CP Violation studies with Rare *B* Physics at CLEO

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for the CLEO Collaboration

February 19-23, 2001

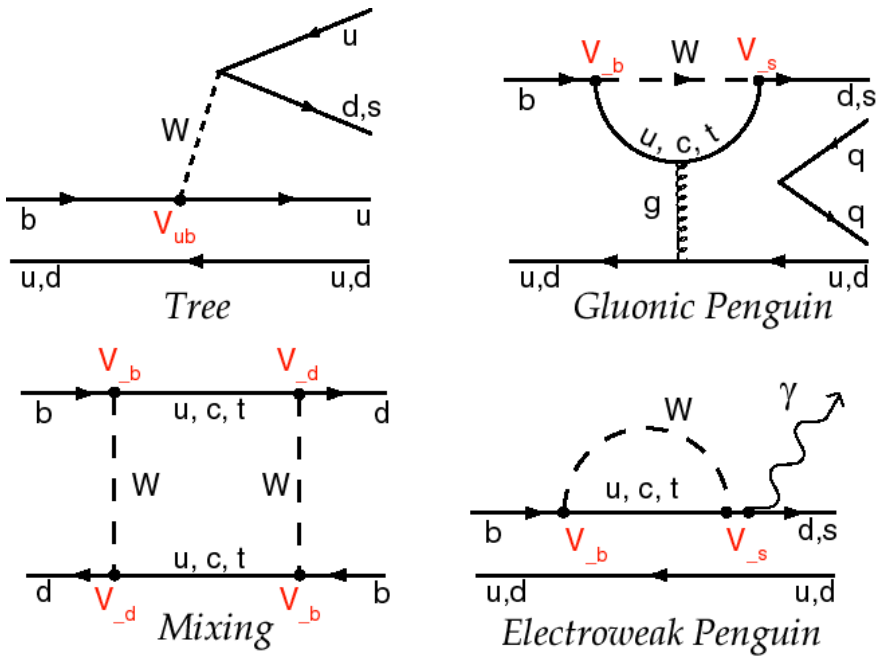
4th International Workshop on *B* Physics and *CP* violation *Ise-Shima, Japan*

Outline

- Charmless Hadronic Decays
  - $B \to \phi K$, $B \to \phi K^*$
  - Summarize $B \to K\pi$, $\pi\pi$; $B \to \eta' h$; Asymmetry
- Radiative Decays
  - $b \to s\,\gamma$ inclusive (Asymmetry), exclusive
  - $b \to d\,\gamma$ exclusive

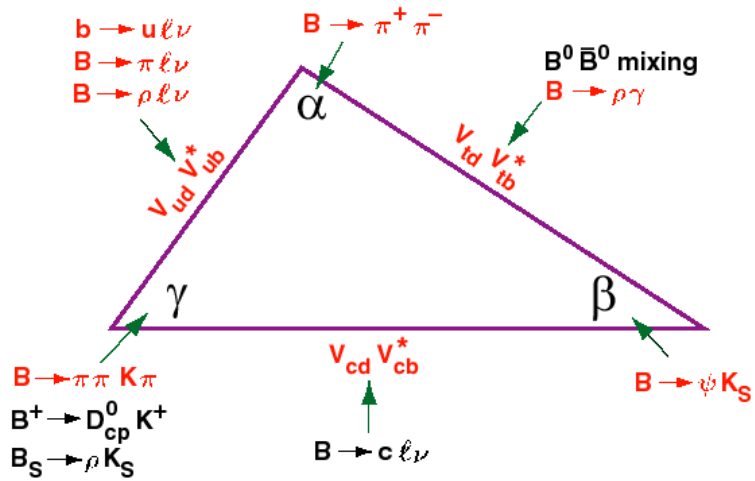
Rare B Physics

- Involving loops and boxes



Rates from loops and boxes are non-negligible because Top is so heavy (incomplete GIM)

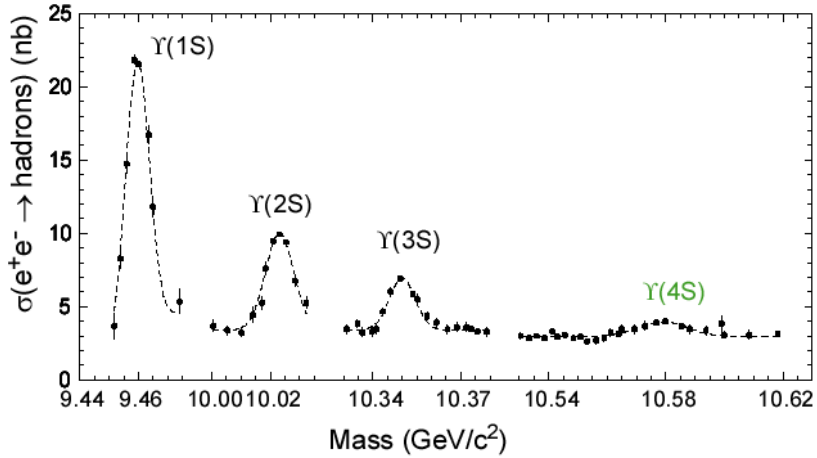
- Learn about Unitarity Triangle:

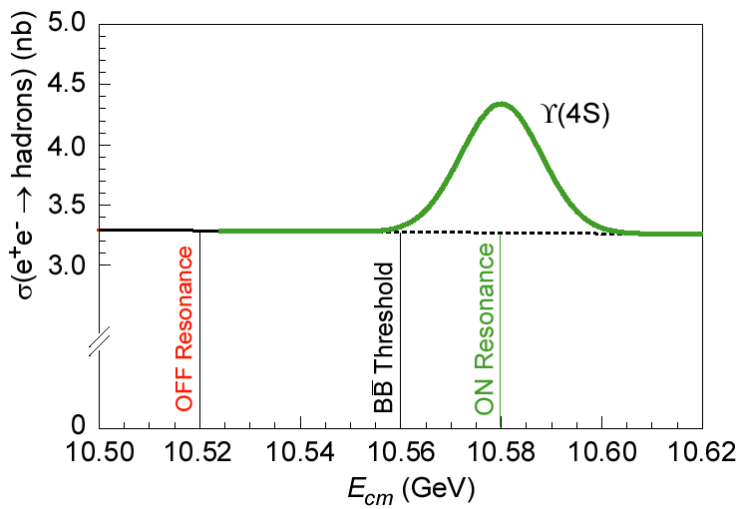


- CP Violation:
  - Direct (decay amplitude interference)
  - Mixing (mixing amplitude interference)

CESR and CLEO

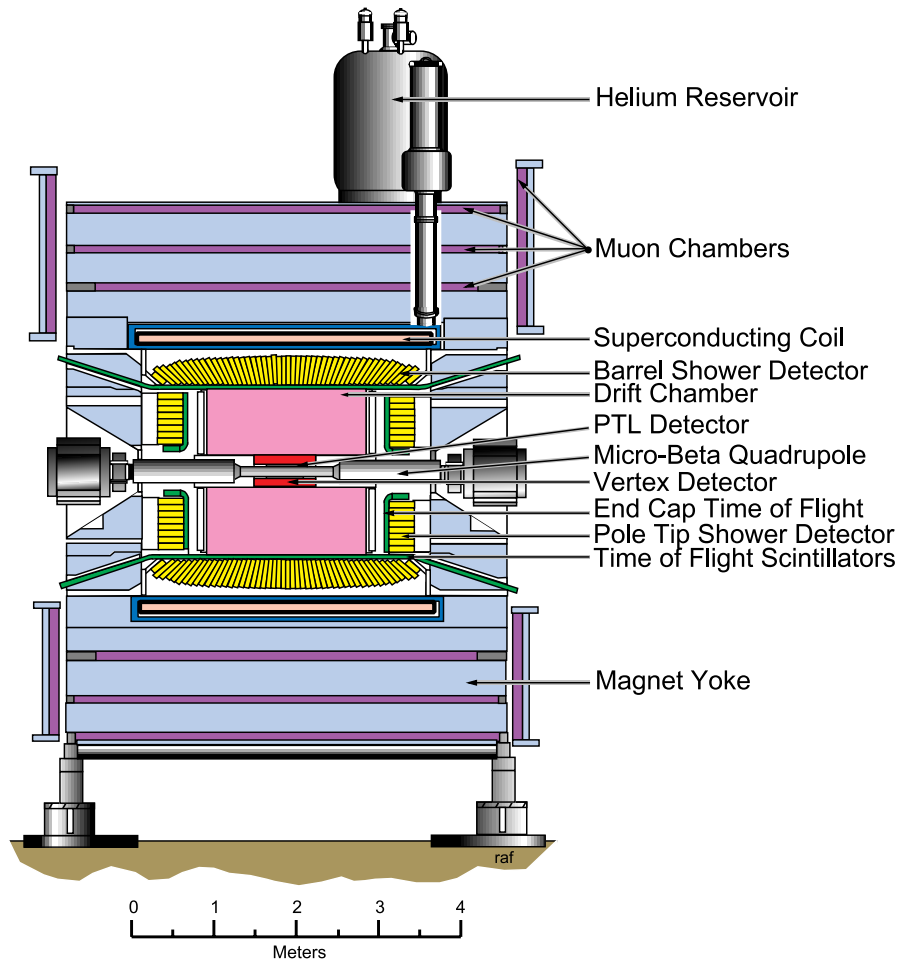
- Symmetric e^+e^- accelerator at or near $\Upsilon(4S)$ ($P_B \sim 300$ MeV/ c)
- On the $\Upsilon(4S)$:
  $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$ ($\sigma \sim 1$ nb)
  $e^+e^- \rightarrow q\bar{q}$, ($q = u, d, c, s$) ($\sigma \sim 3$ nb)
- 1/ 3 running at OFF Υ(4S) for continuum bkg subtraction
- CLEO II + II.V collected
  ON: 9.1 fb^{-1} (9.7M $B\bar{B}$)
  OFF: 4.4 fb^{-1}





The CLEO Detector

- Cleo II (1989-1995):
  - 1.5T Solenoidal Field
  - 3 Tracking chambers
  - CsI Calorimeter
  - Time of Flight
  - Muon
  - 3.1 fb^{-1} ON, 1.6 fb^{-1} OFF
- Cleo II.V (1996-1999):
  - 3 layer silicon detector replaces innermost tracker
  - Replaced Drift Chamber Gas (Argon Ethane $\rightarrow$ HePr)
  - 6.0 fb^{-1} ON, 2.8 fb^{-1} OFF



Charmless Hadronic: Common analysis techniques

- Selecting Signal
  - Beam constrained mass

    $M_B = \sqrt{E_{beam}^2 - |\mathbf{p}|^2}$

    σ ~ 2.5 MeV (3.0 MeV if π^0)
  - Energy difference

    $\Delta E = \sum_{B \text{ daughters}} E_i - E_{beam}$

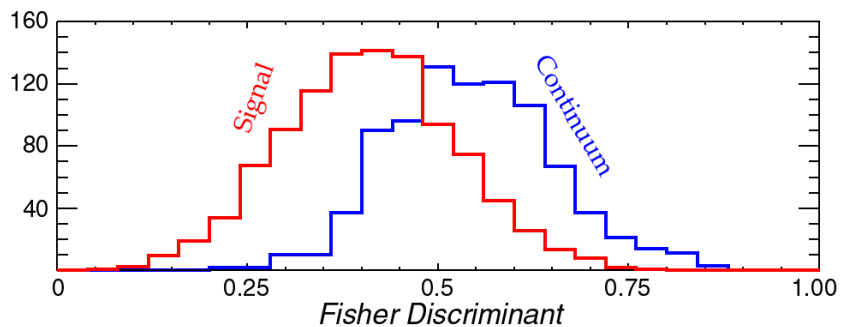
    Resolution is mode dependent, but generally
    σ ~ 20-25 MeV
    (×2 worse if π^0)
  - dE/dx and ΔE for PID

- *Put all this and more into ML fit*

- Rejecting continuum

  Signal = isotropic (2 uncorrelated *B*'s), continuum = jetty
  - *Thrust angle*
  - *Fisher discriminant:*

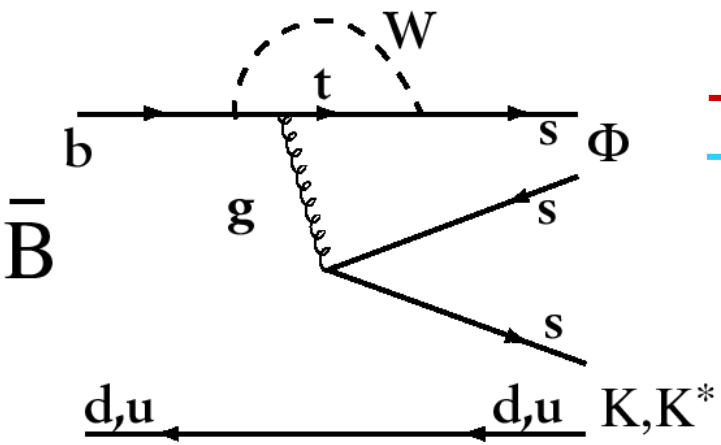
    Linear combination of 11 shape variables:
    - Sphericity angle (signal isotropic)
    - R_2 (signal < continuum)
    - Energy distribution about Sphericity axis
      use nine 10° angular bins



$B \to \phi K^{(*)}$

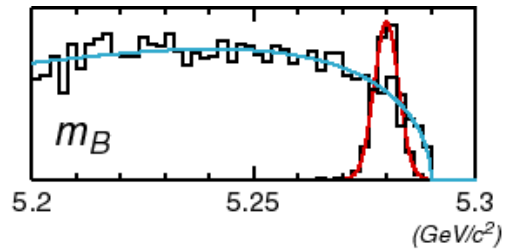
Submitted to PRL
hep-ex/0101032

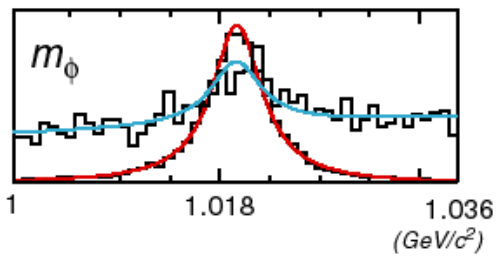
new

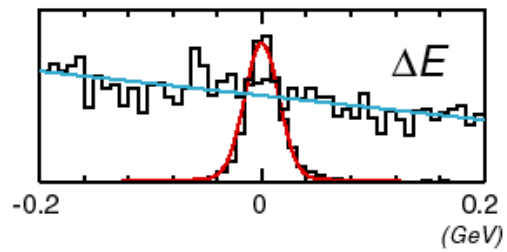


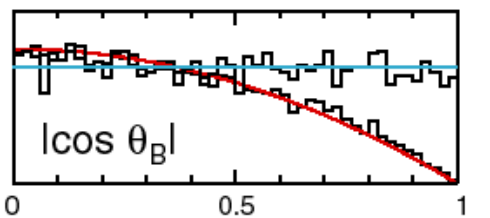
PDF shapes for $\phi K^{*0}_{\to K^-\pi^+}$

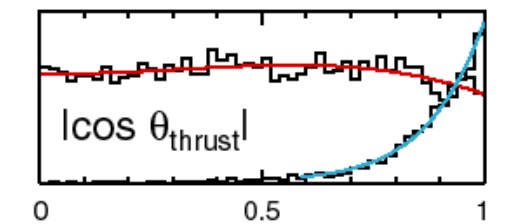
- Signal (MC)
- Continuum (Off data)

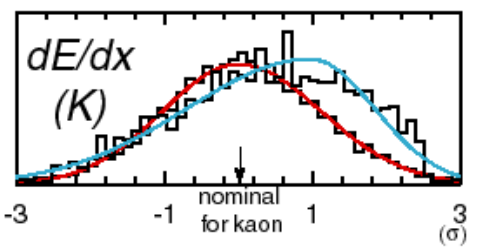


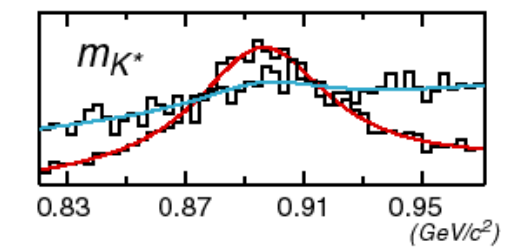












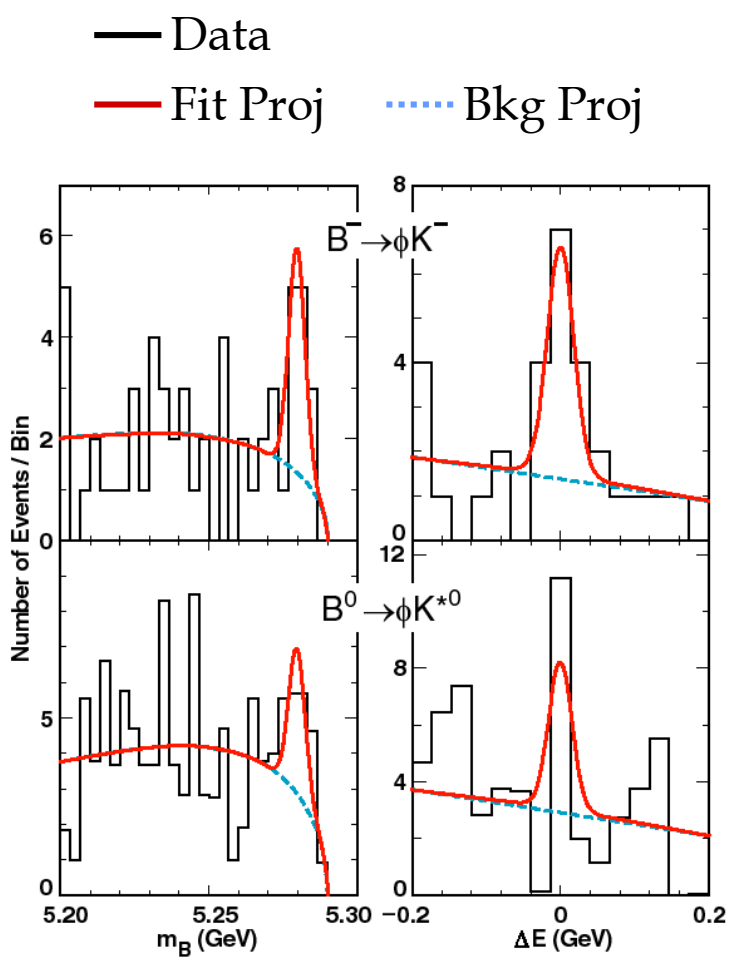
- Clean signature for gluonic penguin (no $B\bar{B}$ bkg)
- Maximum likelihood fits for each topology:

$$\phi K^-,\ \phi K^0,\ \phi K^{*0}_{\to K^-\pi^+},$$

$$\phi K^{*0}_{\to K^0\pi^0},\ \phi K^{*-}_{\to K^-\pi^0},\ \phi K^{*-}_{\to K^0\pi^-}$$

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

	Yield	Reco eff (%)	Stat signif	BF (10^{-6})	Theory BF (10^{-6})
ϕK^-	$14.2^{+5.5}_{-4.5}$	54	5.4σ	$5.5^{+2.1}_{-1.8} \pm 0.6$	0.7 - 16
ϕK^0	$4.2^{+2.9}_{-2.1}$	48	2.9σ	< 12.3	0.7 – 13
$B \to \phi K$			6.1σ	$5.5^{+1.8}_{-1.5} \pm 0.7$	
$\phi K^{*0}_{\to K^-\pi^+}$	$12.1^{+5.3}_{-4.3}$	38	4.5σ		
$\phi K^{*0}_{\to K^0\pi^0}$	$5.1^{+3.9}_{-2.8}$	20	2.7σ		
$B \to \phi K^{*0}$			5.1σ	$11.5^{+4.5+1.8}_{-3.7-1.7}$	0.2 - 31
$\phi K^{*-}_{\to K^-\pi^0}$	$3.8^{+4.1}_{-2.8}$	25	1.5σ		
$\phi K^{*-}_{\to K^0\pi^-}$	$4.0^{+2.1}_{-2.2}$	32	2.7σ		
$B \to \phi K^{*-}$			3.1σ	< 22.5	0.2 - 31
$B \to \phi K^*$			5.9σ	$11.2^{+3.6+1.8}_{-3.1-1.7}$	

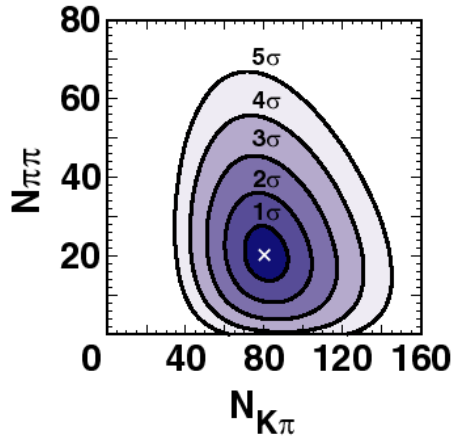


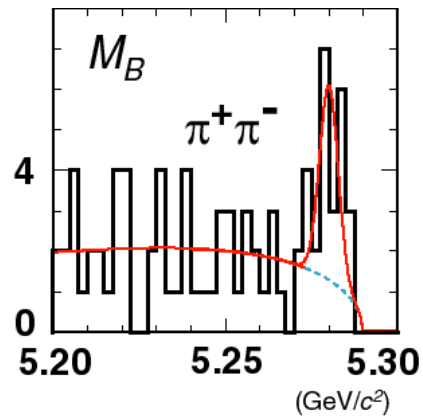
Belle: $BF(B \to \phi K) = (17.2^{+6.7}_{-5.4} \pm 1.8) \times 10^{-6}$
(ICHEP2000)

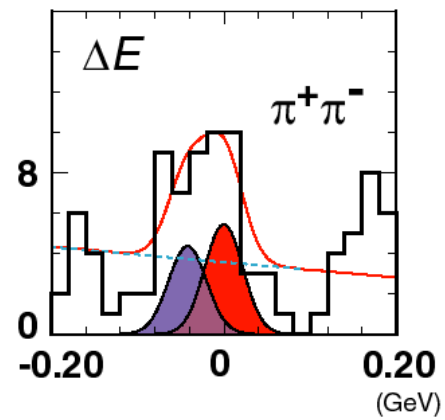
$B \to K\pi,\ KK,\ \pi\pi$ Results

CLEO $K\pi$: PRL **85,** 515 (2000)
BaBar/Belle ICHEP2000

Mode	CLEO (9.7M $B\bar{B}$) N_{Sig}	Signif.	Eff (%)	BF $\times 10^{-6}$	Theory BF $\times 10^{-6}$	Belle (ICHEP2000) [5.5M $B\bar{B}$] BF $\times 10^{-6}$	BaBar (ICHEP2000) [8.6M $B\bar{B}$] BF $\times 10^{-6}$
$\pi^+\pi^-$	$20.0^{+7.6}_{-6.5}$	4.2σ	48	$4.3^{+1.6}_{-1.4} \pm 0.5$	8-26	< 16.5	$9.3^{+2.6\,+1.2}_{-2.3\,-1.4}$
$\pi^+\pi^0$	$21.3^{+9.7}_{-8.5}$	3.2σ	39	< 12.7	3-20	< 10.1	
$\pi^0\pi^0$	$6.2^{+4.8}_{-3.7}$	2.0σ	29	< 5.7	0.3-4.6		
$K^+\pi^-$	$80.2^{+11.8}_{-11.0}$	11.7σ	48	$17.2^{+2.5}_{-2.4} \pm 1.2$	7-24	$17.4^{+5.1}_{-4.6} \pm 3.4$	$12.5^{+3.0\,+1.3}_{-2.6\,-1.7}$
$K^0\pi^+$	$25.2^{+6.4}_{-5.6}$	7.6σ	14	$18.2^{+4.6}_{-4.0} \pm 1.6$	3-15	< 34	
$K^+\pi^0$	$42.1^{+10.9}_{-9.9}$	6.1σ	38	$11.6^{+3.0\,+1.4}_{-2.7\,-1.3}$	8-26	$18.8^{+5.5}_{-4.9} \pm 2.3$	
$K^0\pi^0$	$16.1^{+5.9}_{-5.0}$	4.9σ	11	$14.6^{+5.9\,+2.4}_{-5.1\,-3.3}$	3-9	$21.0^{+9.3\,+2.5}_{-7.8\,-2.3}$	
K^+K^-	$0.7^{+3.4}_{-0.7}$	0σ	48	< 1.9		< 6	< 6.6
K^+K^0	$1.4^{+2.4}_{-1.3}$	1.1σ	14	< 5.1	0.7-1.5	< 5	$1.9^{+0.6}_{-0.5} \pm 0.2$
$K^0\bar{K}^0$	0	0σ	5	< 17			$2.1^{+0.9}_{-0.8} \pm 0.2$







- Good agreement with theory
- Small rate and limit for ππ modes
  - No strong phase enhancement
  - Large gluonic penguins

Data
Fit Proj
Continuum
ππ signal
Kπ bkg

$B \to \eta' K,\ \eta K^*$

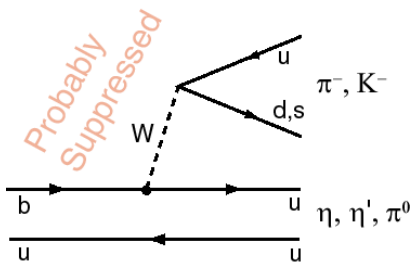
η', η : PRL **85,** 520 (2000)
η_C : hep-ex/ 0007012

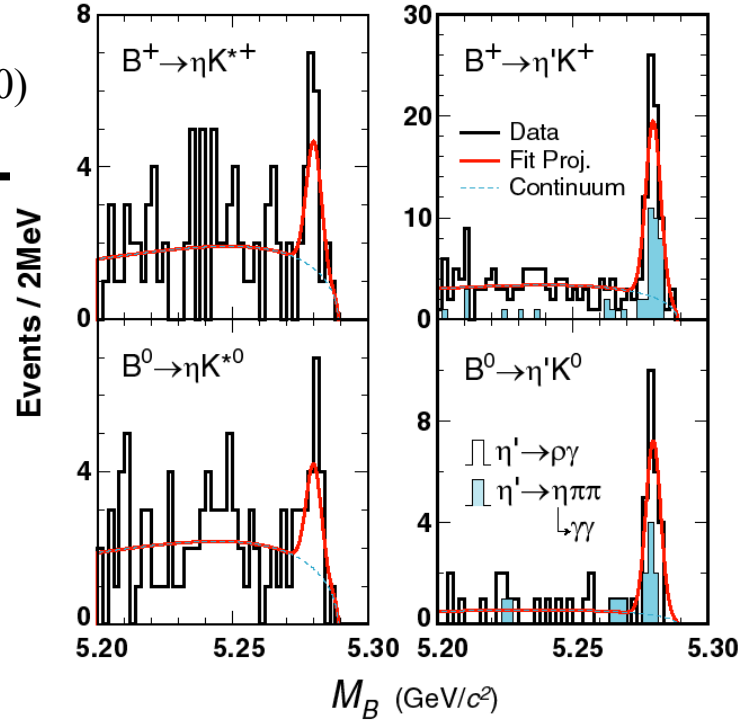
- Significant modes:

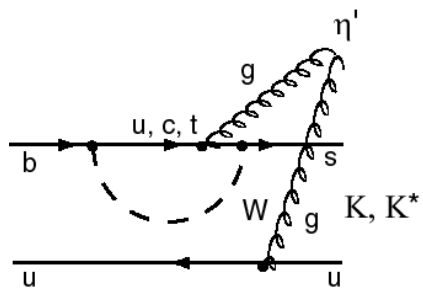
$$BF(B^{\pm} \to \eta' K^{\pm}) = (8.0^{+1.0}_{-0.9} \pm 0.7) \times 10^{-5}$$
$$BF(B^{0} \to \eta' K^{0}) = (8.9^{+1.8}_{-1.6} \pm 0.9) \times 10^{-5}$$
$$BF(B^{\pm} \to \eta' \pi^{\pm}) < 1.2 \times 10^{-5}$$
$$BF(B^{\pm} \to \eta' K^{*\pm}) < 3.5 \times 10^{-5}$$

$$BF(B^{\pm} \to \eta K^{*\pm}) = (2.6^{+1.0}_{-0.8} \pm 0.3) \times 10^{-5}$$
$$BF(B^{0} \to \eta K^{*0}) = (1.4^{+0.6}_{-0.5} \pm 0.2) \times 10^{-5}$$
$$BF(B^{\pm} \to \eta \pi^{\pm}) < 0.6 \times 10^{-5}$$
$$BF(B^{\pm} \to \eta K^{\pm}) < 0.7 \times 10^{-5}$$

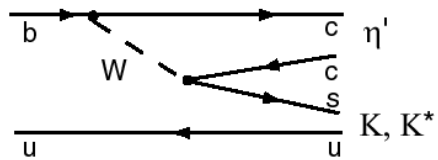
- $BF(B \to \eta') > BF(B \to \eta)$ and large!







These enhanced?

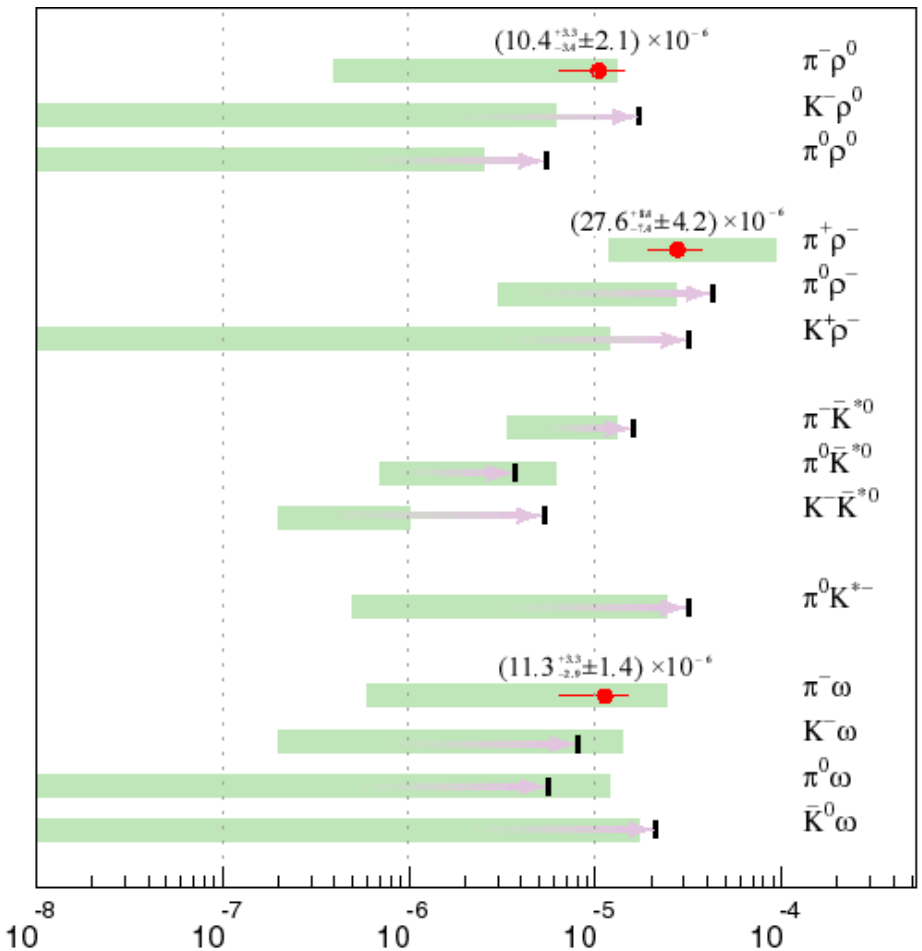


But no enhancement in $B \to \eta_C K$

$$BF(B^{\pm} \to \eta_C K^{\pm}) = (0.7^{+0.3}_{-0.2} \pm 0.1 \pm 0.2) \times 10^{-3}$$
$$BF(B^{0} \to \eta_C K^{0}) = (1.1^{+0.6}_{-0.4} \pm 0.1 \pm 0.3) \times 10^{-3}$$

$B \to PV$, $B \to VV$ modes

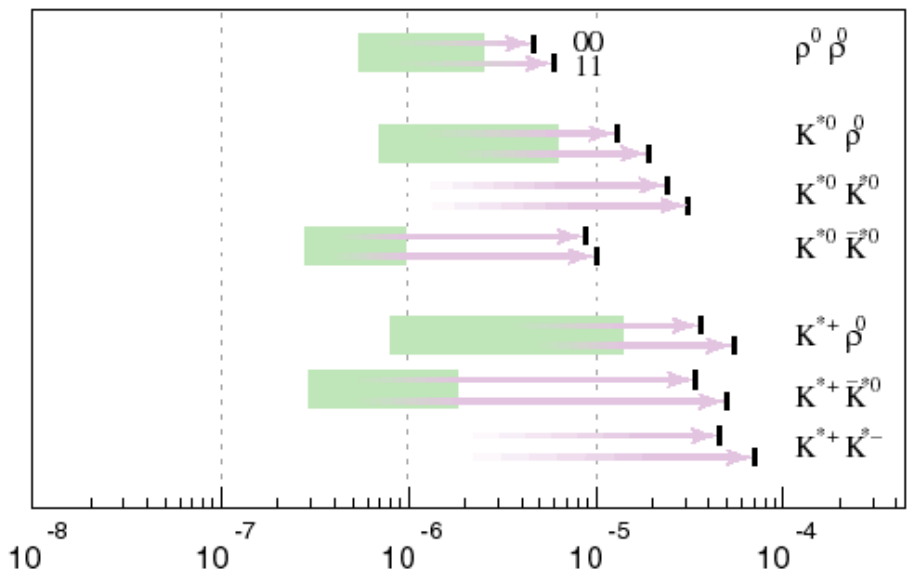
PV: PRL **85,** 2881 (2000)
VV: Submitted to PRL (hep-ex/0101029)



Theory

UL (90% CL)

Measured BF (>5σ)



Direct CP Asymmetry

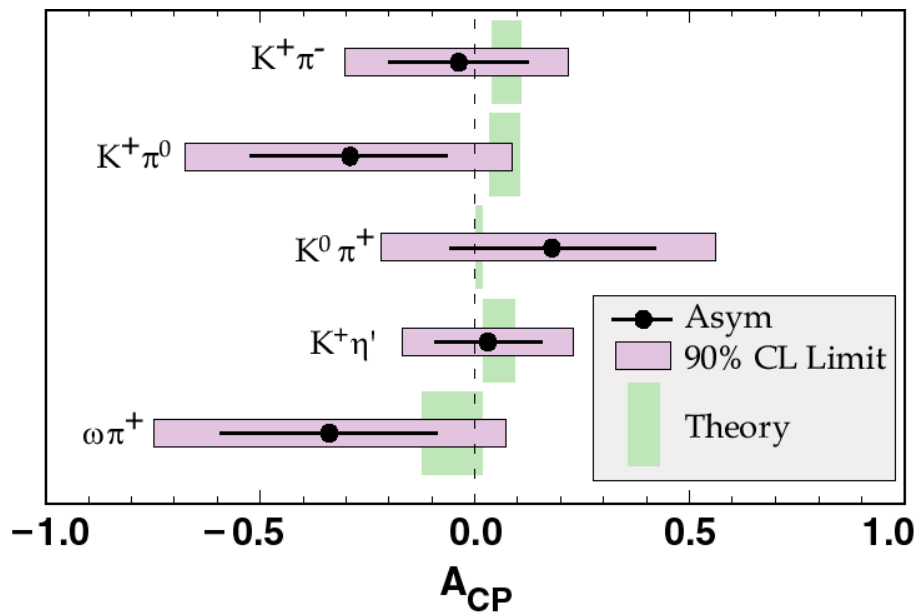
Theory: Ali, Kramer & Lü, PRD **59,** 014005 (1999)
CLEO Results: PRL **85**, 525 (2000)

- A_{CP} comes from two or more amplitudes with different weak and strong phases

$$A_{CP} \equiv \frac{BF(\overline{B} \to \bar{f}) - BF(B \to f)}{BF(\overline{B} \to \bar{f}) + BF(B \to f)}$$

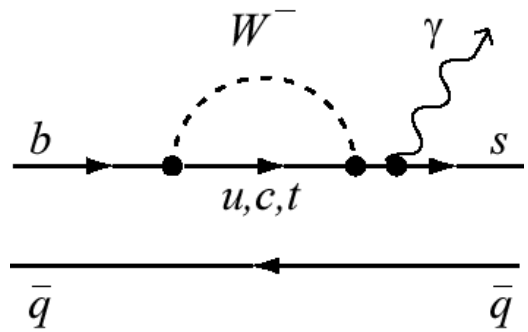
Mode	Yield	A_{CP}
$K^{\pm}\pi$	$80.2^{+11.8}_{-11.0}$	-0.04 ± 0.16
$K^{\pm}\pi^{0}$	$42.1^{+10.9}_{-9.9}$	-0.29 ± 0.23
$K^{0}\pi^{\pm}$	$25.2^{+6.4}_{-5.6}$	$+0.18 \pm 0.24$
$K^{\pm}\eta'$	100^{+13}_{-12}	$+0.03 \pm 0.12$
$\omega\pi^{\pm}$	$28.5^{+8.2}_{-7.3}$	-0.34 ± 0.25

- Use self tagging modes (high-p daughter tags B flavor)
- A_{CP} free parameter in ML fits
- Factorization: $A_{CP} < 0.1$, but final state interaction or new physics could enhance

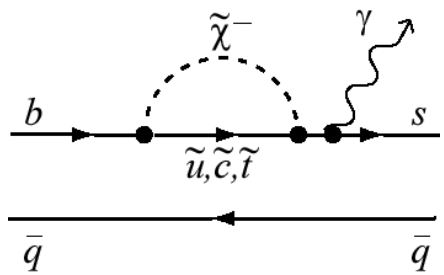


Inclusive $b \to s\,\gamma$

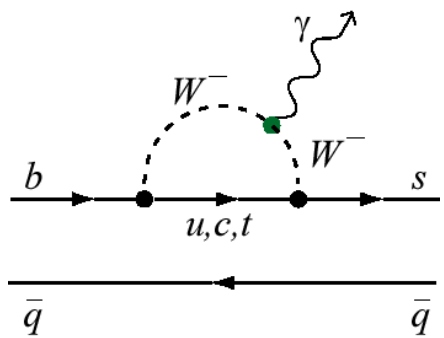
- Electroweak Penguin
  - No FCNC at tree level
  - Provides direct look at loops and boxes
  - Sensitive to $V_{tb}V_{ts}$



- $b \to s\gamma$
  - SM NLO prediction:
    BF(b → sγ) = $(3.28 \pm 0.33) \times 10^{-4}$

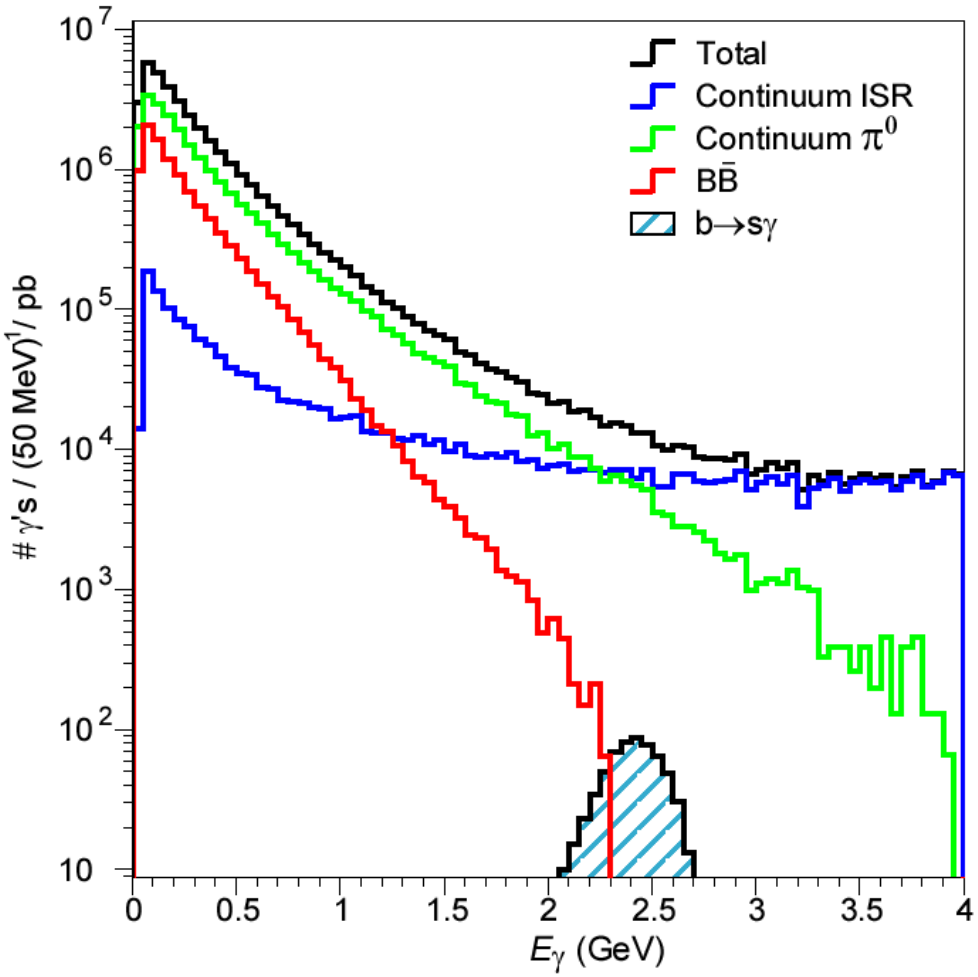


- Perhaps there's new physics in the penguin!
  - Charginos
  - Charged Higgs
  - Anomalous WWγ couplings



Analysis Strategy

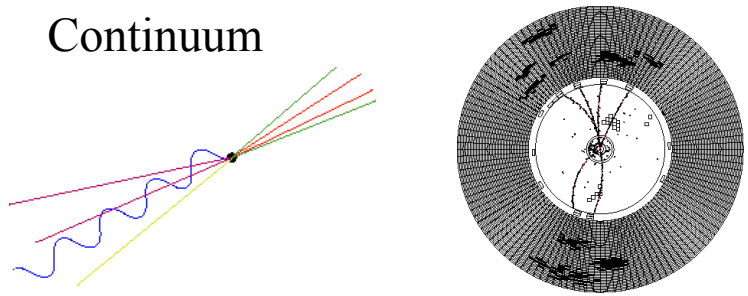
- Basic idea:
  Measure E_γ spectrum for ON and OFF resonance and subtract
- But, must suppress **huge** continuum background!
  [veto is not enough]
- Three attacks:
  - Shape analysis
  - Pseudoreconstruction
  - Leptons



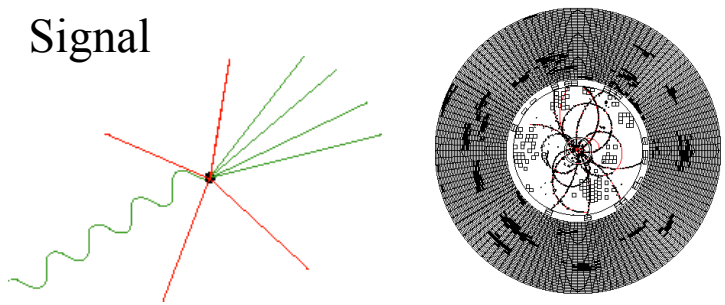
Analysis Details

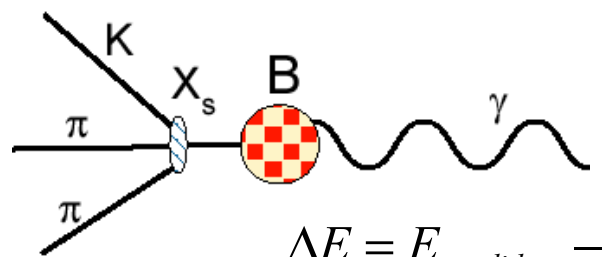
- Require 2.0 < E_γ < 2.7 GeV
- Shape Analysis:
  - Exploit shape differences
  - Combine shape variables (energy cones, event topology, photon isolation) with Neural Net
- Pseudoreconstruction:
  - Loosely find the X_s system
  - K + up to 4π (at most 1 π^0)
  - χ^2 to choose best combination
  - Use NN to combine shape analysis, χ^2, cos θ_{thrust}

Continuum



Signal



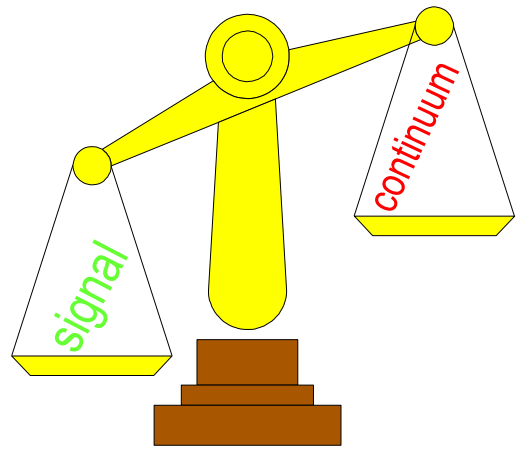


$$\Delta E = E_{candidate} - E_{beam}$$

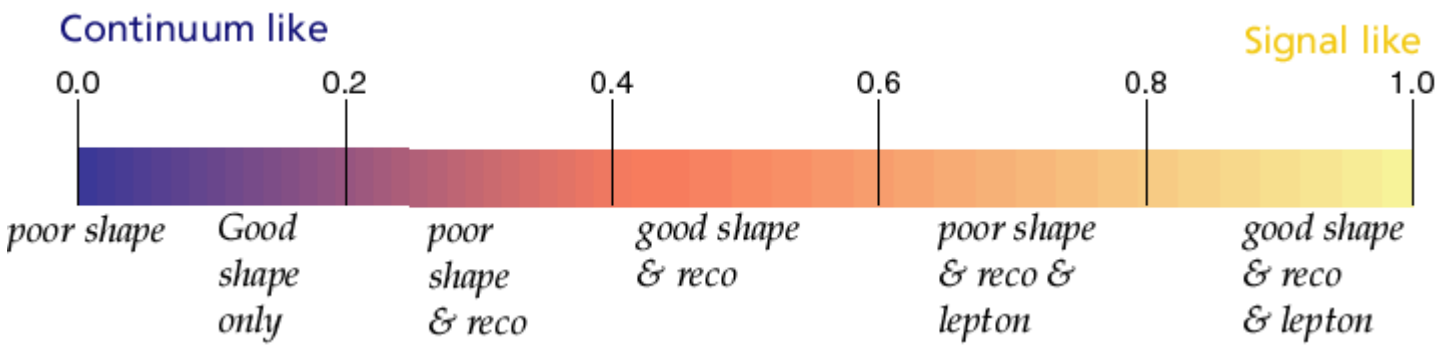
$$M_B = \sqrt{E_{beam}^2 - |\mathbf{p}|^2} \qquad E = \sum_i \sqrt{|\mathbf{p}_i|^2 + m_i^2}$$

(more) Analysis Details

- High energy lepton
  - From the other *B*
  - Not likely from continuum



- Putting it all together:
  - Every event gets a weight
  - Weights are chosen to minimize statistical uncertainty

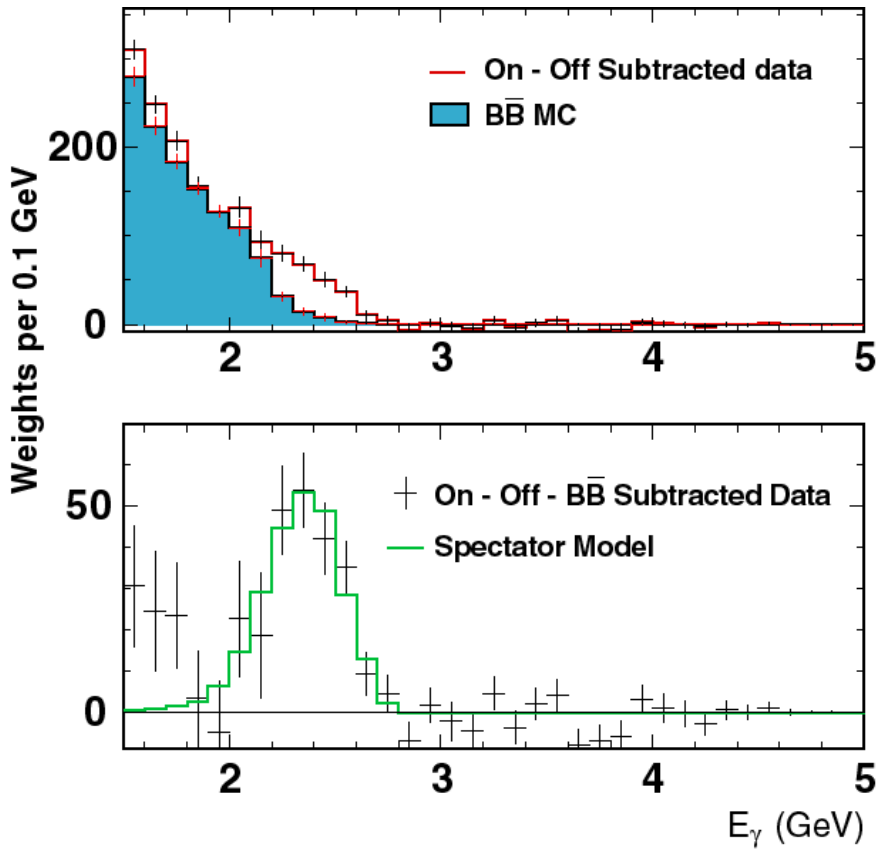


Inclusive $b \to s\,\gamma$ Results

Preliminary

$$BF(b \to s\gamma) = (2.85 \pm 0.35_{\text{stat}} \pm 0.22_{\text{sys}}) \times 10^{-4}$$

- Cleo II + II.V data
  9.1 fb^{-1} ON, 4.4 fb^{-1} OFF
- *BF* measured for
  $2.0 < E_\gamma < 2.7$ GeV
  Factor of 0.94 → Full spectrum
- NLO Prediction:
  $(3.28 \pm 0.33) \times 10^{-4}$
  Chetyrkin, Misiak, and Münz
- Belle (ICHEP2000) measures:
  $\left(3.34 \pm 0.50^{+0.34\ +0.26}_{-0.37\ -0.28}\right) \times 10^{-4}$



CP Asymmetry in $b \to s\gamma$?

- SM says its small! Another window on new physics?

$$b \to s\gamma = A_{sm} + A_{new} e^{i\theta_s} e^{i\theta_w}$$

$$\bar{b} \to \bar{s}\gamma = A_{sm} + A_{new} e^{i\theta_s} e^{-i\theta_w}$$

$$BF = |b \to s\gamma|^2 + |\bar{b} \to \bar{s}\gamma|^2$$

$$\sim A_{sm}^2 (1 + 2\rho \cos\theta_s \cos\theta_w + \rho^2) \qquad \rho = \frac{A_{new}}{A_{sm}}$$

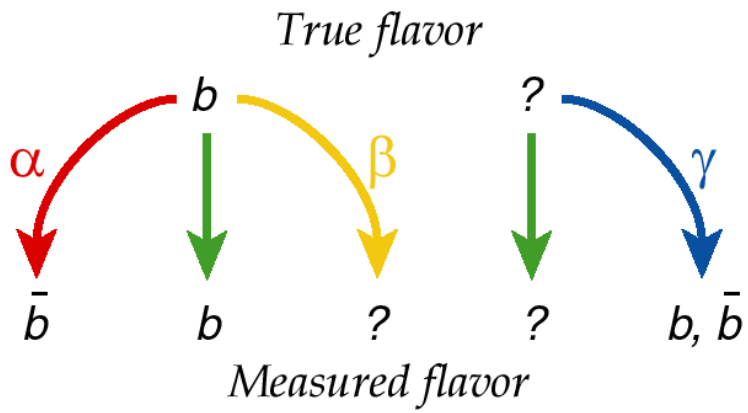
New physics could appear in Asymmetry that would not alter branching fraction

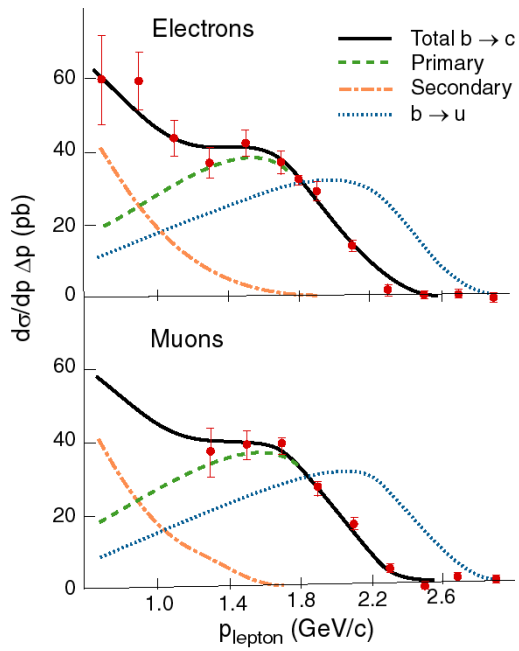
$$A_{CP} = \frac{|b \to s\gamma|^2 - |\bar{b} \to \bar{s}\gamma|^2}{|b \to s\gamma|^2 + |\bar{b} \to \bar{s}\gamma|^2} \sim 2\rho \sin\theta_s \sin\theta_w$$

- A. Kagan, M. Neubert PRD **58**, 094012 (1998); Aoki, Cho, Oshimo PRD **60**, 035004 (1999)

$b \to s\,\gamma$ CP Asymmetry *(Tagging)*

- Require $2.2 < E_\gamma < 2.7$ GeV
- Pseudoreconstruction:
  - Same algorithm as for BF
  - Aggressive particle ID
  - If K^0_S and neutral pions, then ambiguous flavor (*?*)
  - $\alpha \sim 9\%$, $\beta \sim 1.7\%$, $\gamma \sim 25\%$
- Lepton Tag:
  - Tag lepton from the *other B*
  - $1.4 < P_{lepton} < 2.2$ GeV/ c
  - Recover events not pseudoreconstructed
  - If event has a lepton, ignore pseudoreconstruction
  - $\alpha \sim 11\%$ (most from mixing)





$b \to s\,\gamma$ A_{CP} Results

- Data: Full CLEO II + II.V
  9.1 fb^{-1} ON (9.7M B$\bar{\text{B}}$)
  4.4 fb^{-1} OFF Resonance

- PseudoReco (TOF + dE/dx):

	N	W(b)	W(b-bar)	W(?)
ON	5542	171.2 ± 6.8	174.7 ± 7.0	23.0 ± 2.7
OFF	4878	111.6 ± 6.6	101.5 ± 6.1	11.5 ± 2.0
BB-bar	113	8.7	8.7	1.2
Yield	551	57.0 ± 9.5	64.6 ± 9.2	10.3 ± 3.4

(dE/dx only):

	N	W(b)	W(b-bar)	W(?)
ON	2408	65.5 ± 3.8	72.3 ± 4.3	8.2 ± 1.3
OFF	2114	47.5 ± 4.2	40.7 ± 3.7	5.5 ± 1.4
BB-bar	35	2.9	2.9	0.4
Yield	260	15.0 ± 5.7	28.7 ± 5.6	2.3 ± 2.0

$$A_{CP}^{pseudo} = -0.178 \pm 0.132$$

- Lepton tag:

	N	W(b)	W(b-bar)
ON	507	127.1 ± 8.9	107.3 ± 7.8
OFF	280	51.7 ± 6.8	48.0 ± 7.0
BB-bar	40	12.8	12.8
Yield	187	62.6 ± 11.1	46.5 ± 10.5

$$A_{CP}^{lepton} = +0.191 \pm 0.181$$

- Pseudo & Lepton analyses are statistically independent: combine, weighting by expected statistical accuracy

$$A_{CP}^{combined} = -0.079 \pm 0.108$$

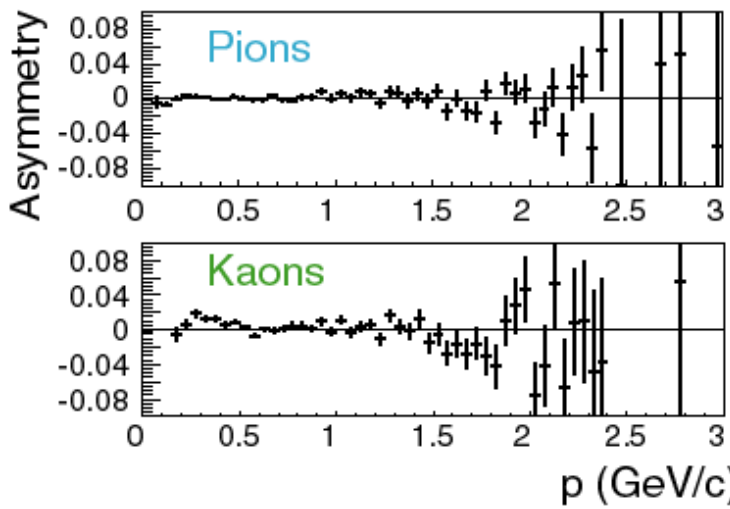
$b \to s\,\gamma$ Asymmetry Results

Submitted to PRL
hep-ex/0010075

$$A_{CP} = (-0.079 \pm 0.108_{stat} \pm 0.022_{addsys}) * (1.0 \pm 0.03_{multsys})$$

- Data: Full CLEO II + II.V
  9.1 fb^{-1} ON (9.7M $B\bar{B}$)
  4.4 fb^{-1} OFF Resonance
- 90% CL Limit:
  $-0.27 < A_{CP} < +0.10$
- Systematics
  - Multiplicative: Mistake rates; on, off subtraction; ambiguous events, f_{+-}/f_{00}
  - Additive: Particle detection biases

Lepton	Detection Asymmetry [All ON-OFF Data]
Central electrons	0.0032±0.0029
More forward e	0.0097±0.0077
Muons	-0.0005±0.0021



But what did we really measure?

- We actually observe a weighted sum of $b \to s\,\gamma$ decays:
  - Charged B, neutral B
  - Low mass X_s, high mass
  - Ambiguous decays for PseudoReco ($B^0 \to K^0 \ldots$) are only measured by lepton analysis
  - If at most ±10% difference in individual A_{CP}'s: Unevenness in our weightings asymmetry that differs from uniform weighting by no more than ± 0.02 -- **add to systematic**
- Measure no A_{CP} dependence on M_X or $E_{\gamma'}$ (but limited stats)

- Sensitivity to $b \to d\,\gamma$
  - In SM, rate down by $|V_{td}/V_{ts}|^2 \approx 1/20$
  - But A_{CP} for $b \to d\,\gamma$ up by factor of 20 and opposite sign
  - Lepton tag: $\varepsilon_d/\varepsilon_s = 1.1$
    PseudoReco: $\varepsilon_d/\varepsilon_s = 0.56$
    Combined: $\varepsilon_d/\varepsilon_s = 0.65$
  - MisId rates
    Lepton – same
    PseudoReco – $\alpha = 0.4$
  - We've really measured a weighted sum

$$A_{CP} = 0.965\,A(b \to s\gamma) + 0.02\,A(b \to d\gamma)$$

Exclusive Radiative *B* decays

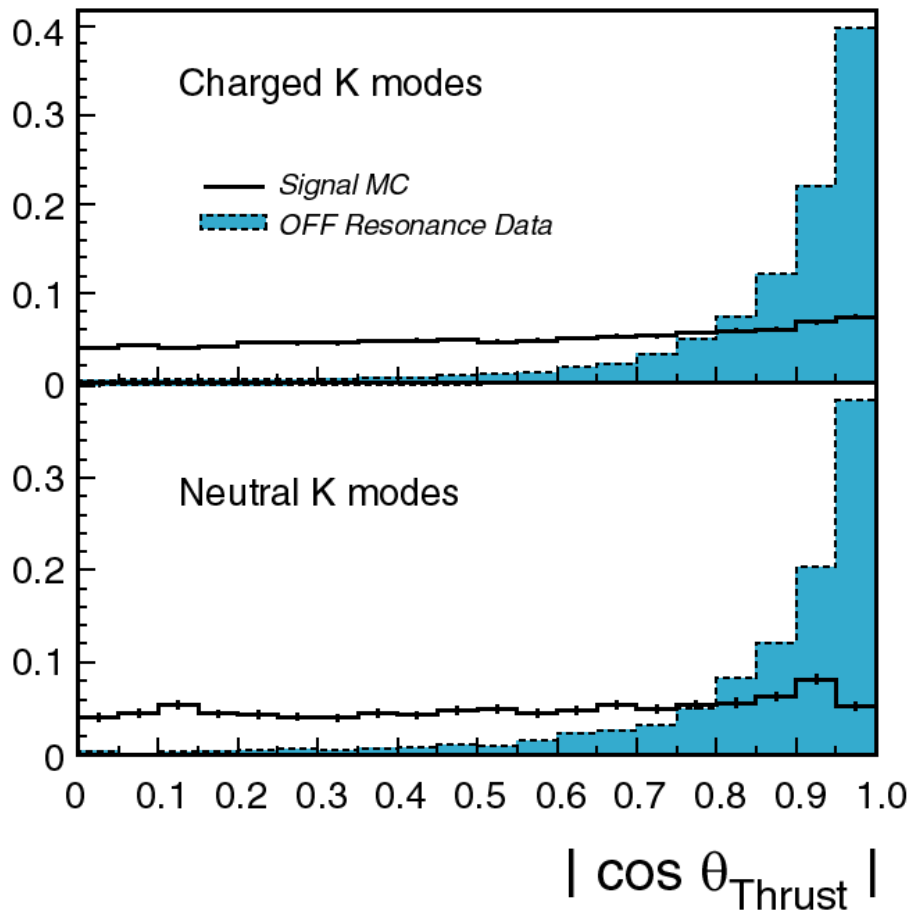
- Analyses:
  - Update the 1993 $K^*\gamma$ discovery analysis with full Cleo II+II.V dataset
  - Look for heavier K^* resonances
  - Look for exclusive $b \to d\gamma$ to set limits on $|V_{td}/V_{ts}|$
  - Look for $B \to \phi\gamma$ (non-penguin radiative box diagram) [No theoretical rate prediction]
    [All new analyses above: PRL **84**, 5283 (2000)]

  - and $\bar{B}^0 \to D^{*0}\gamma$ (possibly enhanced non-penguin)

9.7×10^6 BB pairs 4.1 fb^{-1} off resonance

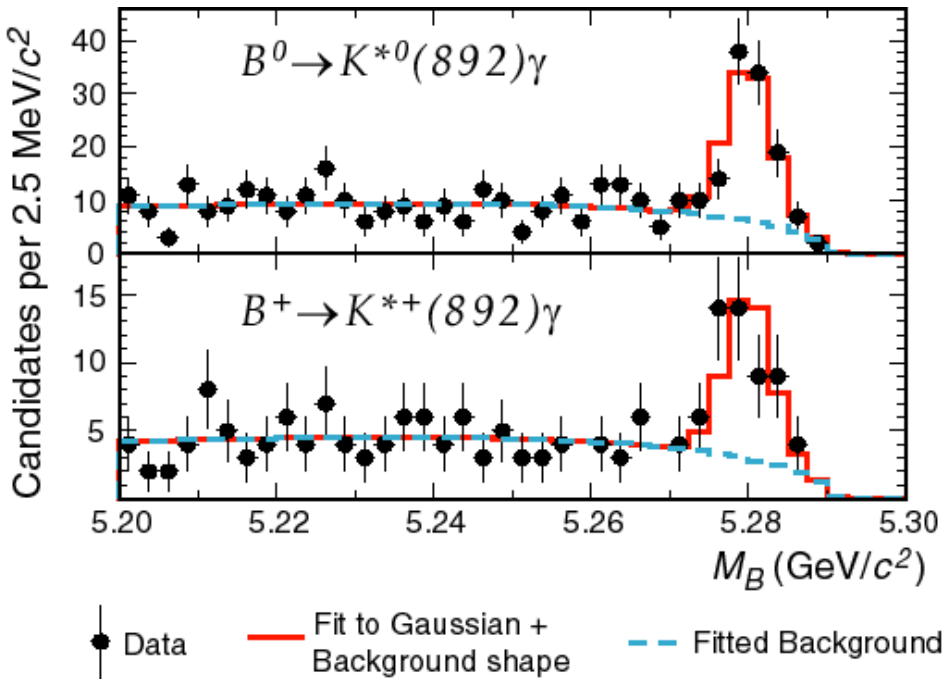
Main Analyses Requirements

- $E_\gamma > 1.5$ GeV $|\cos\theta| < 0.7$
- Backgrounds from continuum
  - γ from ISR – take central γ
  - γ from π^0 and η -- veto
- Mode dependent cuts to reduce remaining continuum
  - $\cos\theta_{thrust}$
  - $\cos\theta_B$
  - $\cos\theta_{helicity}$
- Mass of desired meson
- Full B reconstruction!
- Require at least
  $|\Delta E| < 300$ MeV,
  $5.2 < M_B < 5.3$ GeV/ c^2



$B \to K^*\gamma$

- $K^*(892)$:
  - $|\Delta E| < 100$ MeV
  - Simultaneous, binned maximum likelihood fit to K^* charged and neutral M_B distributions



Mode	Yield	$\varepsilon[\pi^\pm]$	$\varepsilon[\pi^0]$ (%)	BF (10^{-5})
$B^0 \to K^{*0}(892)\gamma$	$88.3^{+12.2}_{-11.5}$	28.4 ± 0.3	13.3 ± 0.3	$4.55^{+0.72}_{-0.68} \pm 0.34$
$B^+ \to K^{*+}(892)\gamma$	$36.7^{+8.3}_{-7.6}$	25.2 ± 0.5	13.4 ± 0.5	$3.76^{+0.89}_{-0.83} \pm 0.28$

$B \to K^*\gamma$

	$BF(10^{-5})$
<u>CLEO</u>:	9.7M $B\bar{B}$
$B^0 \to K^{*0}(892)\gamma$	$4.55^{+0.72}_{-0.68} \pm 0.34$
$B^+ \to K^{*+}(892)\gamma$	$3.76^{+0.89}_{-0.83} \pm 0.28$
<u>BaBar</u>: *(ICHEP2000)*	8.6M $B\bar{B}$
$B \to K^*(892)\gamma$	$5.4 \pm 0.8 \pm 0.5$
<u>Belle</u>: *(ICHEP2000)*	5.5M $B\bar{B}$
$B^0 \to K^{*0}(892)\gamma$	$4.9 \pm 0.9 \pm 0.5$
$B^+ \to K^{*+}(892)\gamma$	$2.9 \pm 1.2^{+0.5}_{-0.4}$

- Asymmetry

$$A_{CP} = \left(\frac{1}{1-2\alpha}\right)\frac{BF(\bar{B} \to \bar{K}^*\gamma) - BF(B \to K^*\gamma)}{BF(\bar{B} \to \bar{K}^*\gamma) + BF(B \to K^*\gamma)}$$

  - Use $K^\pm\pi^0, K_s^0\pi^\pm, K^\pm\pi$
  - Mistake rate α only for $K^\pm\pi$
    - Require $|p_\pi - p_K| > 500\ \mathrm{MeV}/c$
    - From MC $\alpha = (3.45 \pm 0.02)\%$
- Fit M_B distributions:

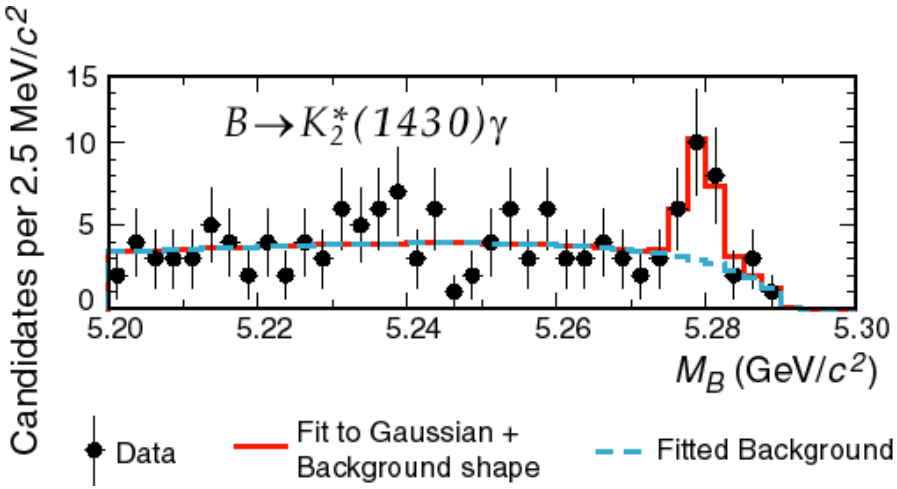
- Neutral K^* $A_{CP} = -0.13 \pm 0.17$
- Charged K^* $A_{CP} = +0.38^{+0.20}_{-0.19}$

- Combined:

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

$B \to K^*\gamma$ Heavier Resonances

- $K_2^*(1430)$, $K^*(1410)$:
  - Use $\theta_{helicity}$ and resonance widths to distinguish (1430) from (1410).
  - See no $K^*(1410)$
  - Fit $K^*(1430)$ M_B
- $B \to K_2^*(1430)\gamma$:
  - Yield = $15.9^{+5.7}_{-5.1}$ events
  - $\varepsilon[\pi^{\pm}] = (18.5 \pm 0.7)\%$
  - $\varepsilon[\pi^0] = (7.7 \pm 0.7)\%$
  - BF = $(1.66^{+0.59}_{-0.53} \pm 1.3) \times 10^{-5}$
- BF($B \to K^*(1410)\gamma$) $< 12.7 \times 10^{-5}$ @ 90% CL

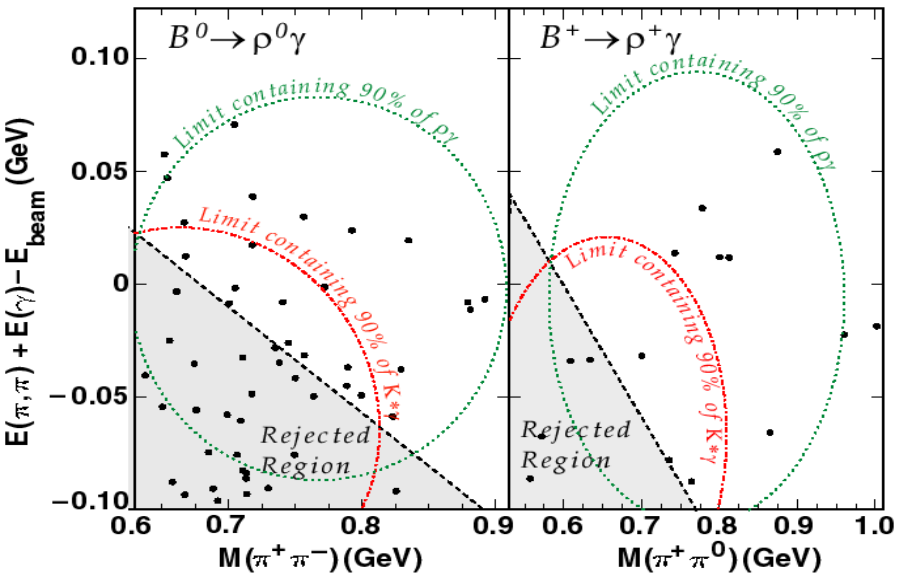


$$R_{1430/892} \equiv \frac{BF(B \to K_2^*(1430)\gamma)}{BF(B \to K^*(892)\gamma)}$$

Veseli & Olsson	0.37 ± 0.10
Ali, Mannel, & Ohl	3.0 - 4.9
CLEO	$0.39^{+0.15}_{-0.13}$

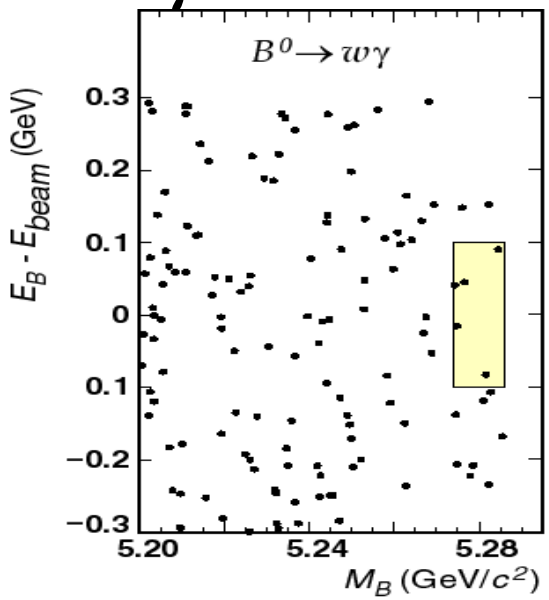
$b \to d\gamma$

- $B \to \rho\gamma$



ε (%)	12.8±0.7	8.5±0.6
$K^*\gamma$ ×-feed	5.4±0.8	2.6±0.6
$q\bar{q}$ *bkg*	9.3±0.6	5.2±0.4
BF (90% CL)	$< 1.7 \times 10^{-5}$	$< 1.3 \times 10^{-5}$
BELLE BF (ICHEP 2000)	$< 0.6 \times 10^{-5}$	$< 2.3 \times 10^{-5}$

- $B \to \omega\gamma$



combinatoric bkg = 2.7 ± 0.1 events

$\varepsilon = (9.7 \pm 0.8)\%$

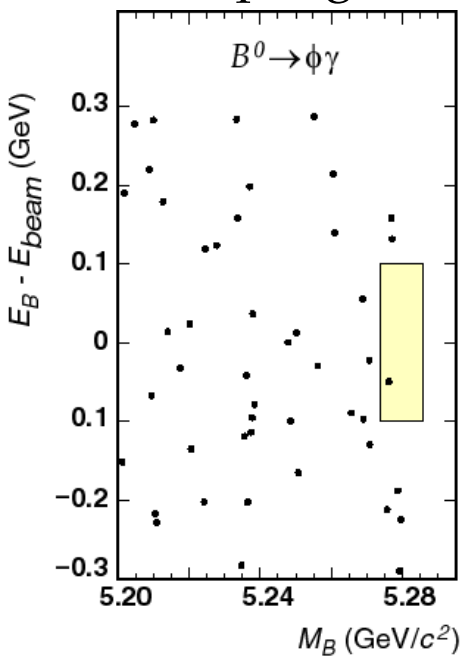
$BF(B \to \omega\gamma) < 0.92 \times 10^{-5}$ @ 90% CL

No observed $b \to d\gamma$

A. Lyon (CLEO) – 2001

$B \to \phi\gamma$

- Look for non-penguin decay:



- Combinatoric bkg = 1.2 ± 0.2
- $\varepsilon = (23.0 \pm 0.6)\%$
- BF($B \to \phi\gamma$) $< 0.33 \times 10^{-5}$ @ (90% CL)

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

$$R \equiv \frac{BF(B \to \rho\gamma)}{BF(B \to K^*\gamma)} = \zeta \left| \frac{V_{td}}{V_{ts}} \right|^2$$

- CLEO: $R < 0.32$ @ 90% CL

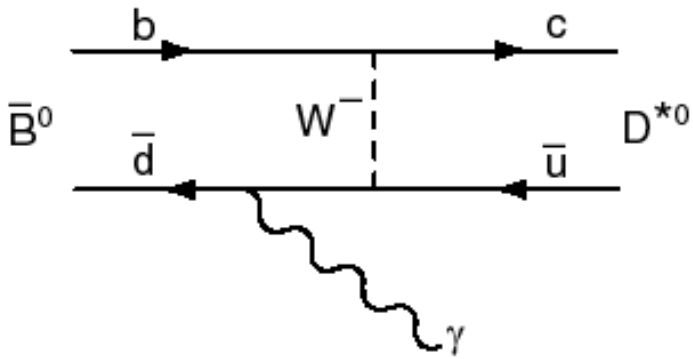
If $\zeta = 0.58$,
$| V_{td} / V_{ts} | < 0.75$

- Assume top-quark electromagnetic penguin dominates

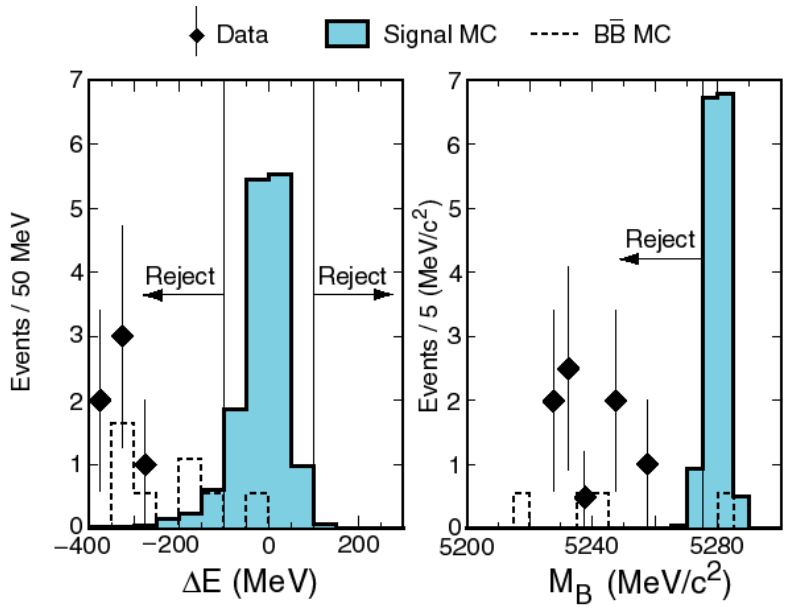
- Belle: $R < 0.28$ @ 90% CL (ICHEP2000)

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

PRL **84**, 4292 (2000)



- Strongly suppressed in SM (10^{-6})
- But possibly enhanced by 10×
  - Gluon emission from initial state quark
  - Large $q\bar{q}g$ component in the B wave function
  - Could be bkg to radiative penguin decays



- $E_\gamma > 1.5$ GeV, π^0 veto, Fisher
- $\varepsilon = 2.3\%$
- In signal region: 0.5 event $\bar{q}q$, 0.9 event BB, No Data Observed
- $\mathrm{BF}(\bar{B}^0 \to D^{*0}\gamma) < 5.0 \times 10^{-5}$
- No big enhancement observed

Conclusions

- **CLEO has examined >60 charmless *B* modes!**
- New results for $B \to \phi K^{(*)}$
  - $BF(B \to \phi K) = (5.5^{+1.8}_{-1.5} \pm 0.7) \times 10^{-6}$
  - $BF(B \to \phi K^*) = (11.2^{+3.6}_{-3.1}{}^{+1.8}_{-1.7}) \times 10^{-6}$
- Small branching fractions ~10^{-6}
  - $BF(B \to \pi^+\pi^-) = (4.3^{+1.6}_{-1.4} \pm 0.5) \times 10^{-6}$
- All but $B \to \eta' K$ in agreement with theoretical predictions (many want more precision)
  - $BF(B \to \eta' K^0) = (8.9^{+1.8}_{-1.6} \pm 0.9) \times 10^{-5}$
- No hint of CP violation
  - from $b \to s\gamma$: $-0.27 < A_{CP} < +0.10$