10 \qquad (90\%\ \text{C.L.})$$

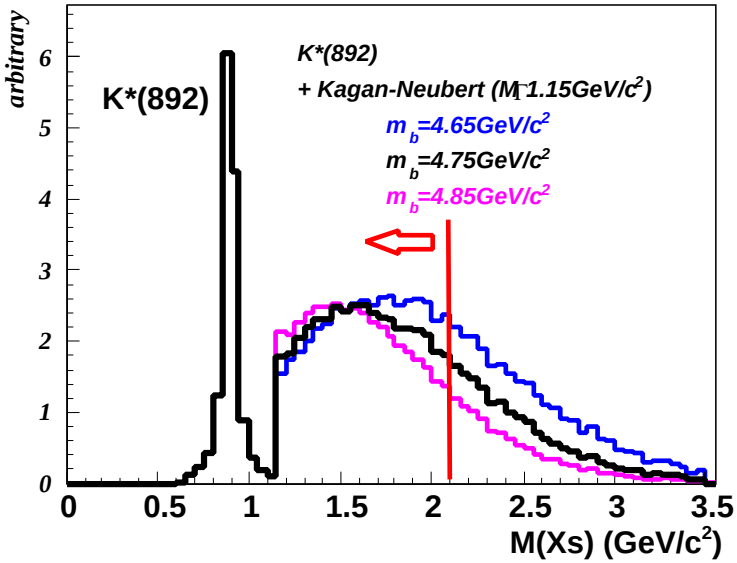
Model	$A_{\rm CP}(b \to s\gamma)[\%]$
SM	0.6
2HDM	~ 0.6
Supergravity	~ -10 to 10
SUSY with squark mixing	~ -15 to 15
SUSY with R-parity violation	~ -17 to 17

[K.Kiers et al. PRD62, 116004 (2000)]

$A_{\rm CP}(B \to X_s\gamma)$

New measurement by Belle

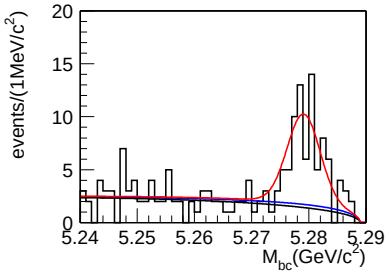
- Pseudo-reconstruction of X_s
  K^+ (K^0_S) + 1 $\sim$ 4 π (up to 1 π^0)
  $K^+K^-K^+(\pi^-)$ / $K^0_S K^+K^-(\pi^+)$
- $M(X_s) < 2.1$ GeV/c^2 ($\sim E_\gamma > 2.2$ GeV)
- High energy lepton from the other side B is required in order to suppress $q\bar{q}$ background.
- $b \to d\gamma$ contamination is negligible.
- Signal yield by fitting $M_{\rm bc}$ to signal, $q\bar{q}$ and $B\bar{B}$ (fixed) components.



$A_{CP}(B \to X_s\gamma)$

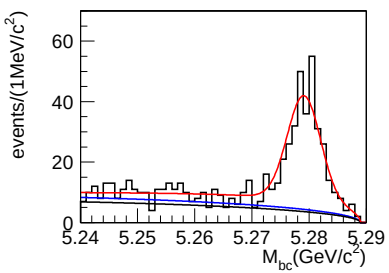
$B \to X_s\gamma$ final states.

$K\pi\gamma$



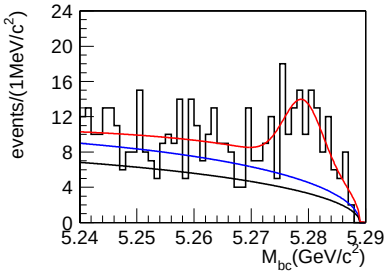
63 ± 10 events

$K\pi\pi\gamma$



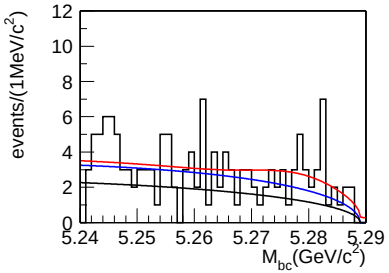
306 ± 21 events

$K\pi\pi\pi\gamma$



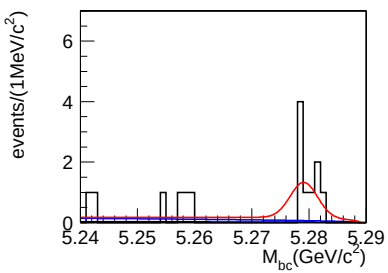
96 ± 17 events

$K\pi\pi\pi\pi\gamma$



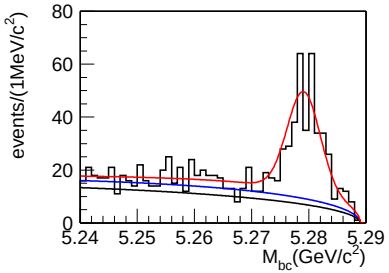
16 ± 11 events

$KKK(\pi)\gamma$



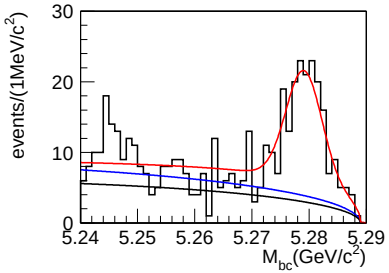
8.6 ± 3.5 events

without π^0



322 ± 24 events

with π^0



160 ± 17 events

- Breakdown is measured for $M(X_s) > 1.15\ \mathrm{GeV}/c^2$ (excluding $B \to K^*\gamma$) in order to estimate the wrong tag fraction etc.

$A_{\rm CP}(B \to X_s\gamma)$

Flavor tagging

- Charged B or odd number of $K \Longrightarrow$ self-tag
  - e.g. $K^+\pi^-\pi^+\pi^-\gamma$, $K^0_S\pi^+\pi^0\gamma$
- Neutral B and even number of $K \Longrightarrow$ ambiguous
  - e.g. $K^0_S\pi^+\pi^-\gamma$

$$A_{\rm CP} = DA^{\rm raw}_{\rm CP} = \frac{1-w_2-w_3}{(1-w_2)(1-2w_1-w_2)} \frac{N(b)-N(\bar{b})}{N(b)+N(\bar{b})-(w_2/(1-w_2))N(\text{amb.})},$$

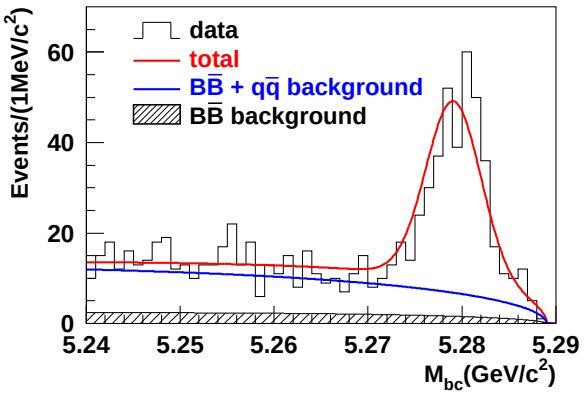
Wrong tag fraction:

$$\begin{array}{rl} w_1 = 0.019 \pm 0.014 & \bar{b} \Leftrightarrow b \\ w_2 = 0.24 \pm 0.19 & \text{ambiguous} \Rightarrow \text{self-tag} \\ w_3 = 0.0075 \pm 0.0079 & \text{self-tag} \Rightarrow \text{ambiguous} \end{array}$$

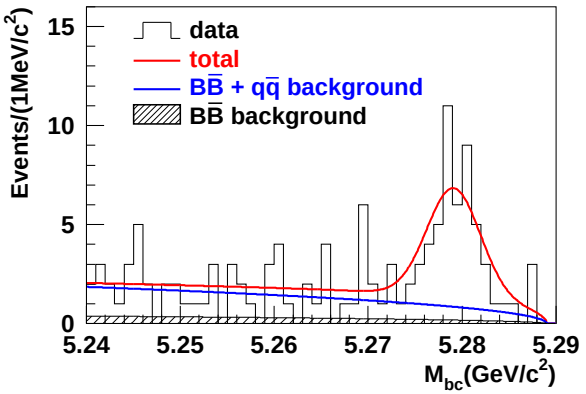
$$D = 1.038 \pm 0.031$$

$A_{\rm CP}(B \to X_s\gamma)$

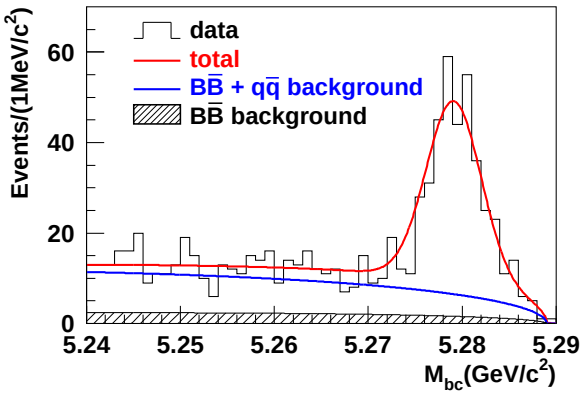
b ambiguous $\bar{b}$



$342 \pm 23^{+7}_{-14}$



$47.8 \pm 8.7^{+1.4}_{-1.8}$



$349 \pm 23^{+7}_{-14}$

$$A_{\rm CP}(B \to X_s\gamma; M(X_s) < 2.1\ {\rm GeV}/c^2) = -0.004 \pm 0.051({\rm stat.}) \pm 0.038({\rm syst.})$$

$$-0.107 < A_{\rm CP}(B \to X_s\gamma; M(X_s) < 2.1\ {\rm GeV}/c^2) < 0.099 \quad (90\%\ {\rm CL})$$

- Null asymmetry.
- Can be used to constrain new physics model (e.g. light chargino in MSSM).

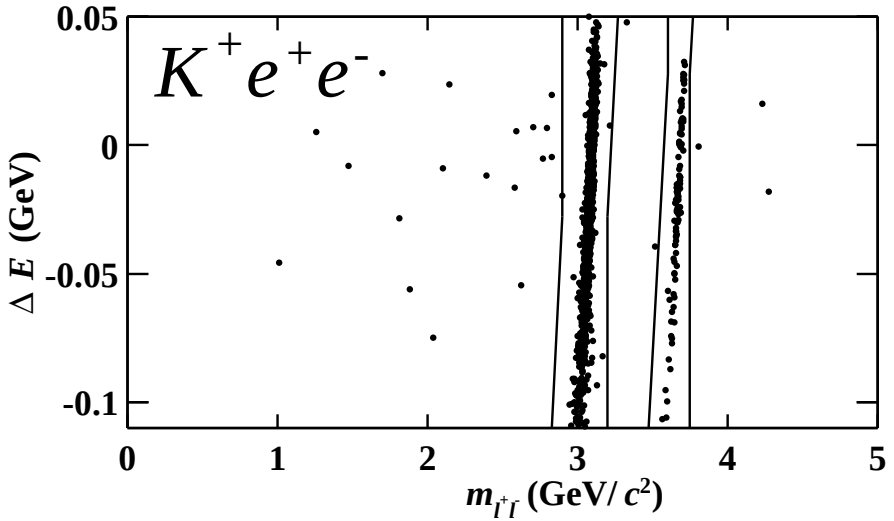
$B \to K\ell^+\ell^-,\ K^*\ell^+\ell^-$

- Belle observed $B \to K\ell^+\ell^-$ in 2001 with $29\ \mathrm{fb}^{-1}$.
- Access to C_9, C_{10}.
- Forward-backward asymmetry in $B \to K^*\ell^+\ell^- \Longrightarrow$ sign of C_7

Analysis

- Hadronic system: K^+, K_S, K^* (from $K^+\pi^-, K_S\pi^+, [K^+\pi^0]$)
- Background
  - Continuum $q\bar{q}$ events.
  - $B\bar{B}$ events (semi-leptonic decays) $\Longrightarrow$ missing energy.
  - $B \to K^{(*)}hh \Longrightarrow$ signal-like peak.
- J/ψ, ψ' veto

Veto region (BaBar)

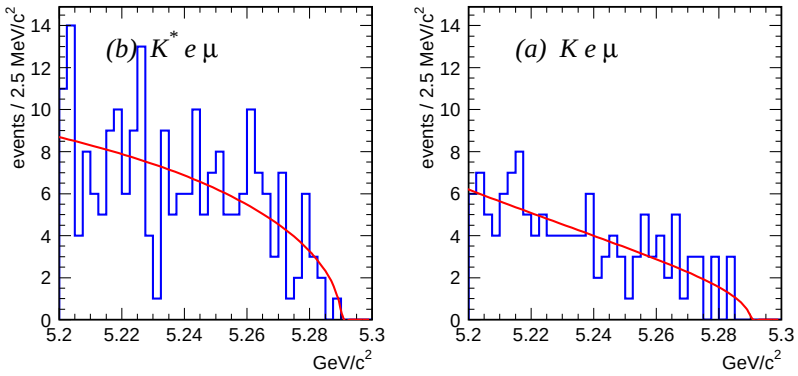


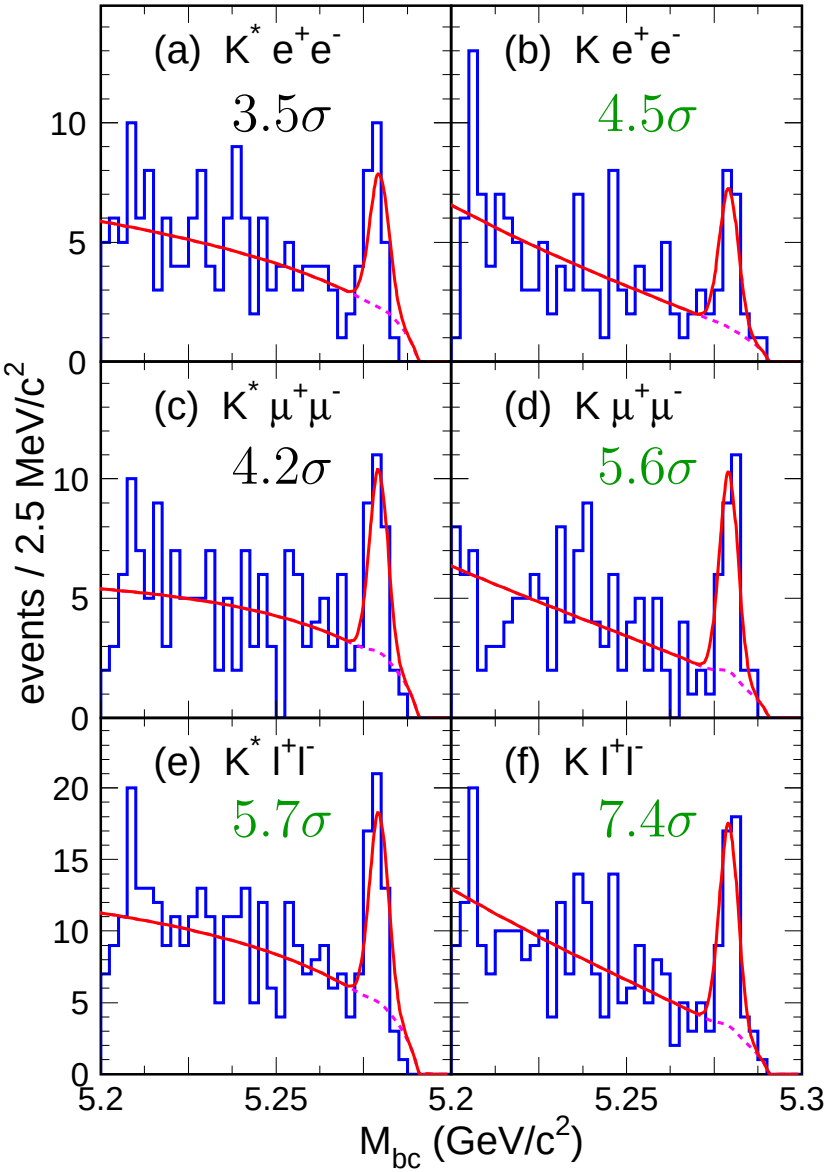
$B \to K\ell^+\ell^-$, $K^*\ell^+\ell^-$

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

- Signal yield from $M_{\rm bc}$ fit.
- First Observation of $B \to K^*\ell^+\ell^-$ mode!!

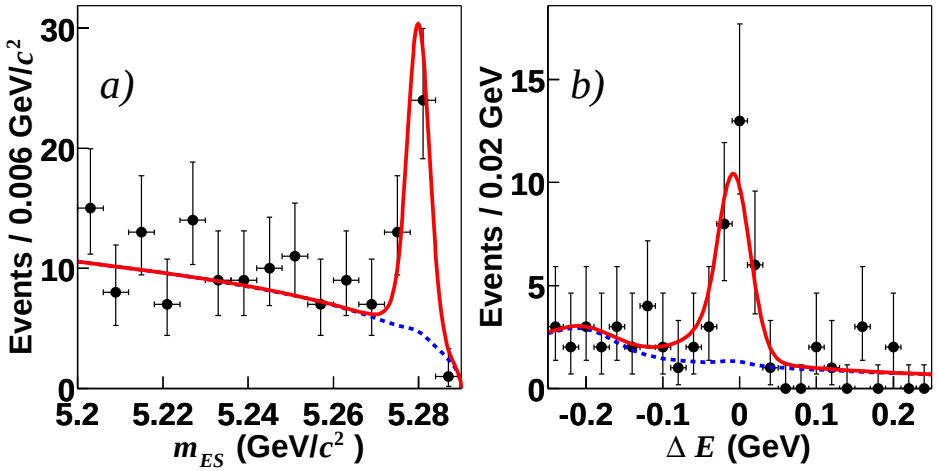
	(a) $K^*e^+e^-$	(b) Ke^+e^-
yield	$15.6\,^{+5.5}_{-4.8} \pm 1.0$	$15.9\,^{+5.1}_{-4.4} \pm 0.7$
eff. [%]	$3.5 \pm 0.2 \pm 0.1$	$10.8 \pm 0.5 \pm 0.2$
	(c) $K^*\mu^+\mu^-$	(d) $K\mu^+\mu^-$
yield	$20.0\,^{+6.0\,+1.1}_{-5.3\,-1.2}$	$22.0\,^{+5.8}_{-5.1} \pm 0.8$
eff. [%]	$5.6 \pm 0.3 \pm 0.3$	$15.2 \pm 0.7 \pm 0.5$
	(e) $K^*\ell^+\ell^-$	(f) $K\ell^+\ell^-$
yield	$35.8\,^{+8.0}_{-7.3} \pm 1.7$	$37.9\,^{+7.6\,+1.0}_{-6.9\,-1.1}$
eff. [%]	$5.1 \pm 0.3 \pm 0.2$	$13.0 \pm 0.6 \pm 0.2$





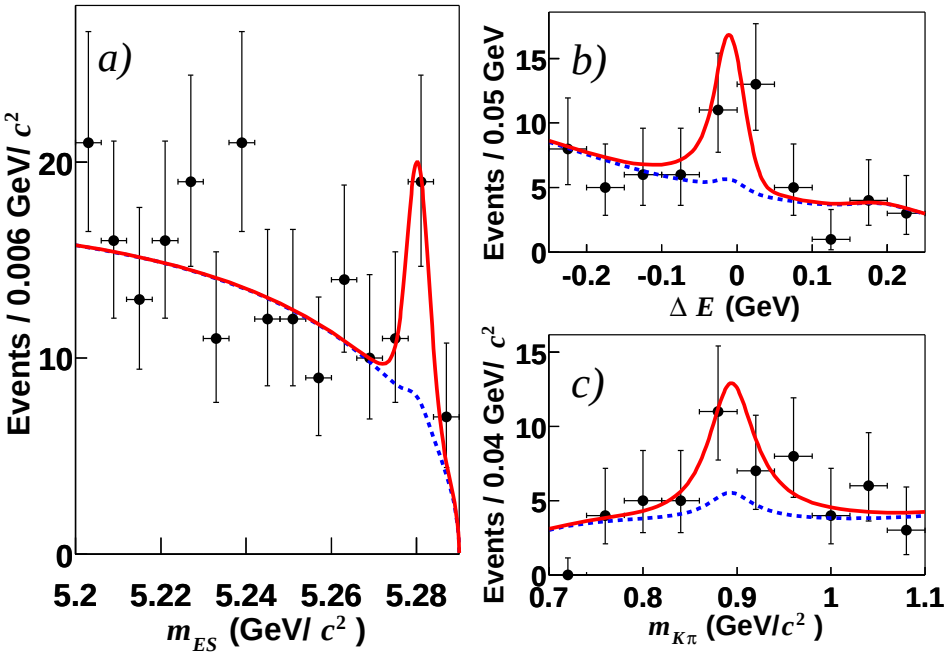
$B \to K^{(*)}\ell^+\ell^-$ from BaBar

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



8.4σ

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



3.3σ

- Simultaneous fit to $m_{\rm ES}$, ΔE, $(m(K\pi))$.
- Evidence for $B \to K^*\ell^+\ell^-$.

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

Branching fraction ($\times 10^{-7}$)

Mode	Belle	BaBar	SM
$B \to Ke^+e^-$	$4.8^{+1.5}_{-1.3} \pm 0.3 \pm 0.1$	$7.4^{+1.8}_{-1.6} \pm 0.5$	
$B \to K\mu^+\mu^-$	$4.8^{+1.2}_{-1.1} \pm 0.3 \pm 0.2$	$4.5^{+2.3}_{-1.9} \pm 0.4$	
$B \to K\ell^+\ell^-$	$4.8^{+1.0}_{-0.9} \pm 0.3 \pm 0.1$	$6.5^{+1.4}_{-1.3} \pm 0.4$	3.5 ± 1.2
$B \to K^*e^+e^-$	$14.9^{+5.2}_{-4.6}{}^{+1.2}_{-1.3} \pm 0.2$	$9.8^{+5.0}_{-4.2} \pm 1.1$	
$B \to K^*\mu^+\mu^-$	$11.7^{+3.6}_{-3.1} \pm 0.9 \pm 0.5$	$12.7^{+7.6}_{-6.1} \pm 1.6$	
$B \to K^*\ell^+\ell^-$	$11.5^{+2.6}_{-2.4} \pm 0.8 \pm 0.2$	$8.8^{+3.3}_{-2.9} \pm 1.0$	11.9 ± 3.9

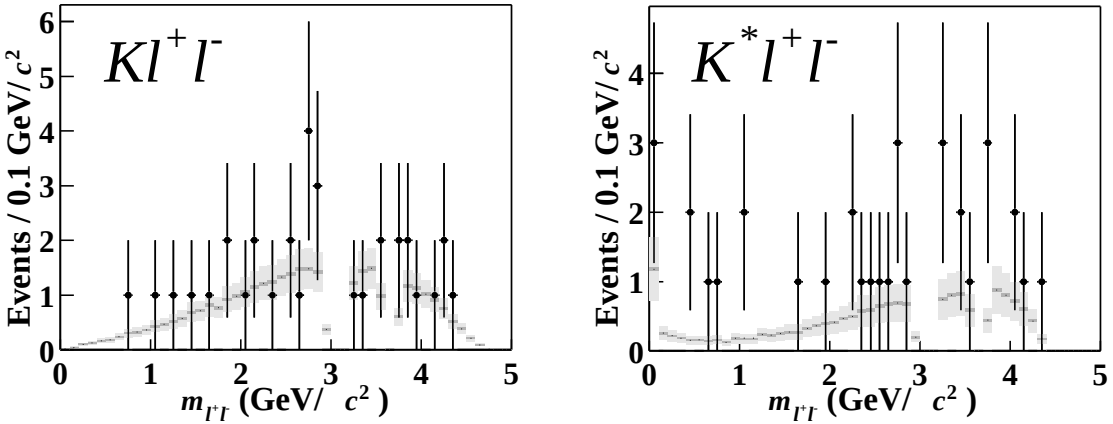
- $\mathcal{B}(B \to K^*\ell^+\ell^-) \equiv \mathcal{B}(B \to K^*\mu^+\mu^-) = 0.75\mathcal{B}(B \to K^*e^+e^-)$ is assumed to compensate $q^2 = 0$ pole in e^+e^-. [A.Ali et al. PRD 66, 034002 (2002)]
- BaBar assumes $\mathcal{B}(B^0 \to K^0\ell^+\ell^-)/\mathcal{B}(B^+ \to K^+\ell^+\ell^-)$ to be 1.085 ± 0.017, while Belle assumes to be 1.0 (similarly for $K^*\ell^+\ell^-$).
- First observation/evidence for $B \to K^*\ell^+\ell^-$.

Submitted to PRL (BaBar: hep-ex/0308042, Belle: hep-ex/0308044)

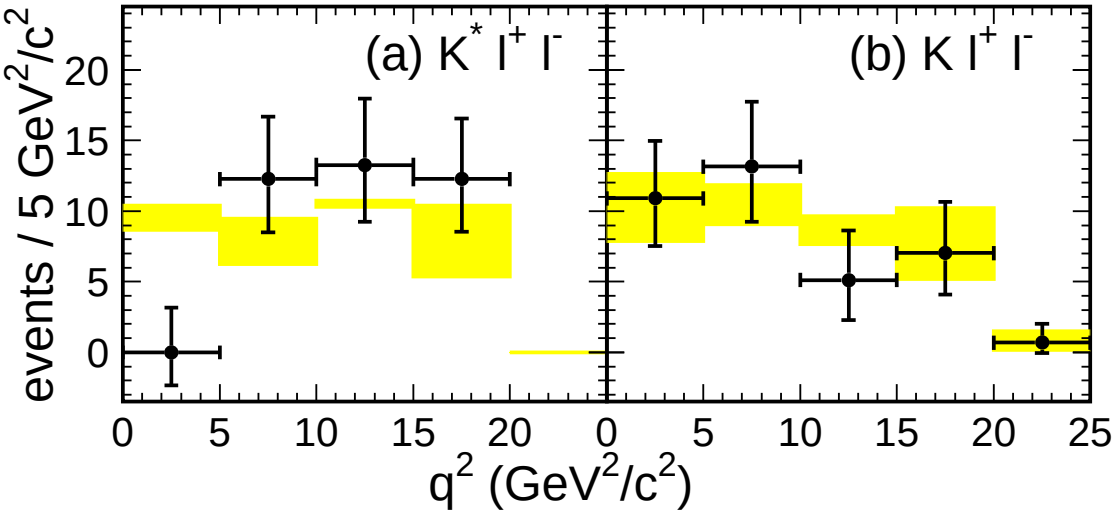
$B \to K\ell^+\ell^-$, $K^*\ell^+\ell^-$

$M(\ell^+\ell^-)$ distribution

BaBar $M(\ell^+\ell^-)$ distribution



Belle $q^2 = M(\ell^+\ell^-)^2$ distribution



- $M(\ell^+\ell^-)$ distribution might be useful to obtain information of New Physics.
- Need more statistics to compare the data and the SM prediction.

Forward-backward asymmetry in $K^*\ell^+\ell^-$, charge asymmetry etc. should be studied with more data.

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

Inclusive $B \to X_s \ell^+ \ell^-$

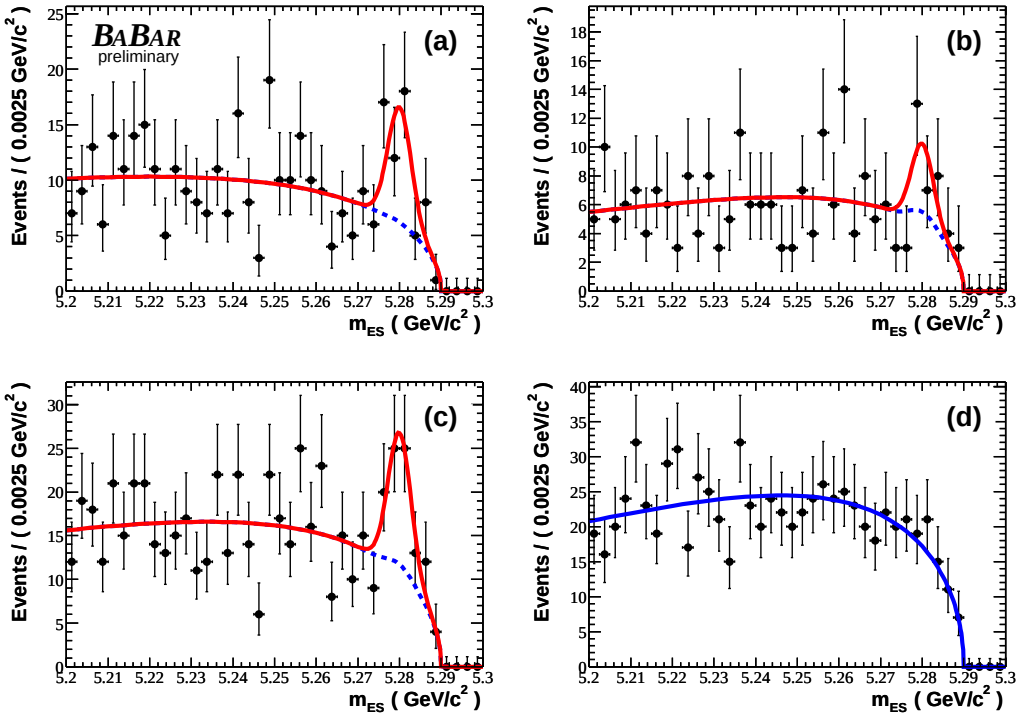
- Smaller theoretical uncertainties than exclusive modes.
- Measurements are more difficult.
- Belle measured the inclusive branching fraction last year using $60\ \mathrm{fb}^{-1}$ data [PRL 90, 021801 (2003)].
- New result from BaBar using $80\ \mathrm{fb}^{-1}$ data!! [hep-ex/0308016]

Analysis (by BaBar [Belle])

- X_s is reconstructed from 1 kaon $+\ 0 \sim 2\ \pi$ [Belle: $0 \sim 4\ \pi$], where up to 1 π^0 is allowed.
  $\Longrightarrow \sim 75\%$ [Belle: 82%] of signals are covered.
- $M(X_s) < 1.8\ \mathrm{GeV}$ [Belle: $M(X_s) < 2.1\ \mathrm{GeV}$]
- Similar selection criteria as exclusive modes.
- $M(\ell^+\ell^-) > 0.2\ \mathrm{GeV}$.

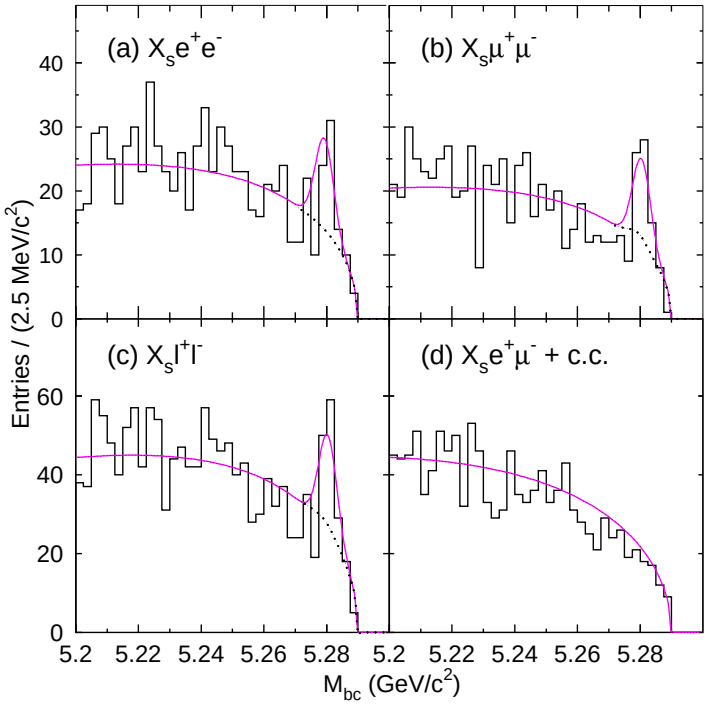
$B \to X_s \ell^+ \ell^-$

BaBar result (New!!) ($80\ \mathrm{fb}^{-1}$)



$41.4 \pm 10.3 \pm 1.5$ events / 4.6σ

Belle result ($60\ \mathrm{fb}^{-1}$)



$60.1 \pm 13.9\,^{+8.6}_{-5.4}$ events / 5.4σ

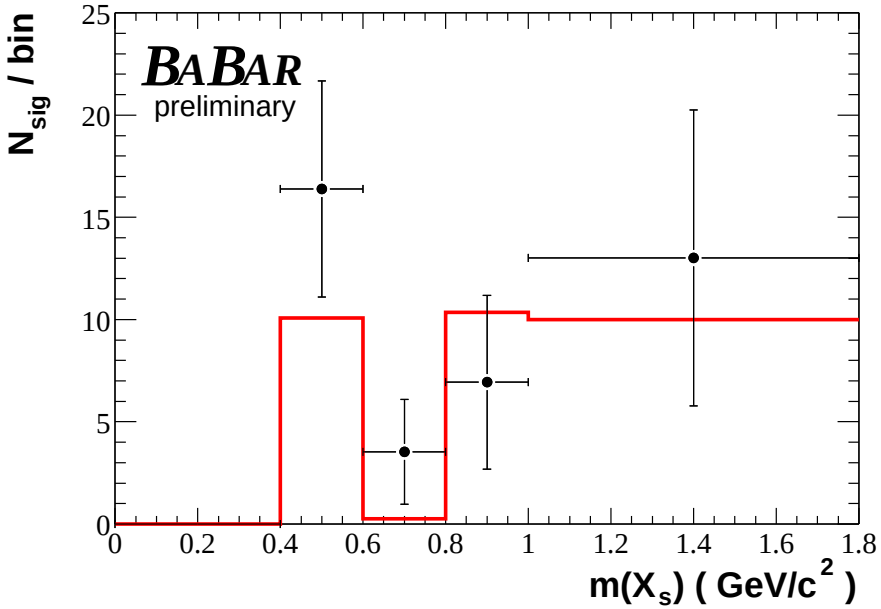
Branching fraction ($\times 10^{-6}$)

Mode	BaBar	Belle
$B \to X_s e^+ e^-$	$6.6 \pm 1.9\,^{+1.9}_{-1.6}$	$5.0 \pm 2.3\,^{+1.3}_{-1.1}$
$B \to X_s \mu^+ \mu^-$	$5.7 \pm 2.8\,^{+1.7}_{-1.4}$	$7.9 \pm 2.1\,^{+2.1}_{-1.5}$
$B \to X_s \ell^+ \ell^-$	$6.3 \pm 1.6\,^{+1.8}_{-1.5}$	$6.1 \pm 1.4\,^{+1.4}_{-1.1}$

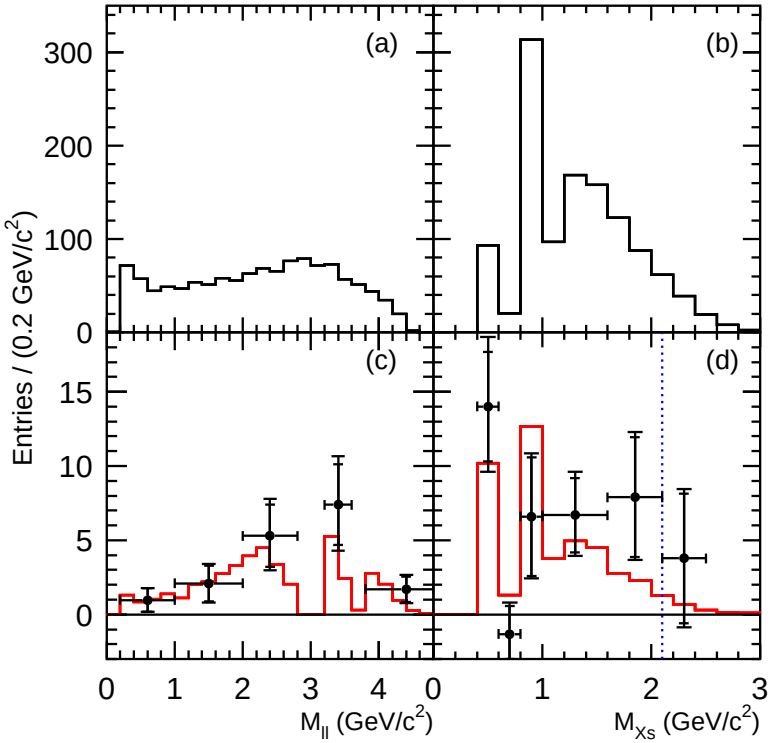
$B \to X_s \ell^+ \ell^-$

$M(X_s)$, $M(\ell^+\ell^-)$ distribution

BaBar

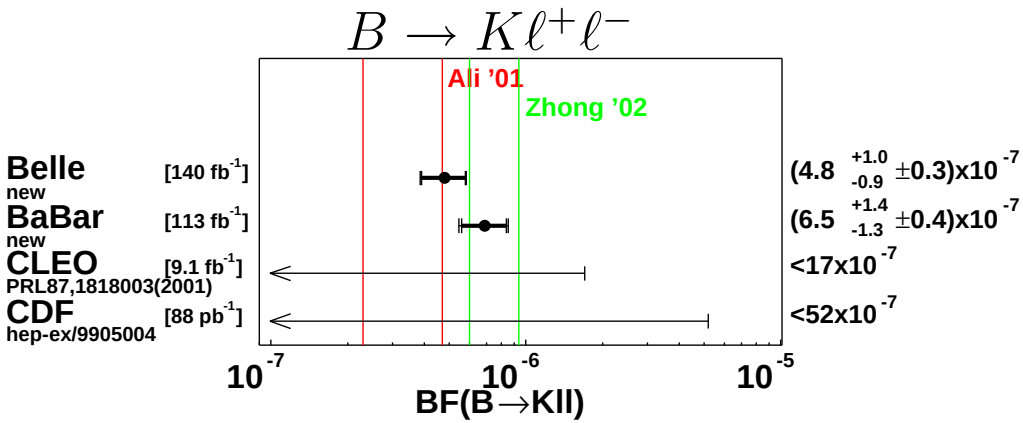


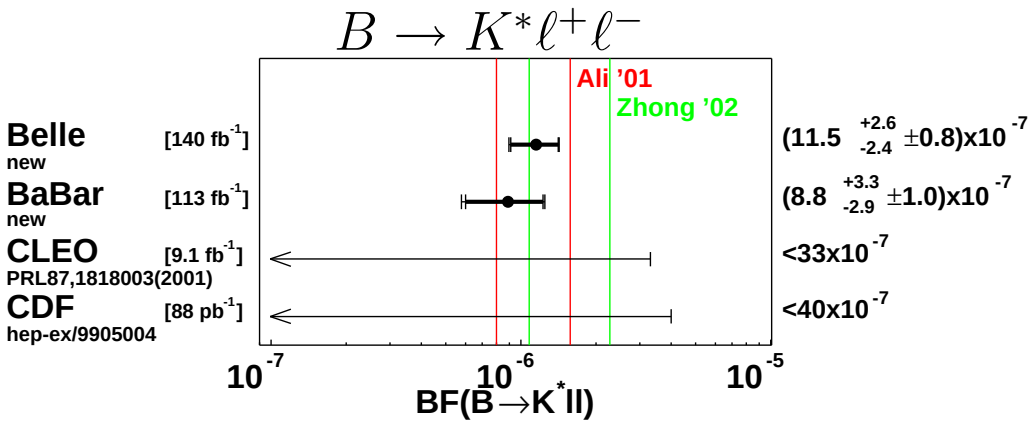
Belle

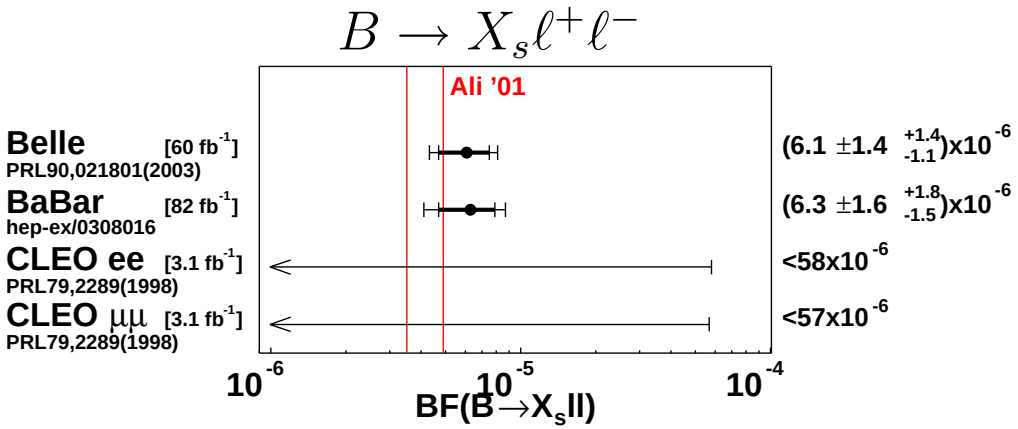


- Consistent with the S.M.
- Need more data.

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







- $B \to K^*\ell^+\ell^-$ is measured.
- No significant deviation from the SM.
- Precise measurement with larger data set is necessary.
  - Branching fraction of $B \to X_s\ell^+\ell^-$
  - Forward-Backward asymmetry.

Summary

Radiative B decays

- Many studies on exclusive $b \to s\gamma$ mode.
- $A_{\rm CP}(B \to X_s\gamma)$: consistent null asymmetry.

Electroweak B decays

- First observation of $B \to K^*\ell^+\ell^-$.
- Updated results on $B \to K\ell^+\ell^-$.
- Measurement of inclusive $B \to X_s\ell^+\ell^-$ branching fraction.

So far, all the results look consistent with the SM expectation.

$b \to s\gamma$ and $b \to s\ell^+\ell^-$ are still important probes to the physics beyond the SM.

- $A_{\rm CP}$, photon helicity in $b \to s\gamma$.
- $b \to d\gamma$.
- B.F., forward-backward asymmetry in $b \to s\ell^+\ell^-$.

Still many programs! Awaiting more data (and more precise calculation).