Radiative B Decays at CLEO

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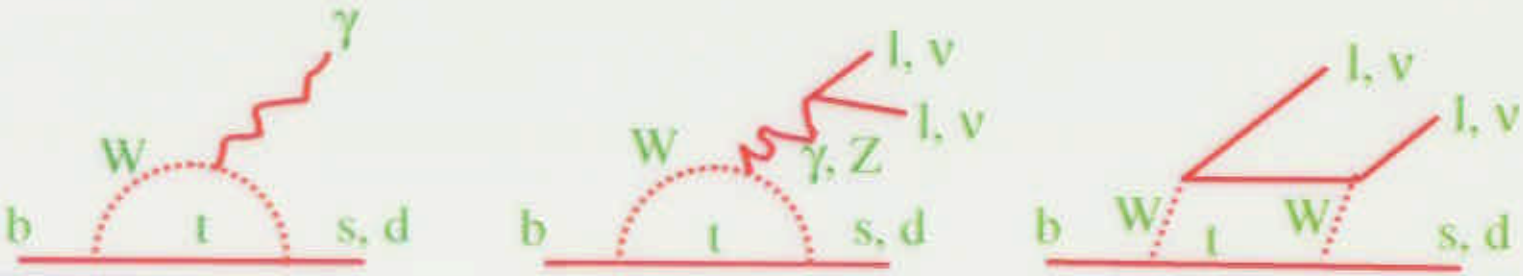
Why EW Penguins

- FCNCs forbidden by SM at tree level (GIM mechanism)
- Loop diagrams at higher level ("penguins" and "box") can generate effective FCNCs: $b \to s$ and $b \to d$



- SM $Br(b \to s, d)$ depend on t, W, Z
- Deviations from SM $Br(b \to s, d)$ ⇒ non-SM physics ($H^{\pm}$, SUSY)

$Br(b \to s, d)$: low-energy tool for probing higher energy non-SM physics

CLEO Experimental Strategy

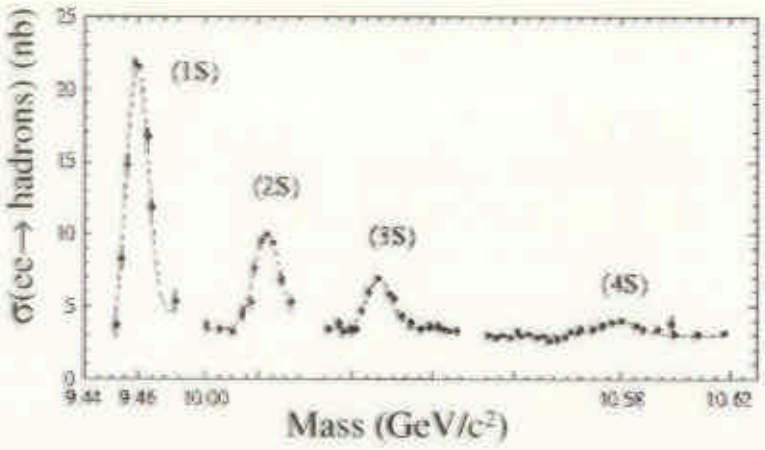
- Symmetric e+e− collider at $\sqrt{s} \approx 10.58$ GeV ($\Upsilon(4S)$)

  $p_B \sim 300$ MeV

- 2/3 at $\sqrt{s} = \Upsilon(4S)$ for $B\bar{B}$ production (9.6 fb^{-1})

- 1/3 at $\sqrt{s} \approx \Upsilon(4S) - 60$ MeV to study continuum

  $e^+e^- \rightarrow q\bar{q}$ (q = u, d, s, c) (4.4 fb^{-1})



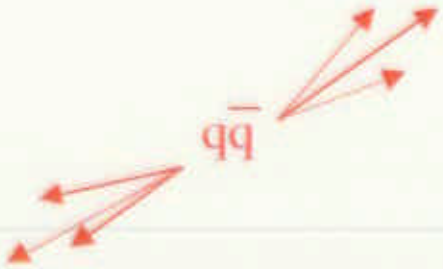
- $\int L\sigma\, dt = 14$ fb^{-1} ⇛ 9.7 x 10^6 $B\bar{B}$ pairs

- Key analysis variables:

  $\Delta E = E_B - E_{beam}$

  $M(B) = [E^2_{beam} - p^2_B]^{1/2}$

- $q\bar{q}$ v. BB event shapes:



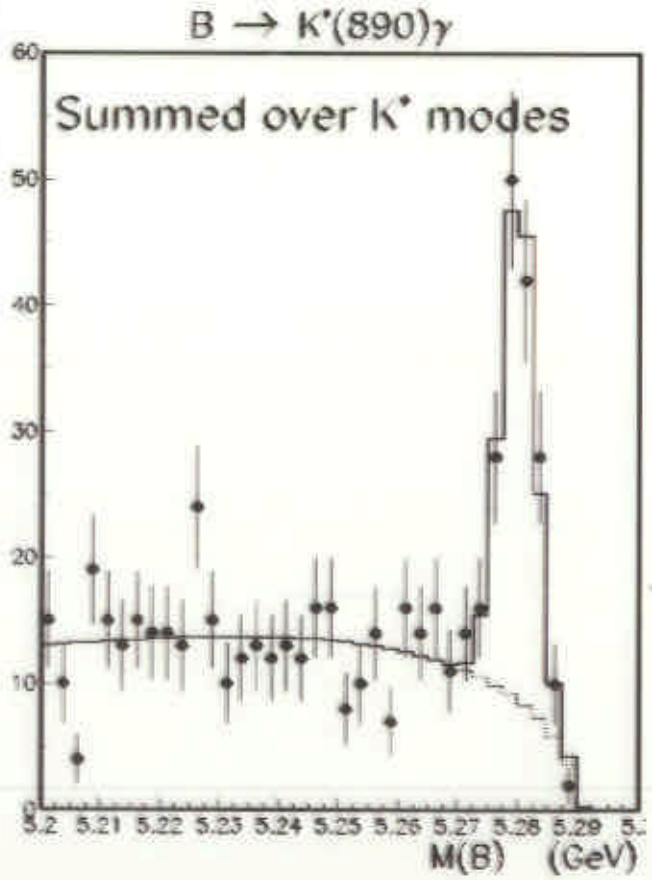
Exclusive $B \to K^*\gamma$

- Continuation of $B \to K^*\gamma$ previous studies [PRL, **71**, 674 (1993)]
- $K^*(890) \to K\pi$ ($Br = 100\ \%$)
  - $\to K^{\pm}\pi^{\pm}$, $K_S^0\pi^0$, $K^{\pm}\pi^0$, $K_S^0\pi^{\pm}$
- M($K\pi$) consistent w/ $K^*(890)$ (no nearby resonances)
- M($K\pi\gamma$) consistent w/ B decay using ΔE and M(B)
- Major BKG from ($e^+e^- \to q\bar{q}$, q = u, d, s, c) events w/ ISR or $e^+e^- \to (\pi^0, \eta)\, X$ w/ $\pi^0, \eta \to \gamma\gamma$.
- BKG suppressed by event shape and π^0, η vetoes

$Br(\ B^0 \to K^{*0}\gamma\ ) = (4.5 \pm 0.7 \pm 0.3) \times 10^{-5}$

$Br(\ B+ \to K^{*+}\gamma\ ) = (3.8 \pm 0.9 \pm 0.3) \times 10^{-5}$

[PRL **84** 5283 (2000)]



Search for Direct CPV in $B \to K^*\gamma$

$$A_{CP} \equiv \frac{Br(\mathrm{b}) - Br(\overline{\mathrm{b}})}{Br(\mathrm{b}) + Br(\overline{\mathrm{b}})}$$

$Br(\mathrm{b}) \sim \mathrm{B}^-, \overline{B}^0 \to K^*\gamma$

$Br(\overline{\mathrm{b}}) \sim \mathrm{B}^+, B^0 \to K^*\gamma$

- Use self-tagging K^* decay modes: $K^* \to K^+\pi^-, K^+\pi^0, K_S{}^0\pi+$
- Mistag rate non-zero for $K^+\pi^-$ mode only when $p_\pi \approx p_K$
  - Require $|p(K) - p(\pi)| > 0.5$ GeV/c
- Systematic $|\Delta A_{CP}|$ from detector/recon. induced Q asymmetries and feed across "small"

$$A^0_{CP} = -0.13 \pm 0.17$$

$$A^\pm_{CP} = +0.38 \pm 0.20$$

Summed: $A_{CP} = +0.08 \pm 0.13 \pm 0.03$

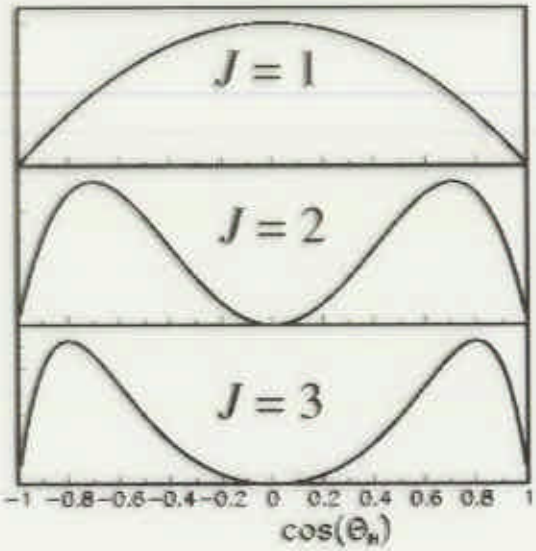
Heavier K^* Resonances

- High statistics in $B \to K^*\gamma$ mode permits searches for heavier resonances.

$Br(K_2^*(1430) \to K\pi) = 50 \pm 1\%$ w/ $\Gamma \sim 100$ MeV

$Br(K^*(1410) \to K\pi) = 7 \pm 1\%$ w/ $\Gamma \sim 230$ MeV

(PDG '98, '99)

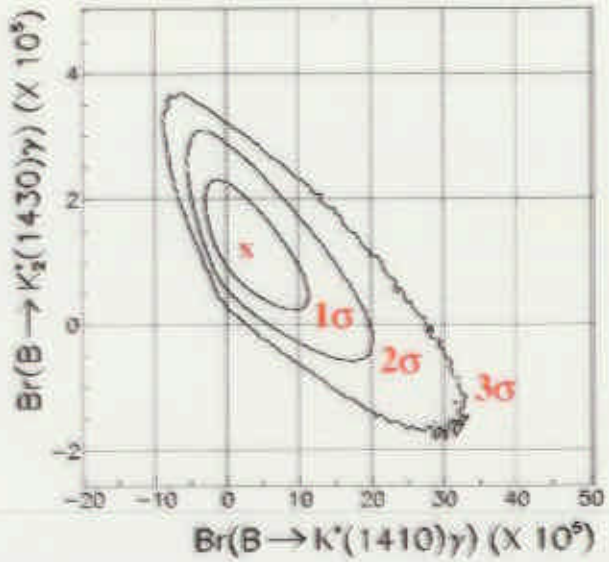


- Modes differ by their helicity Θ_H distribution.
- Fit for both $K^*(1430)$ and $K^*(1410)$ simultaneously:

$Br(B \to K_2^*(1430)\gamma) = (1.7 \pm 0.6 \pm 0.1) \times 10^{-5}$

$Br(B \to K^*(1410)\gamma) < 12.7 \times 10^{-5}$ @ 90 % CL

$R \equiv Br(B \to K^*(1430)\gamma)/Br(B \to K^*(890)\gamma) = 0.4 \pm 0.1$



- Favors relativistic form factors, $R = 0.4 \pm 0.2$

  Veseli and Olsson, *Phys Lett.* **B367** 309 (1995)

- Disfavors non-relativistic form factors, $R = 3.0 - 4.9$

  Ali, Ohl and Mannel, *Phys Lett.* **B298** 195 (1993)

Search for $b \to d\gamma$

- $Br(B \to \rho\gamma)$ and $Br(B \to \omega\gamma)$ can limit $|V_{td}/V_{ts}|$:

  $R \equiv Br(B \to \rho(\omega)\gamma)/Br(B \to K^*\gamma) = \xi\,|V_{td}/V_{ts}|^2$ w/ $\xi = 0.6 - 0.8$

- $Br(B \to \rho\gamma)$ BKG from qq and $K^*\gamma$ w/ $K^{\pm}/\pi^{\pm}$ misid from dE/dx.

- $Br(B \to \omega\gamma)$ BKG from qq only.

$Br(B^0 \to \rho^0\gamma) < 1.7 \times 10^{-5}$ @ 90 % CL

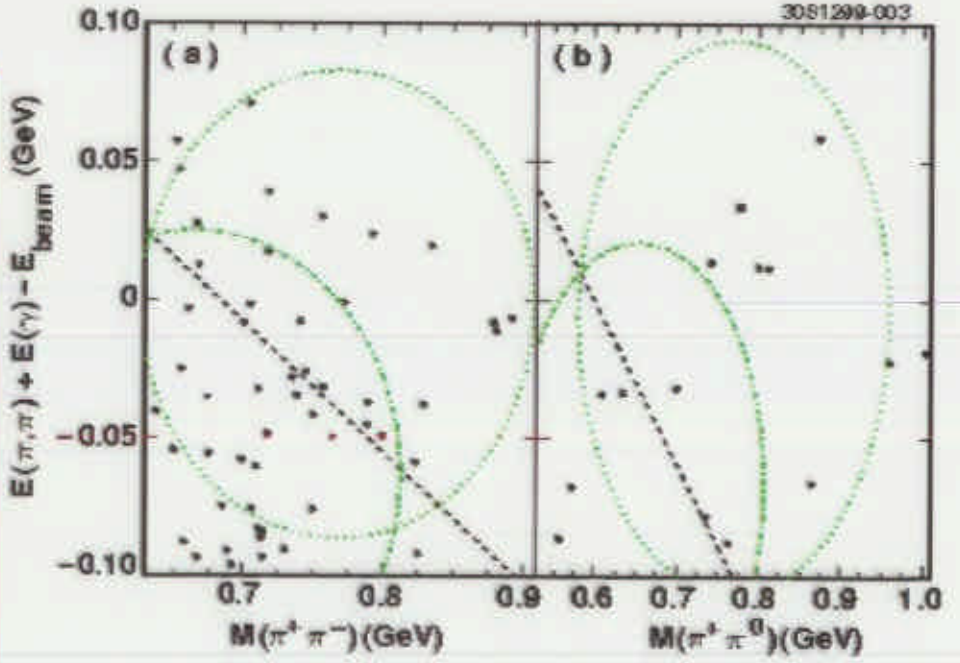
$Br(B^+ \to \rho^+\gamma) < 1.3 \times 10^{-5}$ @ 90 % CL

$R < 0.32$ @ 90 % CL

$|V_{td}/V_{ts}| < 0.72$ @ 90% CL w/ $\xi = 0.6$

$Br(B^0 \to \omega\gamma) < 0.92 \times 10^{-5}$ @ 90 % CL

[PRL **84** 5283 (2000)]



Inclusive $b \to s\gamma$

$Br(b \to s\gamma)$: Determine E_γ spectrum from hard, quasi-monochromatic γ's
Perform ON-resonance – Off-resonance subtraction

2-stage process:

- Use 2 different methods to suppress ON-resonance BKG

  BKG $\equiv$ $e^+e^- \to q\bar{q}\gamma$ and $e^+e^- \to (\pi^0, \eta, \omega)\, X$

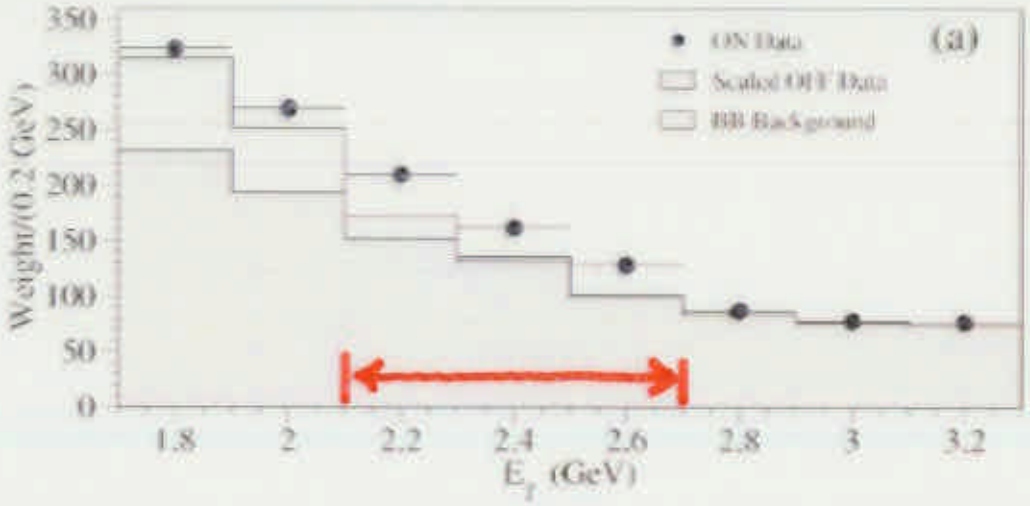
  method 1: use NN (event shape variables) to separate BB from non-BB

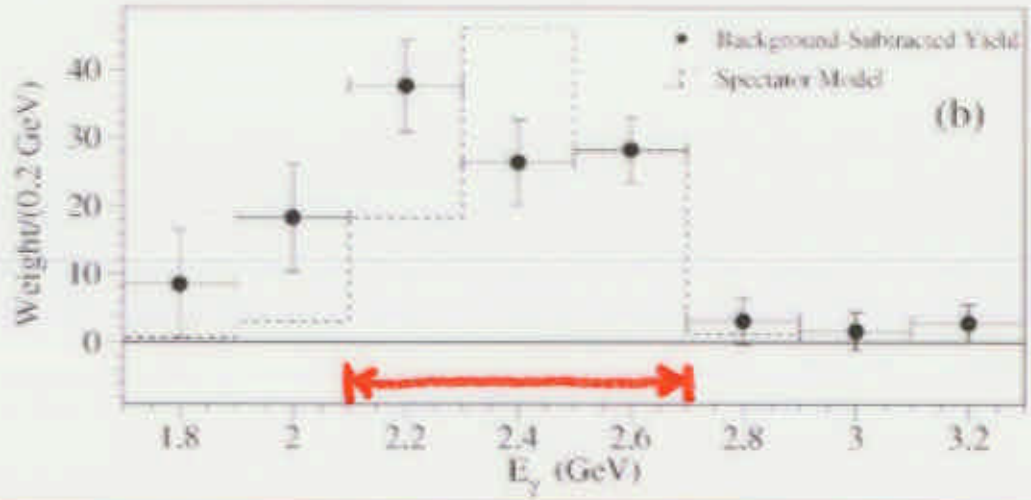
  method 2: pseudoreconstruction of B and 2nd NN

  - Each event is weighted by NN output

- Subtract OFF-resonance data

Inclusive b → sγ





$Br(b \to s\gamma) = (3.15 \pm 0.35 \pm 0.32 \pm 0.26) \times 10^{-4}$

3.1 fb^{-1} ON Only !

CP Asymmetry in $b \to s\gamma$

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

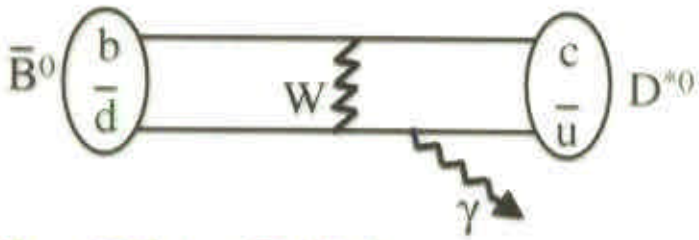
- SM: $A_{CP} < 1\%$
- Non-SM: $A_{CP} < 10 - 40\%$ w/o affecting $Br(b \to s\gamma)$
  [Kagan + Neubert, *Phys Rev D* **58** 094012 (1998)]
  [Aoki et al., *Phys Rev D* **60** 035004 (1999)]
- Flavor tag 2 ways:
  - ID high p lepton ($1.4 < p < 2.2$ GeV/c) of "other" B
  - pseudoreconstruction similar to $Br(b \to s\gamma)$

  } Mis-tag rate ~ 10%
- Major BKG is qq for both tagging techniques.
  - lepton tag: suppress w/ NN (event shape var's)
  - P-recon tag: suppress w/ NN (ev't shape var's), $\chi^2(\Delta E, M(B))$, PID

$$-0.22 < A_{CP} < +0.09 \text{ @ } 90\% \text{ CL}$$

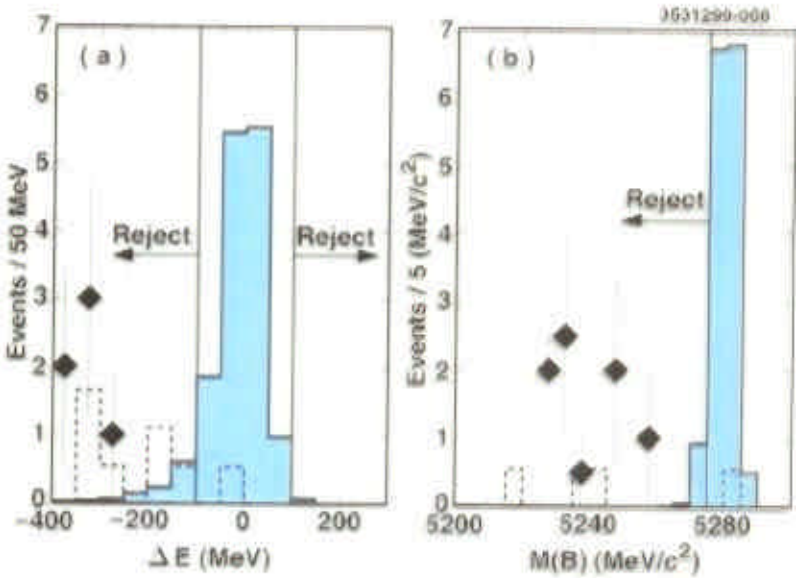
Search for $\bar{B}^0 \to D^{*0}\gamma$

- $b \to s\,\gamma$ M'ment assumed W-exchange radiative decays suppressed



- SM: $Br(\bar{B}^0 \to D^{*0}\gamma) \sim O(10^{-6})$
  [Mendel +Sitarksi, *Phys. Rev. D*, **36**, 983, (1987)]

$\bar{B}^0 \to D^{*0}\gamma$
- $\to D^0\,\pi^0$
- $\to D^0\,\gamma$
  - $\to K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^-\pi^+$



- 0 events found in M(B) - ΔE space

$\therefore Br(\bar{B}^0 \to D^{*0}\gamma) < 5 \times 10^{-5}$ @ 90% CL

[PRL **84** (2000) 4292]

Summary

- $Br(B \to K^*\gamma)$ measured w/ improved precision.
- New radiative decay mode $Br(B \to K_2^*(1430)\gamma)$ observed, agrees w/ (some) theoretical predictions.
- $\Delta A/A\ (B \to K^*\gamma) \sim 15\%$

- $Br(B \to \rho\gamma)\ /Br(B \to K^*(890)\gamma) < 0.32$ @ 90% CL
- $|V_{td}/V_{ts}| < 0.72$ @ 90% CL and some model dependence
- No evidence for $b \to d\gamma$

- $Br(b \to s\gamma)$ measured w/ partial data set (3.1 fb^{-1} on-resonance)
- $-0.22 < A_{CP}(b \to s\gamma) < +0.09$ @ 90% CL

- No evidence for non-penguin radiative decays ($\overline{B}^0 \to D^{*0}\gamma$)