$B \to \rho (K^*) \gamma$, $b \to d (s) \gamma$

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Flavour Physics and CP Violation

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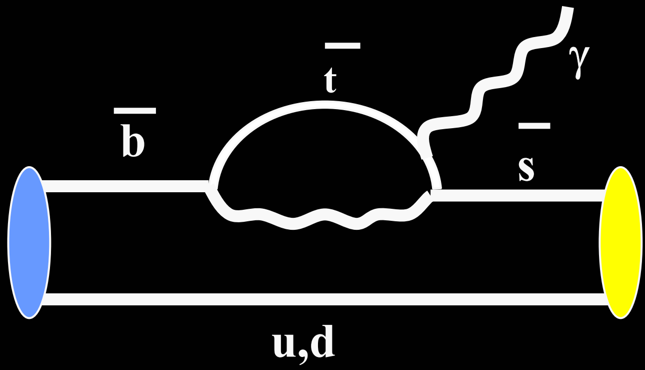
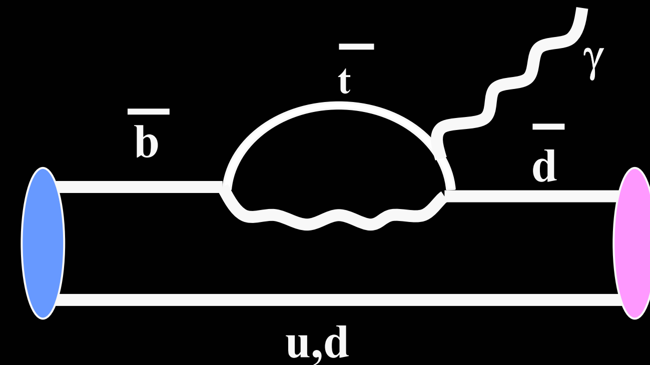
- Results for $b \to s\gamma$
- Results for $B \to K^*(892)\gamma$
- Search for $B \to \rho/\omega\,\gamma$ decays
- Higher K* resonances

Introduction

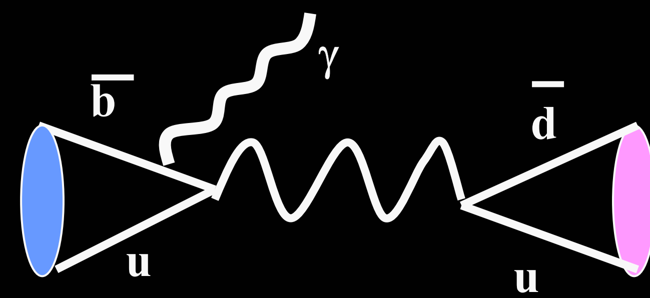


$b \rightarrow s\gamma$ penguin



$b \rightarrow d\gamma$ penguin suppressed by $|V_{td}/V_{ts}|^2$

- Radiative penguin decays are FCNC
- They are an indirect probe for new physics as non Standard Model contributions ($H^{\pm}$, $\chi^{\pm}$, ..) can appear in the loop
- New Physics will affect the Branching Fraction and/or A_{CP}

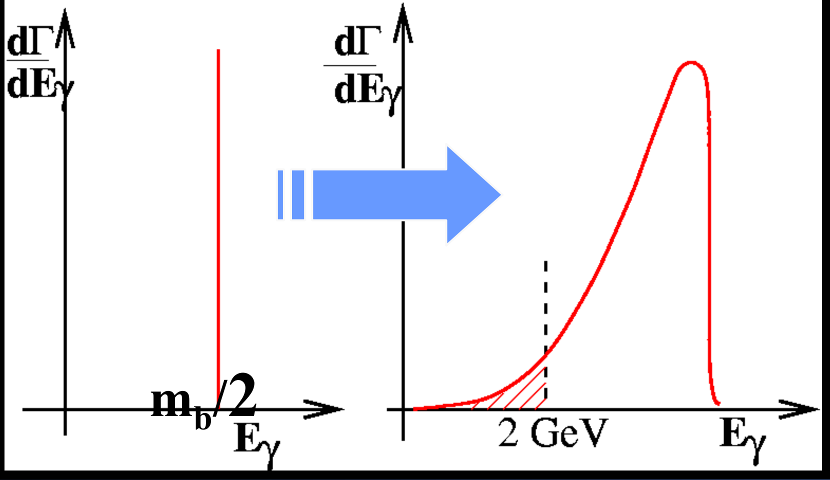


$b \rightarrow d\gamma$ annihilation diagram contributes to $B^{\pm} \rightarrow \rho^{\pm}\gamma$

Introduction (cont'ed)

- **Inclusive final states**: theoretically clean. Treated perturbatively assuming b quark mass large and using **Heavy-Quark Effective Theory (HQET)**
- **Exclusive final states**: large theoretical uncertainties from hadronic form factors

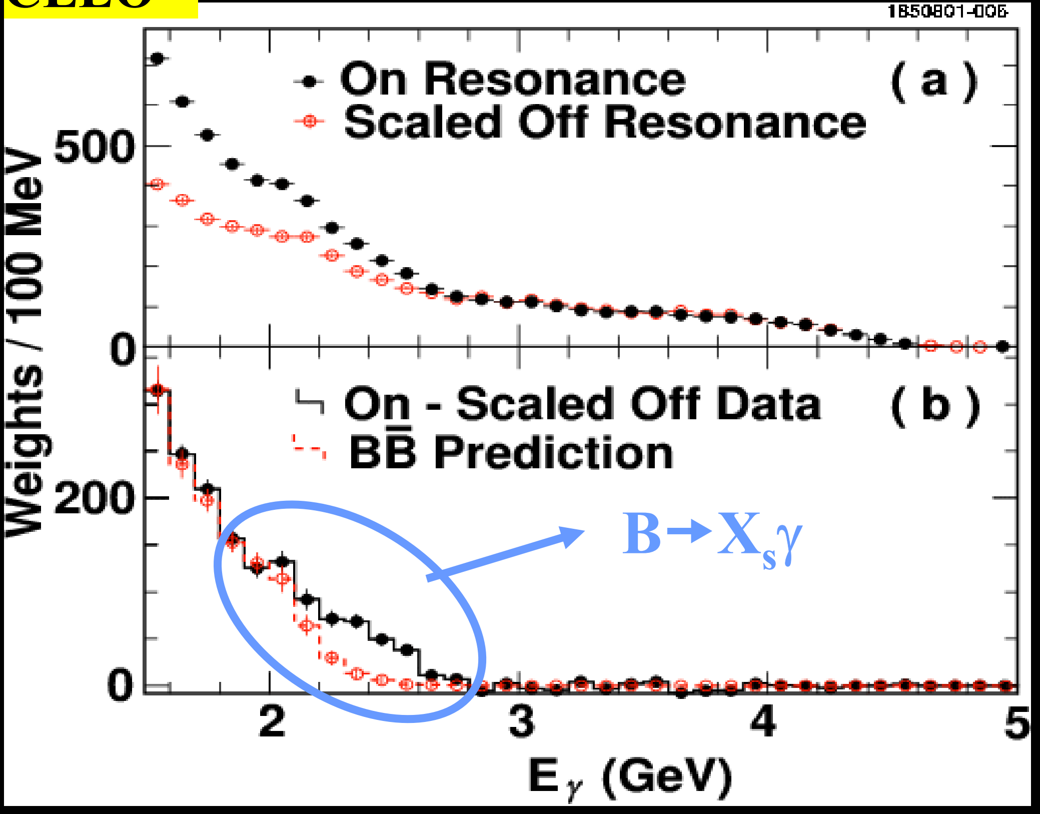
γ Energy Spectrum: No monochromatic γ spectrum because of b quark motion within the B meson



From moments analysis of γ energy spectrum → extraction of HQET parameters:
$\bar{\Lambda}$ = energy of the light degrees of freedom in the B meson
λ_1=average momentum squared of the b quark in the B meson

Inclusive $B \to X_s \gamma$

CLEO



No monochromatic γ spectrum

Experimentally hard to suppress $B\bar{B}$ background at low γ energy

Lower energy cut on the γ energy in all the experimental measurements ➔ theoretical uncertainty

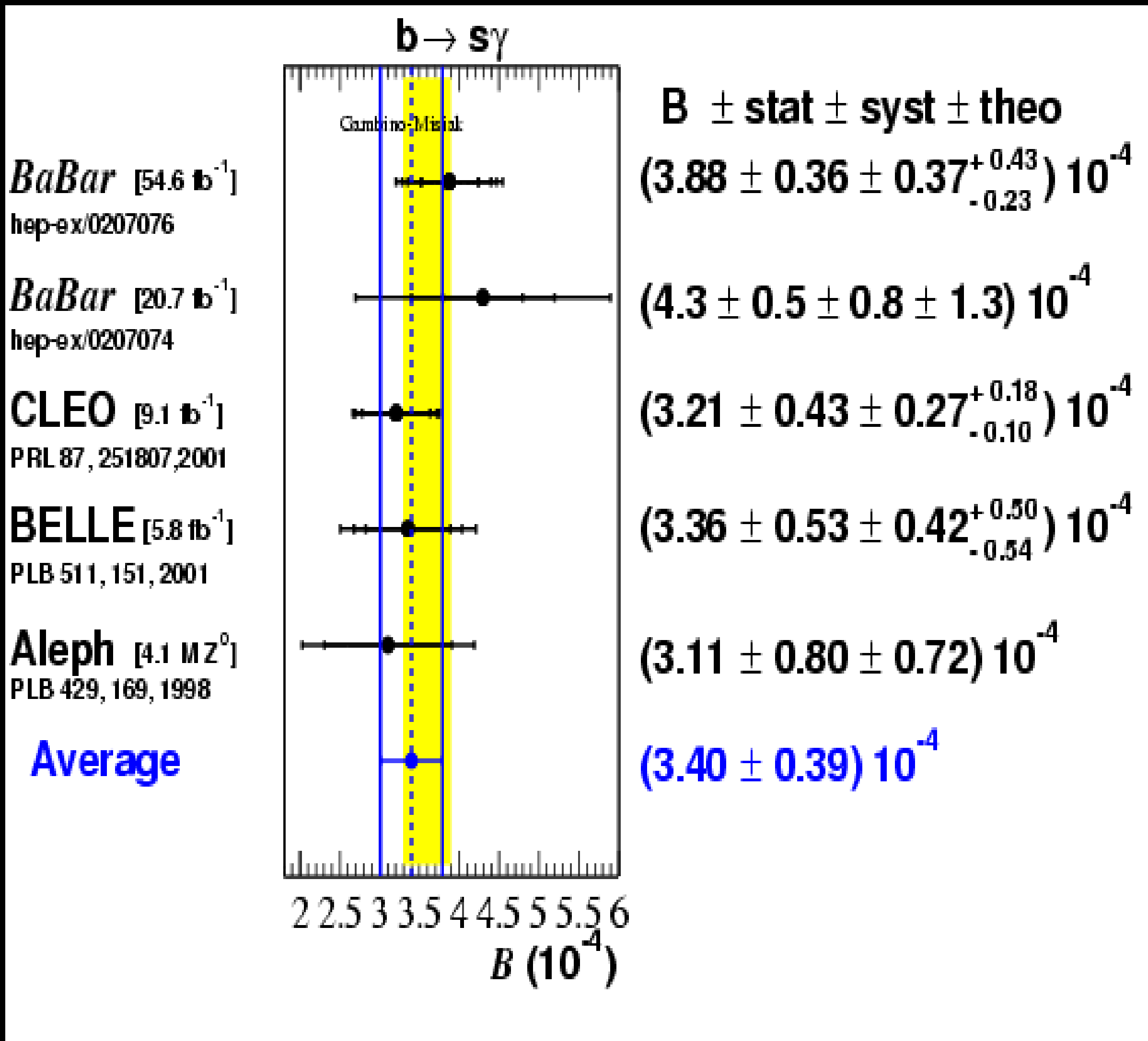
Eg. $E_\gamma > 2$ GeV corresponds to ~ 90% of the whole spectrum

Various Experimental Techniques:

- Sum of exclusive X_s final states, $X_s \to K n\pi m\pi^0$ (BaBar, BELLE)
- Identify γ and suppress background with various techniques (CLEO)
- Identify γ and tag semileptonically the other B (BaBar)

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

This and following averages made by FDL using L.Lyons *et al.*, NIM A270, 110, 1988



Theoretical prediction for $\mathcal{B}(B \to X_s\gamma\ (E_\gamma > 1.6\ \text{GeV})) = (3.60 \pm 0.30) \cdot 10^{-4}$ Gambino, Misiak hep-ph/010434

No consistent treatment of the theoretical errors among the experiments

Average made assuming only theoretical errors correlated

Experimental results consistent with the SM ➔ limits on new physics contributions

Aleph result scaled to expectation at Υ(4S) in making the average

Direct CP asymmetry in $B \to X_s \gamma$

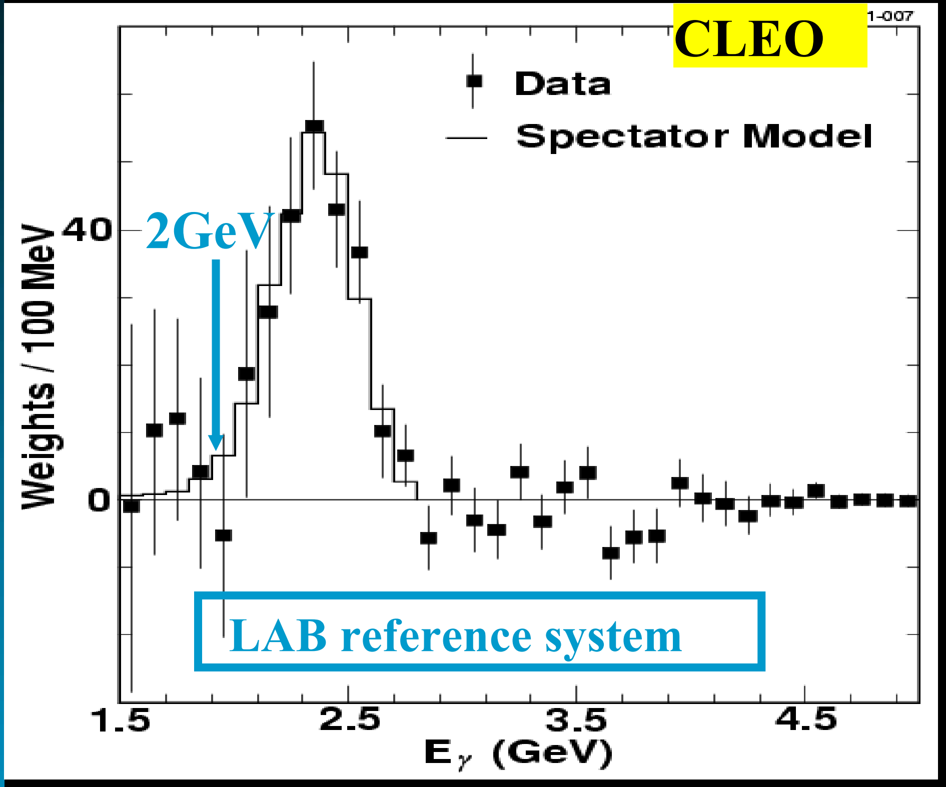
$$A_{CP} = \frac{B(b \to s\gamma) - B(\bar{b} \to \bar{s}\gamma)}{B(b \to s\gamma) + B(\bar{b} \to \bar{s}\gamma)}$$

- **Only a measurement from CLEO, using inclusive and exclusive final states (PRL 86, 5661, 2001), 9.1 fb^{-1}**
- **<u>Inclusive</u> final states: need to flavor tag the other B**
- **<u>Exclusive</u> final states: self-tagging**
- **No distinction between $b \to s\gamma$ and $b \to d\gamma$**

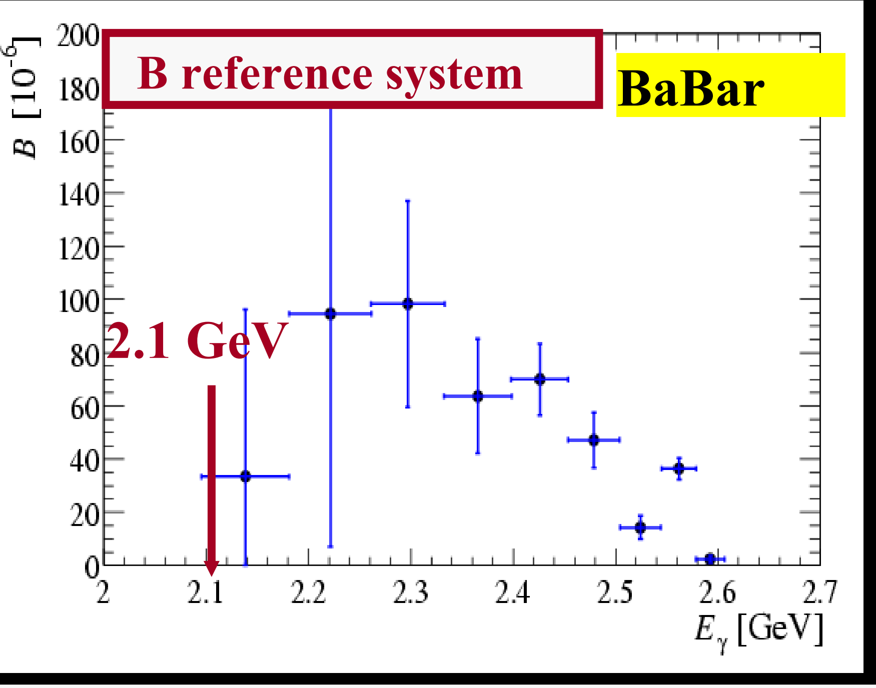
$$A_{CP} = 0.965 * A_{CP}(b \to s\gamma) + 0.02 * A_{CP}(b \to d\gamma) =$$
$$(-0.079 \pm 0.108 \pm 0.22) \cdot (1.0 \pm 0.030)$$

Asymmetry consistent with zero within errors. Very large effects due to new physics are thus already excluded

γ Energy spectrum in $B \to X_s \gamma$



Inclusive analyses need to boost γ from LAB frame to B frame.
Exclusive analyses from M_{Xs} ➔ E_γ in B frame

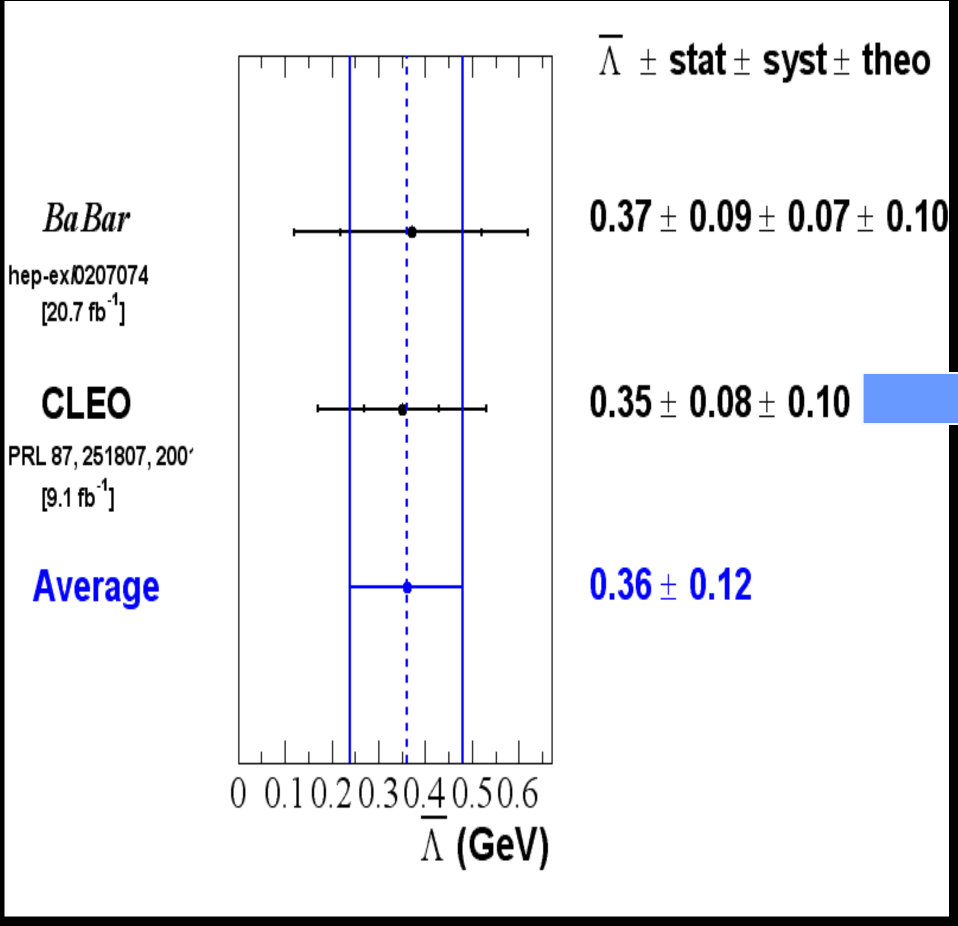


<u>CLEO</u> (PRL 87, 251807, 2001)
$E_\gamma > 2.0$ GeV
$\langle E_\gamma \rangle = 2.346 \pm 0.032 \pm 0.011$ GeV
$\langle E_\gamma^2 \rangle - \langle E_\gamma \rangle^2 =$
$0.0226 \pm 0.0066 \pm 0.0020$ GeV^2

<u>BaBar</u> (hep-ex/0207074)
$E_\gamma > 2.1$ GeV
$\langle E_\gamma \rangle = 2.35 \pm 0.04 \pm 0.04$ GeV

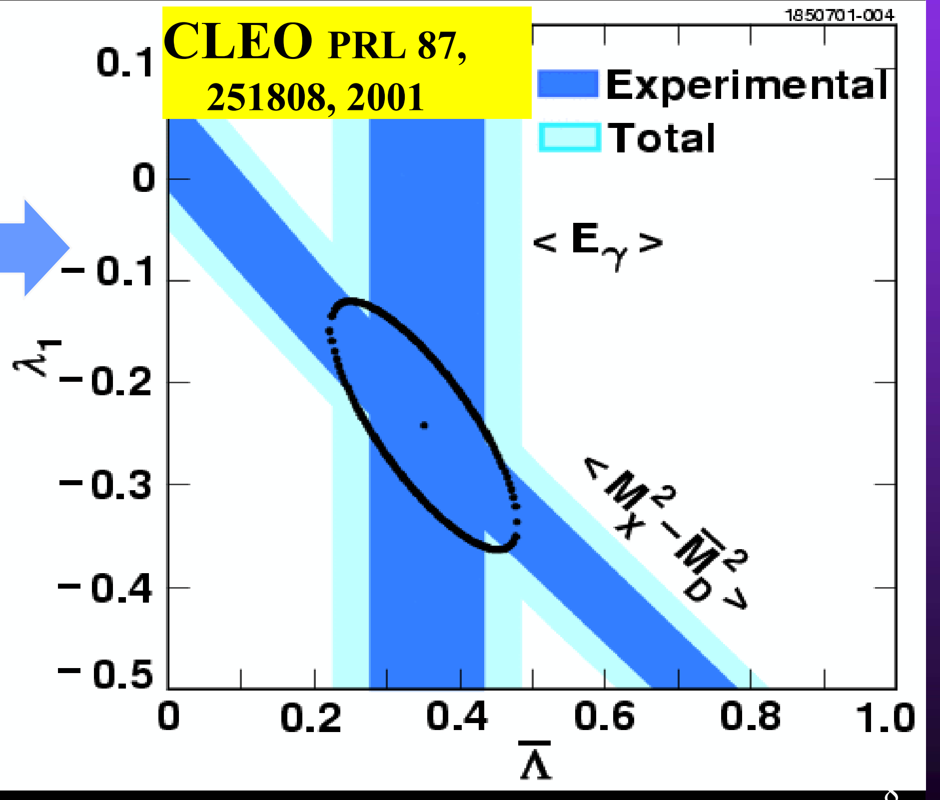
HQET parameters from $B \to X_s\gamma$

$\bar{\Lambda}$ from first E_γ moment
(Ligeti et al. PRD 60, 034019, 1999):

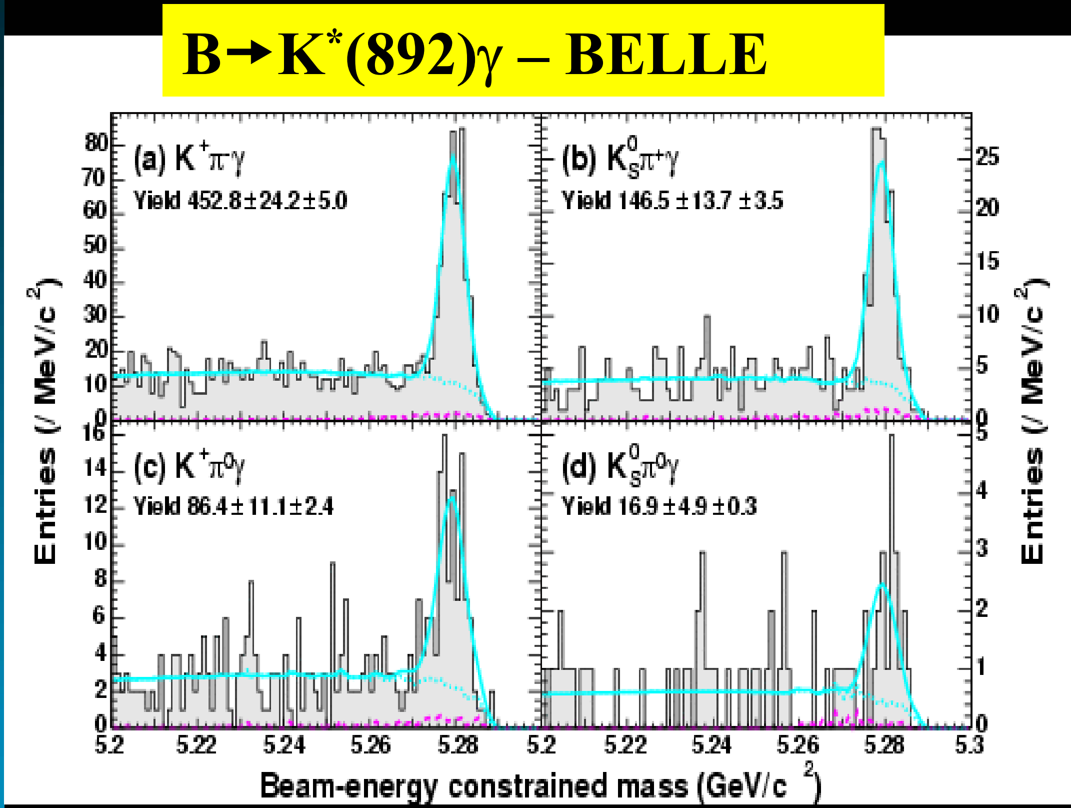


Using the hadronic mass moments in inclusive semileptonic B decays (see M. Artuso's talk):

λ_1 = -0.24 ± 0.11 GeV^2

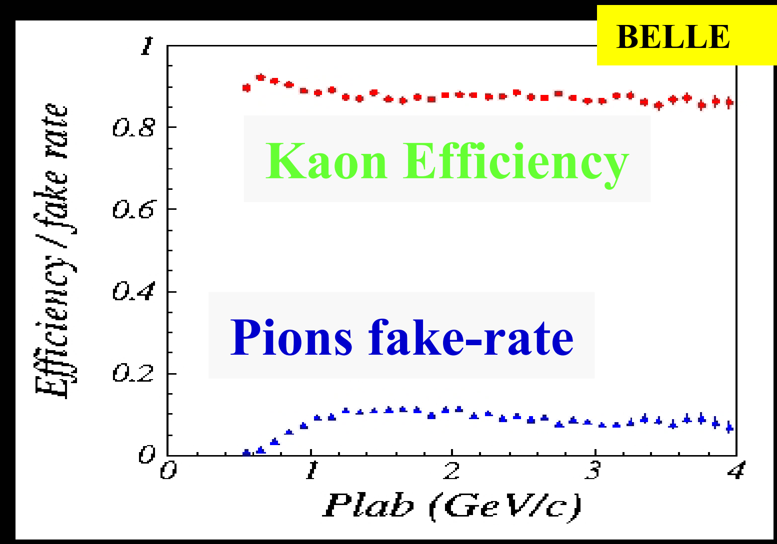


$B \to K^* \gamma$

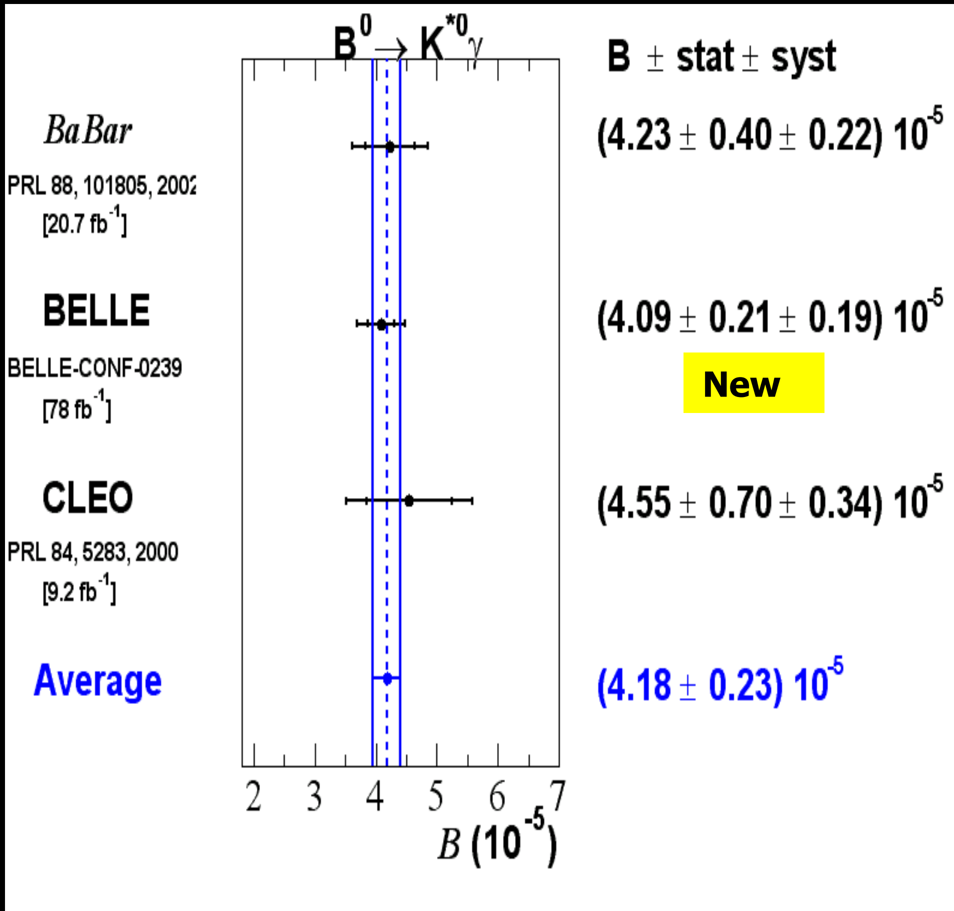


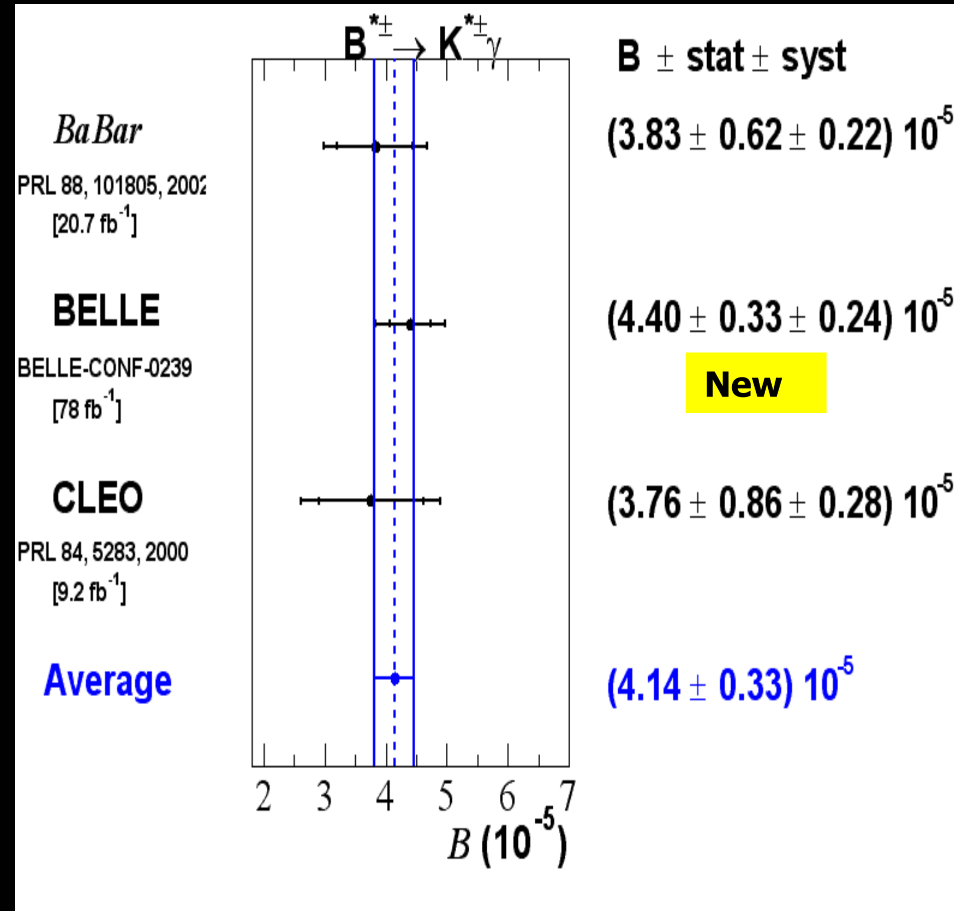
- First observation of $B \to K^*(892)\gamma$ and $B \to K^*_2(1430)\gamma$ by CLEO (1993 and 2000).
- Much higher statistics now. Results close to being systematics limited.
- Measurements of Branching Fractions, CP asymmetries and isospin asymmetry between B^0 and $B^\pm$ decay widths

Kaon ID is important to reduce background



$\mathcal{B}(B \to K^{*}\gamma)$ results





New

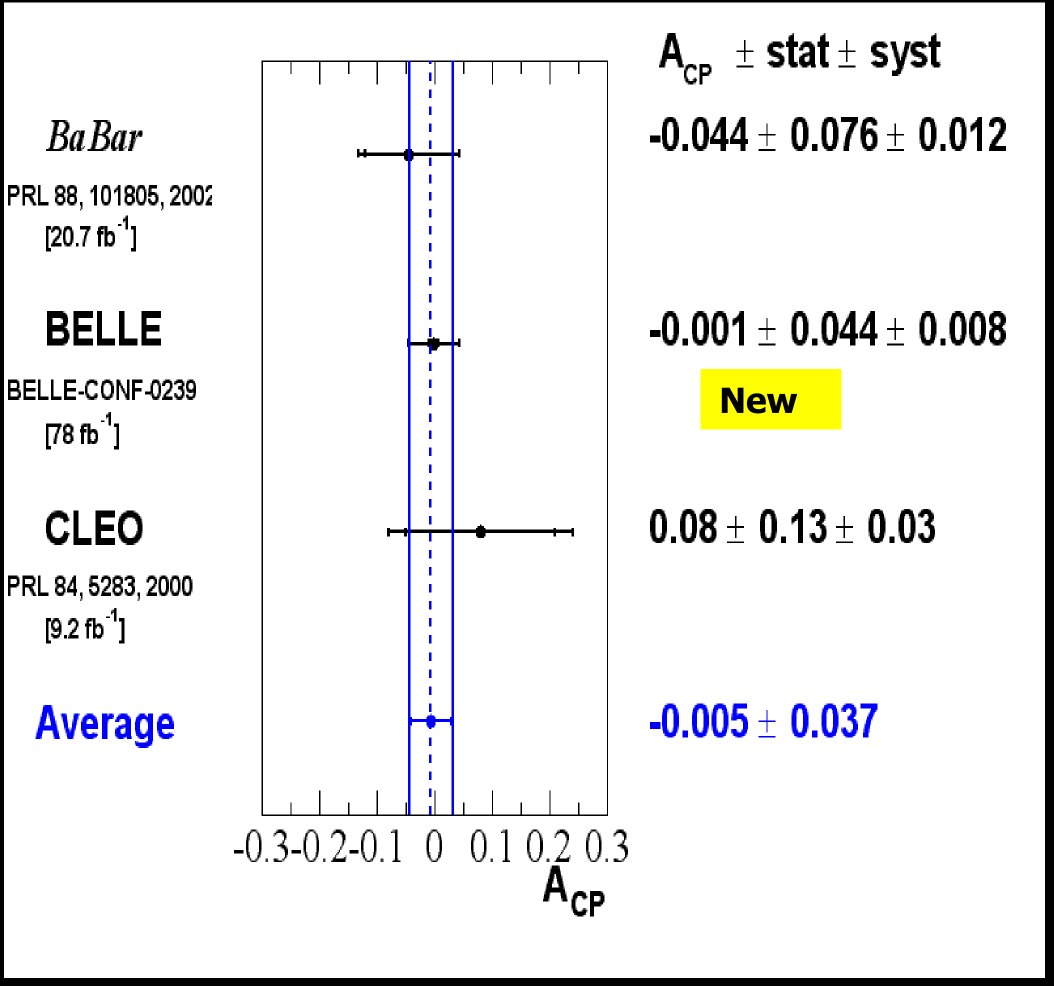
BELLE isospin asymmetry:

$r = \tau_{B\pm}/\tau_{B0} = 1.083 \pm 0.017$

$$\Delta_{0\pm} = \frac{r\mathcal{B}(B^0 \to K^{*0}\gamma) - \mathcal{B}(B^\pm \to K^{*\pm}\gamma)}{r\mathcal{B}(B^0 \to K^{*0}\gamma) + \mathcal{B}(B^\pm \to K^{*\pm}\gamma)} = +0.003 \pm 0.045 \pm 0.018$$

Isospin breaking (Kagan & Neubert hep-ph/0110078) can test Wilson coefficients (C_6/C_7)

Direct CP asymmetry in $B \to K^{*}\gamma$



$$A_{CP} = \frac{B(\bar{B}\to\bar{K}^{*}\gamma) - B(B\to K^{*}\gamma)}{B(\bar{B}\to\bar{K}^{*}\gamma) + B(B\to K^{*}\gamma)}$$

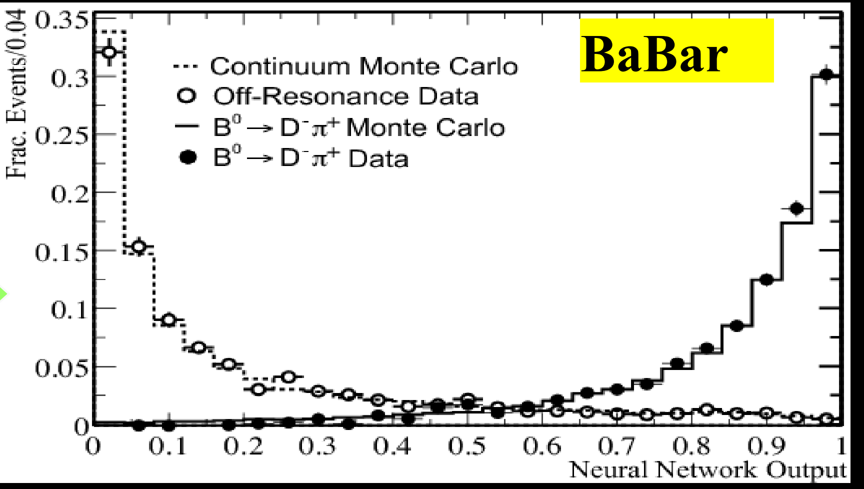
- Measurement with high accuracy!
- Error dominated by statistical uncertainty
- Systematic error mainly due to particle identification asymmetry and background asymmetry. Most of systematic errors present in Branching Fraction measurement cancel in A_{CP} measurement

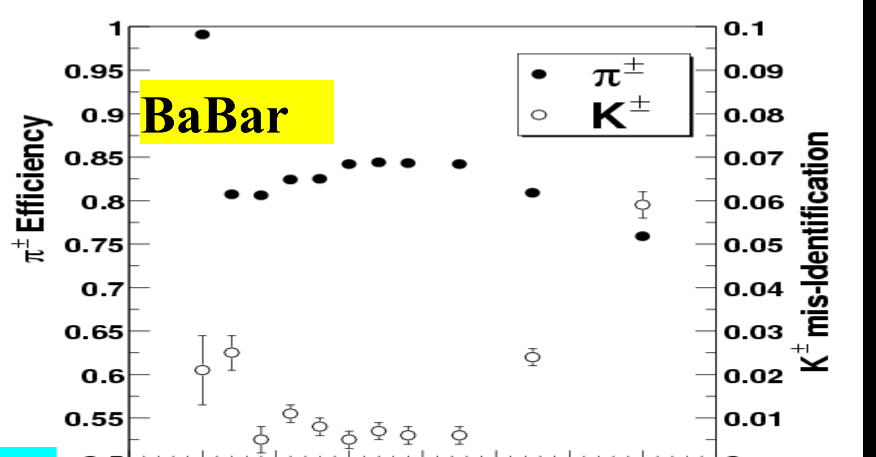
$-0.070 < A_{CP} < 0.053$ @ 90% CL

$B \to \rho/\omega\gamma$

Challenges :

- **Lower branching fraction and higher background than for $B \to K^*\gamma$. Most effective techniques in reducing the background are needed (eg Neural Network)**
- **Feed-through from $K^*\gamma$ has to be removed. Use particle identification to reduce $K \to \pi$ fake rate to ~1%**
- **Irreducible background from $B \to \rho\pi^0$**

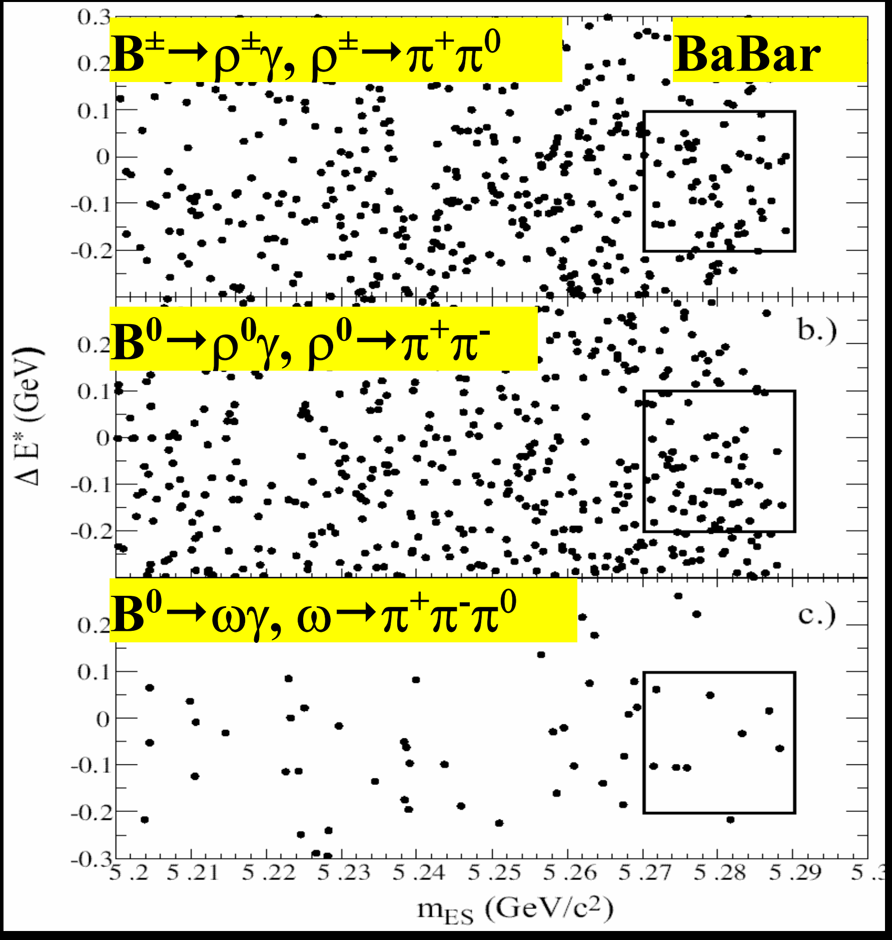


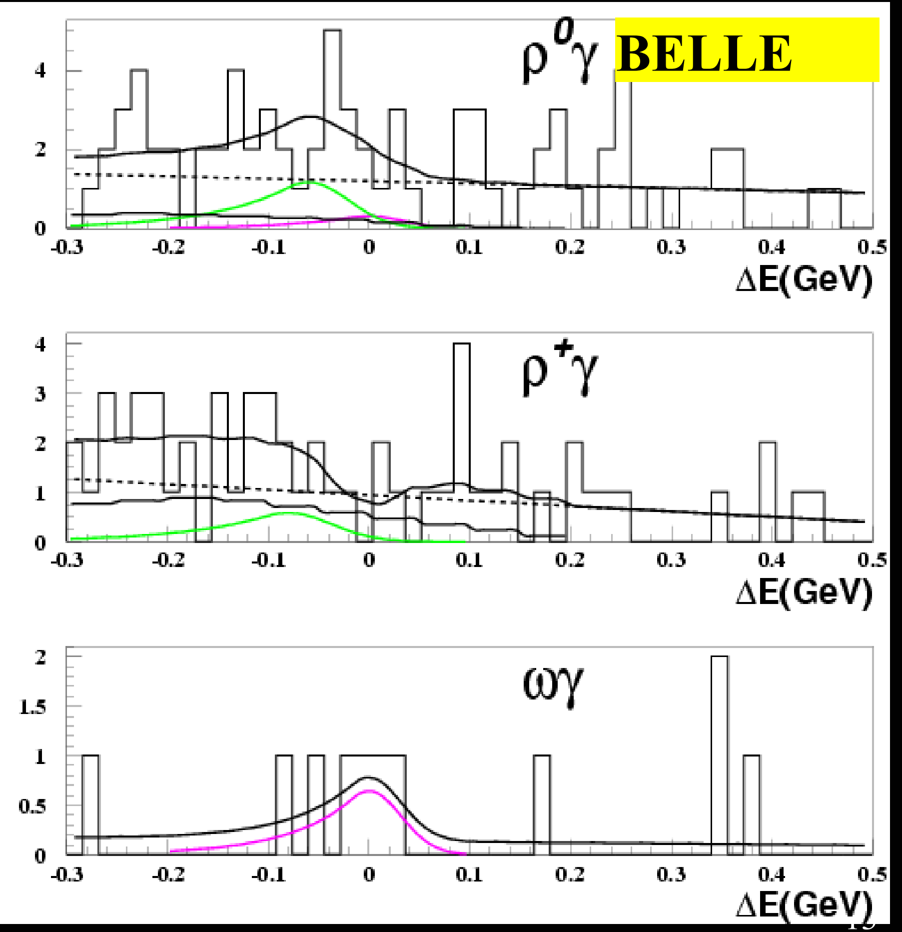


~80% π efficiency with ~1-2% K mis-ID up to ~3 GeV

$B \to \rho/\omega\gamma$

After the selection is applied, there is no evidence of signal (data consistent with expected background)





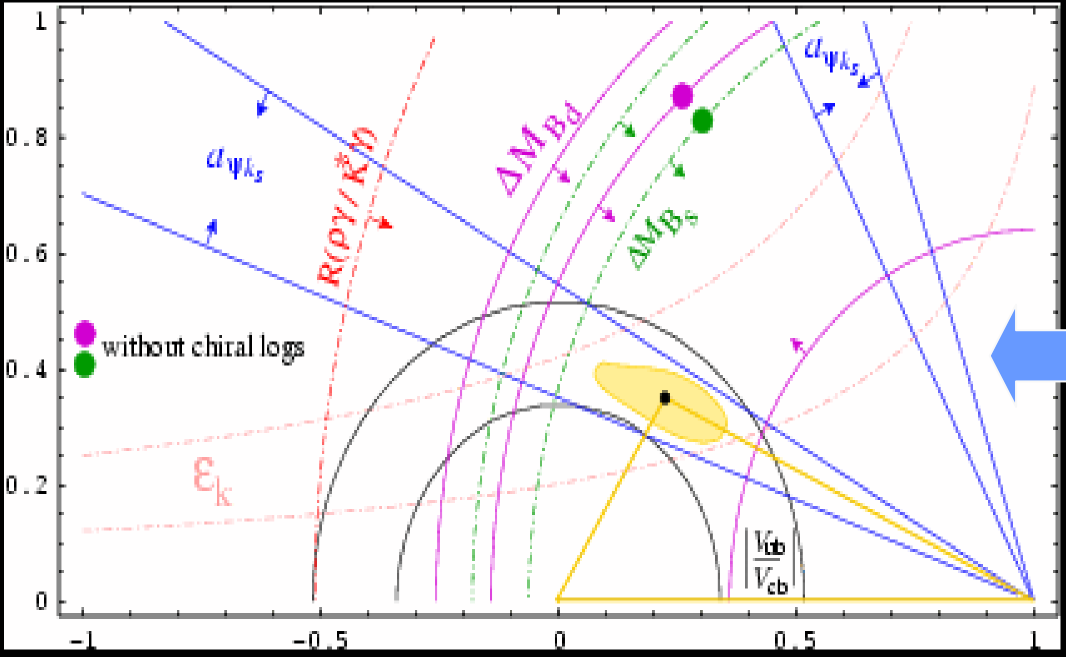
Upper Limits at 90% CL on $\mathcal{B}(B \to \rho/\omega\gamma)$ are set:

	BaBar (Moriond '03) 78 fb^{-1}	BELLE (Moriond '03) 78 fb^{-1}	CLEO (PRL 84, 5283, 00) 9.2 fb^{-1}	Theory (Ali & Parkhomenko) hep-ph/0105203
$\mathcal{B}(B^0 \to \rho^0\gamma)$	$< 1.2 \cdot 10^{-6}$	$< 2.6 \cdot 10^{-6}$	$< 17 \cdot 10^{-6}$	$= (0.49 \pm 0.18) \cdot 10^{-6}$
$\mathcal{B}(B^\pm \to \rho^\pm\gamma)$	$< 2.1 \cdot 10^{-6}$	$< 2.7 \cdot 10^{-6}$	$< 13 \cdot 10^{-6}$	$= (0.90 \pm 0.34) \cdot 10^{-6}$
$\mathcal{B}(B^0 \to \omega\gamma)$	$< 1.0 \cdot 10^{-6}$	$< 4.4 \cdot 10^{-6}$	$< 9.2 \cdot 10^{-6}$	$= (0.49 \pm 0.18) \cdot 10^{-6}$

Limits on $|V_{td}/V_{ts}|$

- Using $B \to K^{*}\gamma$ and $B \to \rho\gamma$, limits on $|V_{td}/V_{ts}|$ can be set
- Assuming isospin symmetry $\mathcal{B}(B \to \rho\gamma) = \mathcal{B}(B^{\pm} \to \rho^{\pm}\gamma) = 2 \cdot \mathcal{B}(B^{0} \to \rho^{0}\gamma)$ we obtain an upper limit $\mathcal{B}(B \to \rho\gamma) < 1.9 \cdot 10^{-6}$
- $\mathcal{B}(B \to \rho\gamma) / \mathcal{B}(B \to K^{*}\gamma) < 0.047$ @ 90% CL

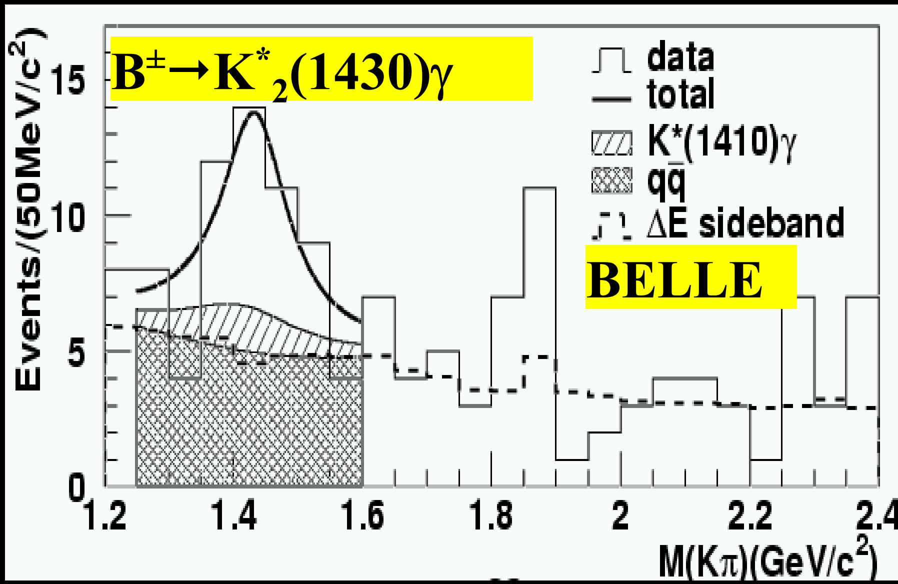
BaBar



Ali & Parkhomenko
Eur. Phys. J C23, 89, 2002

Ali & Lunghi
Eur. Phys. J C26, 195, 2002

Higher K* resonances



Ultimate goal is to track down all the resonances which contribute to the $b\to s\gamma$ spectrum!

$\mathcal{B}(B\to K^*_2(1430)\gamma)$

BELLE	$(1.5^{+0.6}_{-0.5}\pm 0.1)\cdot 10^{-5}$
CLEO	$(1.66^{+0.59}_{-0.53}\pm 0.13)\cdot 10^{-5}$
Average	$(1.58\pm 0.39)\cdot 10^{-5}$

90% CL limits on other resonances

- $\mathcal{B}(B\to K_1(1270)\gamma) < 8.7\cdot 10^{-5}$
- $\mathcal{B}(B\to K_1(1400)\gamma) < 4.6\cdot 10^{-5}$
- $\mathcal{B}(B\to K^*(1410)\gamma) < 6.2\cdot 10^{-5}$

Help from helicity distributions to distinguish the resonances

Results from BELLE (PRL 89, 231801, 2002), 29.4 fb^{-1}, and CLEO (PRL 84, 5283, 2000), 9.2 fb^{-1}

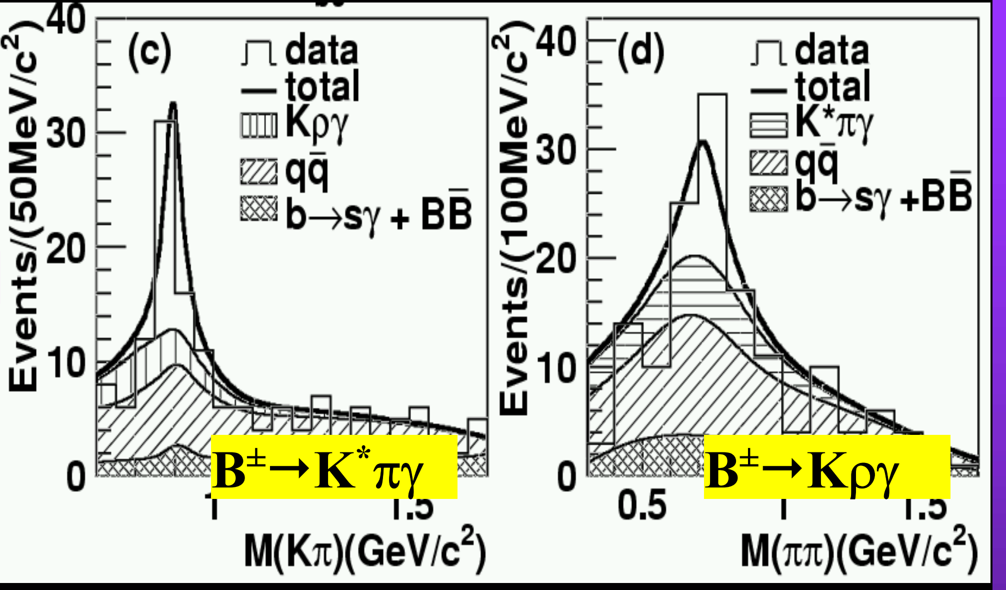
Higher mass systems

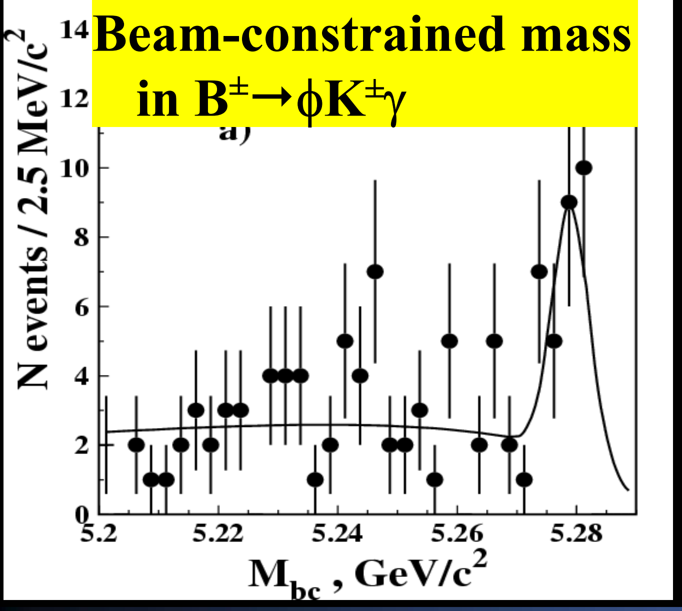
BELLE (PRL 89, 231801, 2002), 29.4 fb^{-1}

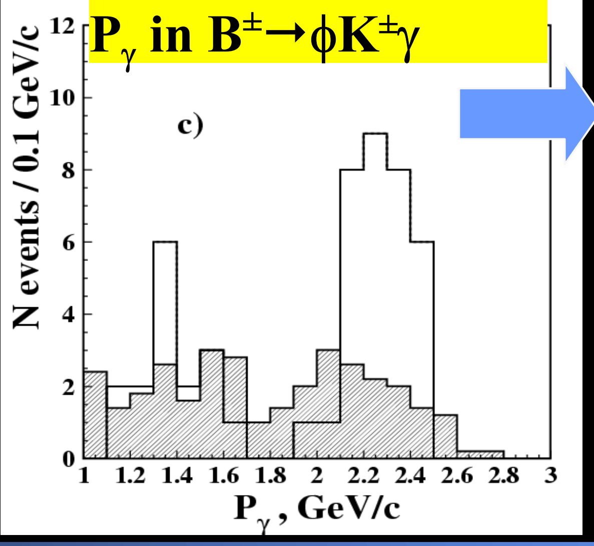
$\mathcal{B}(B \to K^{*}\pi\gamma) = (3.1 \pm 1.0)\cdot 10^{-5}$

$\mathcal{B}(B \to K\rho\gamma) = (3.0 \pm 1.6)\cdot 10^{-5}$

~ 1/3 $\mathcal{B}(B \to X_s\gamma)$ due to $K^{*}\gamma + K^{*}_{2}(1430)\gamma + K^{*}\pi\gamma + K\rho\gamma$







NEW result from BELLE, 90 fb^{-1}

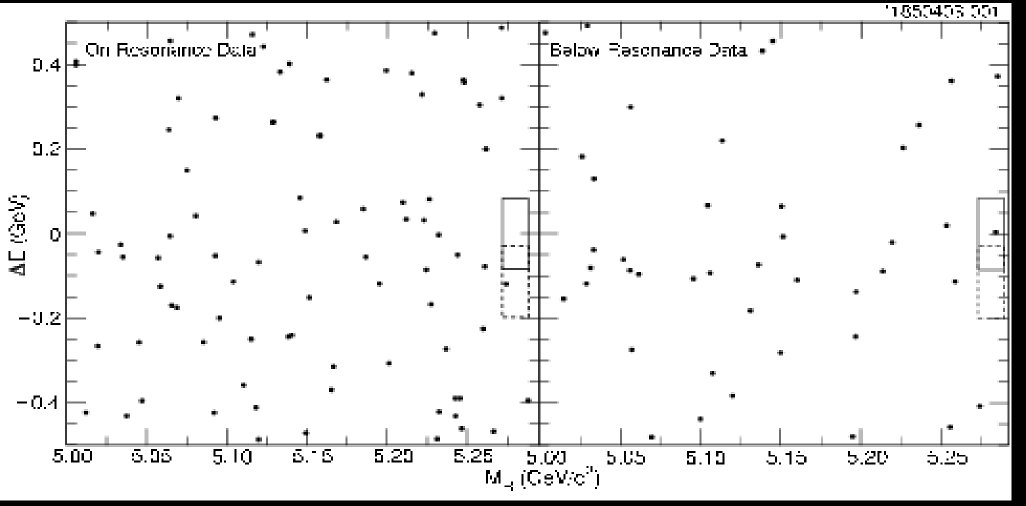
$\mathcal{B}(B^{\pm} \to K^{\pm}\phi\gamma) = (3.4 \pm 0.9 \pm 0.4)\cdot 10^{-6}$

(5.5σ significance)

$\mathcal{B}(B^{0} \to K^{0}\phi\gamma) < 8.3\cdot 10^{-6}$ @ 90%CL

Baryonic final states

CLEO (hep-ex/0305005), 9.1 fb^{-1}



Search for $\mathcal{B}(B \to \Lambda \bar{p} \gamma)$ and $\mathcal{B}(B \to \Sigma^0 \bar{p} \gamma)$] motivated by possible sizable rate for $b \to s\gamma$ with baryons

$$[\mathcal{B}(B \to \Lambda \bar{p} \gamma) + 0.3 \cdot \mathcal{B}(B \to \Sigma^0 \bar{p} \gamma)]_{E\gamma > 2.0\ GeV} < 3.3 \cdot 10^{-6}$$
$$[\mathcal{B}(B \to \Sigma^0 \bar{p} \gamma)] + 0.4 \cdot \mathcal{B}(B \to \Lambda \bar{p} \gamma)]_{E\gamma > 2.0\ GeV} < 6.4 \cdot 10^{-6}$$

Limits are @ 90% CL

$$\mathcal{B}(B \to X_s\gamma,\ X_s \text{ containing baryons})_{E\gamma > 2.0\ GeV} < 3.8 \cdot 10^{-5}$$

Upper limits on the baryonic contribution to the results from CLEO (PRL 87, 251807, 2001) on $B \to X_s\gamma$ are:
$\sim 6.5\% \cdot \mathcal{B}(B \to X_s\gamma)$, $6.5\% \cdot \langle E_\gamma \rangle$, $\sim 36\% \cdot (\langle E_\gamma^2 \rangle - \langle E_\gamma \rangle^2)$

Conclusions

- Precise measurements in $b \to s\gamma$
  - Branching Fractions (➔limits on new physics):
    - $\mathcal{B}(b \to s\gamma) = (3.40 \pm 0.39) \cdot 10^{-4}$
    - $\mathcal{B}(B^0 \to K^{*0}\gamma) = (4.18 \pm 0.23) \cdot 10^{-5}$, $\mathcal{B}(B^\pm \to K^{*\pm}\gamma) = (4.14 \pm 0.33) \cdot 10^{-5}$
    - limits on other resonances and higher mass systemms➔ narrowing down all the $b \to s\gamma$ resonant spectrum
  - CP asymmetries (➔limits on new physics):
    - $A_{CP}(b \to s\gamma) = (-.079+-0.108+-0.022) \cdot (1.0 \pm 0.030)$
    - $A_{CP}(B \to K^*\gamma) = (-0.005 \pm 0.037)$
  - Moments are used to extract HQET parameters:
    - $\overline{\Lambda} = (0.36 \pm 0.12)$ GeV
  - Looking, but still waiting, for $b \to d\gamma$! Limits at 90% CL:
  - $\mathcal{B}(B^0 \to \rho^0\gamma) < 1.2 \cdot 10^{-6}$, $\mathcal{B}(B^\pm \to \rho^\pm\gamma) < 2.1 \cdot 10^{6}$, $\mathcal{B}(B^0 \to \omega\gamma) < 1.0 \cdot 10^{-6}$
- More data is coming: ~130-150fb^{-1} at BaBar and Belle in the summer!
- Eagerly looking forward to more precise measurements and discovery of $b \to d\gamma$!