Rare Decays and Search for New Physics with BABAR

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for the *BABAR* Collaboration

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many results are preliminary

Introduction

Rare Decays of B Mesons

- Good for tests of Standard Model (SM) $\leftrightarrow$ search for new physics
- For flavor-changing neutral currents (FCNC):
  - study breaking of (approximate) flavor symmetry of SM
  - no tree-level contributions
  - sensitive to new physics
- High luminosity at B-Factories (*BABAR* & Belle)
  e^+e^- collisions at $s = 10.58\,\mathrm{GeV}$; so far > 250 M $B\overline{B}$ pairs at *BABAR*
  $\Longrightarrow$ searches for rare decays feasible: $\mathcal{B} \approx 10^{-4}$ or less
- Rare decays in different areas:
  - Radiative decays of $B \to X\gamma$ $\longleftarrow$ topic of this talk
  - Leptonic decays, e.g. $B^0 \to ll$, $B^+ \to \nu\nu$, ...
  - Hadronic decays, e.g. $B^+ \to \eta\pi^+$, $B^+ \to D^+K^0$, ...

See also talks by Fernando Ferroni and Gagan Mohanty

Introduction (cont.)

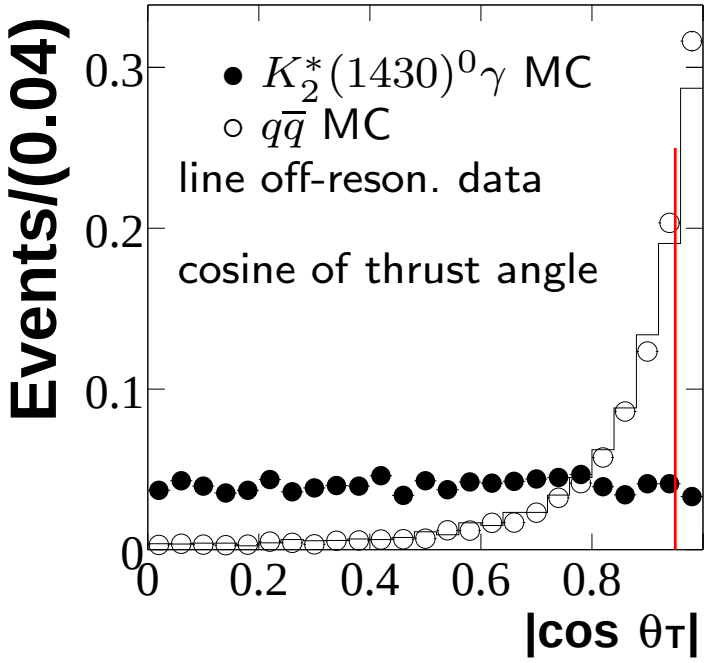
Rare Radiative Decays

- Studies of $b \to s\gamma$
  - inclusive: theoretically clean $\leftrightarrow$ experimentally challenging
    "fully-inclusive" $B \to X_s\gamma$ measurement
    "semi-inclusive" $B \to X_s\gamma$ measurement
  - exclusive: experimentally easier $\leftrightarrow$ theoretically challenging
    $B \to K^*\gamma$, $B \to K_2^*(1430)\gamma$ etc.
- Studies of $b \to sll$
  - semi-inclusive measurements: $B \to X_s ll$
  - exclusive measurements: $B \to K^{(*)} ll$
- Studies of $b \to d\gamma$
  - exclusive measurements: $B \to (\rho, \omega)\gamma$
- $\overline{B}^0 \to D^{*0}\gamma$
- $B^0 \to \phi\gamma$

Analysis Overview

Many analyses share common features

- Hard Photon Selection ($\sim$ 2-3 GeV)
- Hadrons with particle ID
- $q\overline{q}$ (u,d,s,c) continuum
  - hard γ from initial-state radiation & π^0,η decays
  - more jet-like than $B\overline{B}$
  - use *e.g.* thrust $\longrightarrow$
- $B\overline{B}$ Background: Monte Carlo (MC) of generic and specific modes

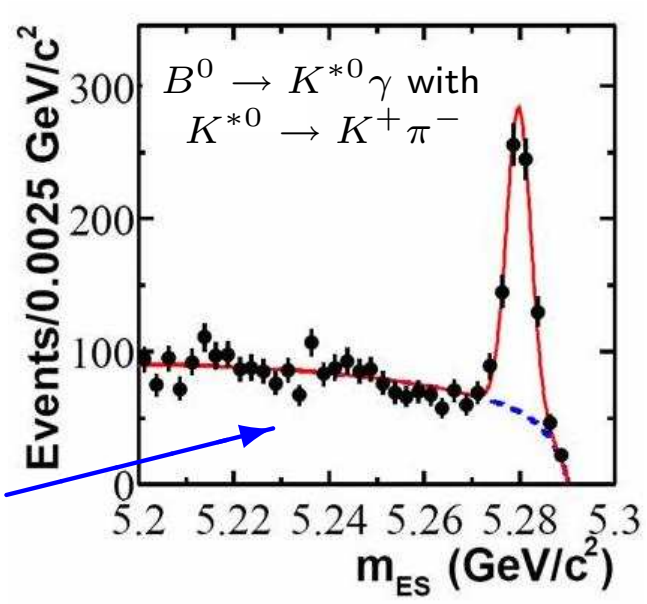


Analysis Overview (cont.)

- Kinematic Variables for B Candidate Selection

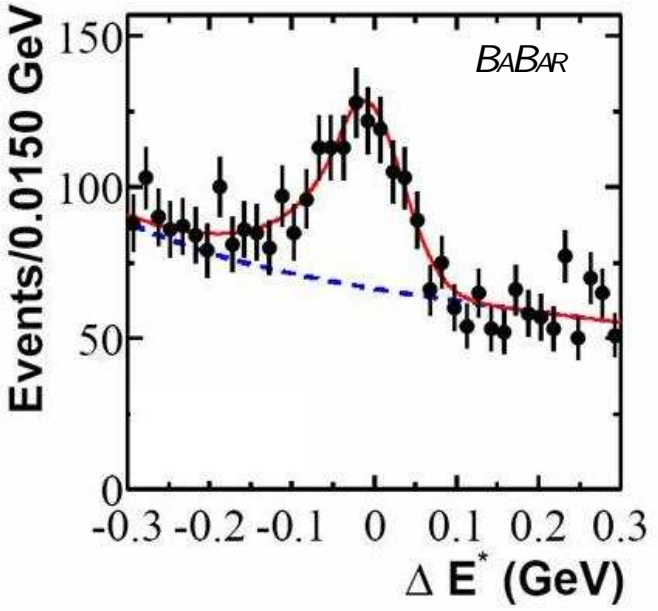
(quantities with * in CM frame)

$$m_{\rm ES} = \sqrt{E^{*2}_{\rm beam} - p^{*2}_B} \qquad \Delta E^* = E^*_B - E^*_{\rm beam}$$



combinatoric background

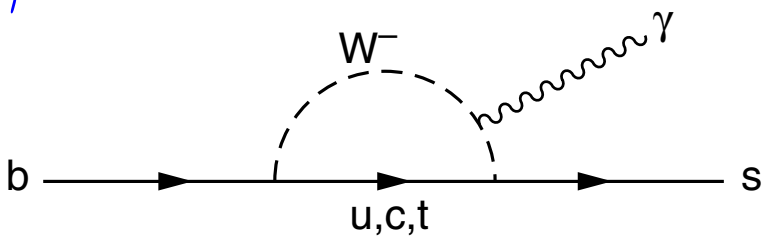
signal peaks at $m_B = 5.28\,\mathrm{GeV}/c^2$



signal peaks at 0 GeV

$B \to X_s\gamma$

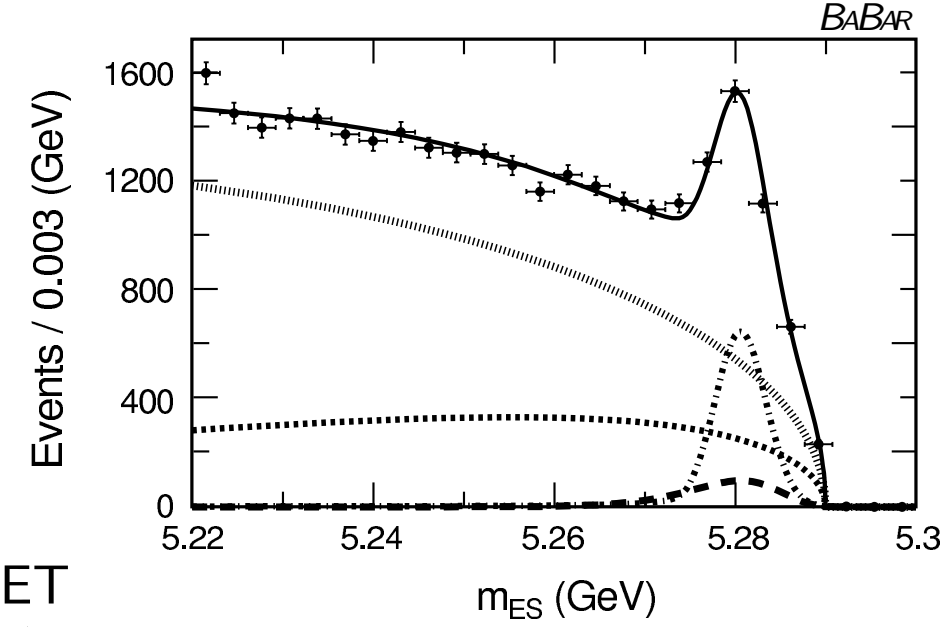
Motivation



- Decay mainly via one-loop $b \to s\gamma$ electromagnetic penguins
- Non-SM virtual particles (e.g. Higgs) may change decay rate
- Measurements of energy-distribution of b quark inside B meson
  $\Longrightarrow$ helps extracting $|V_{ub}|$ from $B \to X_u l\nu$

Fully-inclusive Measurement

- Only photon of $B \to X_s\gamma$ detected
- Large background to suppress

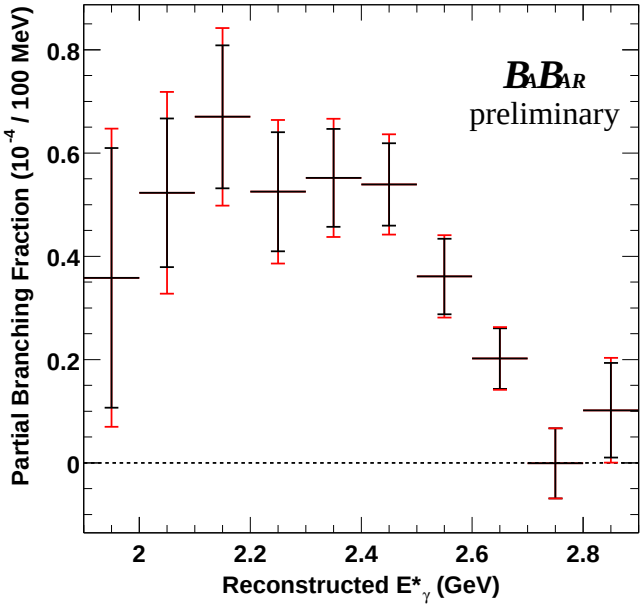


Semi-inclusive Measurement

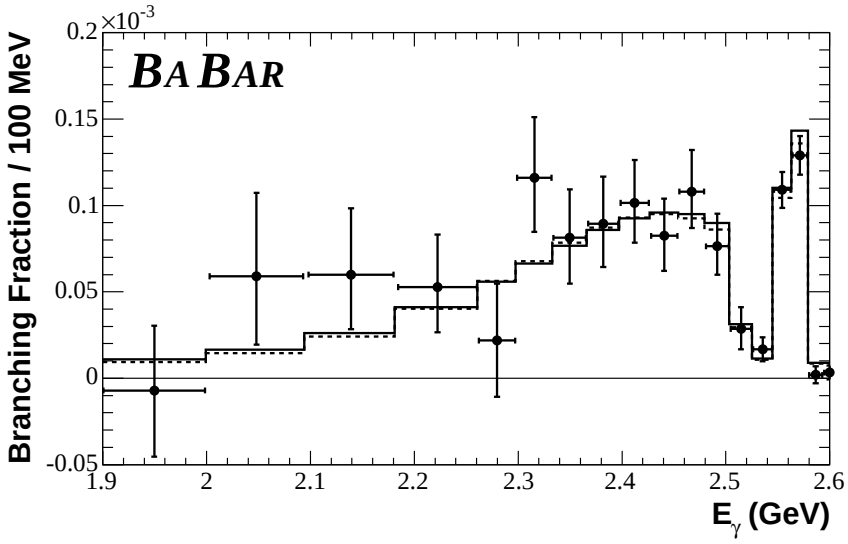
- Sum of 38 exclusive states $\longrightarrow$ involving K, K^0_S, $\pi^{\pm}$,π^0,η
- Fragmentation modeled with JETSET missing modes about 45% of total rate

$B \to X_s\gamma$ (cont.)

Energy Spectra



E_γ spectrum from fully-inclusive analysis (89M $B\overline{B}$ pairs)



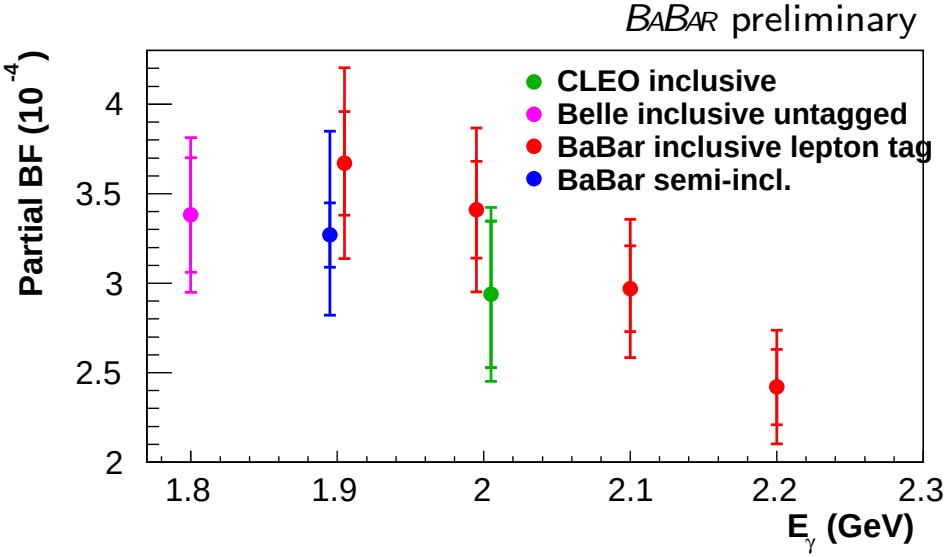
E_γ spectrum (bottom) from semi-inclusive analysis (89M $B\overline{B}$ pairs)

- E_γ would be sharp peak at 2.4 GeV without motion of b quark inside B meson
- Cut at low energy due to backgrounds

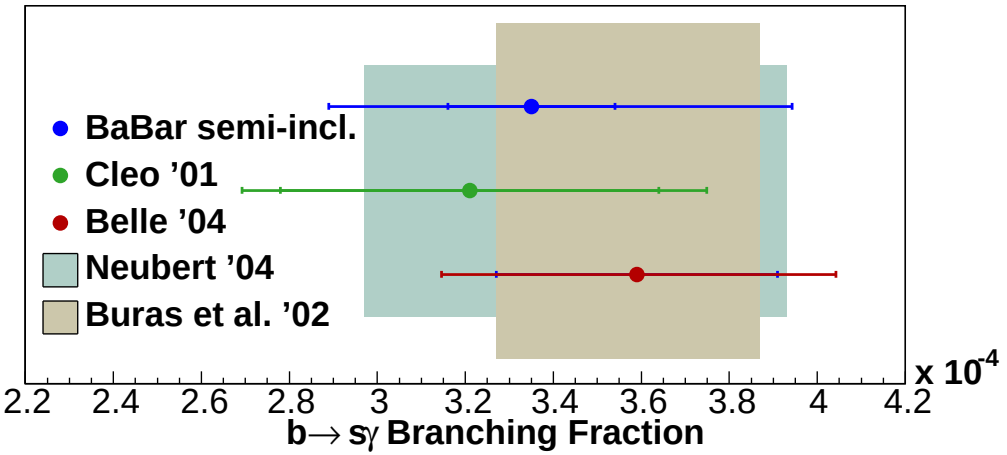
$B \to X_s\gamma$ (cont.)

Results

- Partial branching fractions vs. lower cut in E_γ $\longrightarrow$



- Full branching fractions $\longrightarrow$ (extrapolated to $E_\gamma > 1.6\,\mathrm{GeV}$)



$\Longrightarrow$ agreement with SM and other experiments

hep-ex/0501038,hep-ex/0508004 (accepted by PRD)

$B \to K^*(892)\gamma$ & $B \to K_2^*(1430)\gamma$

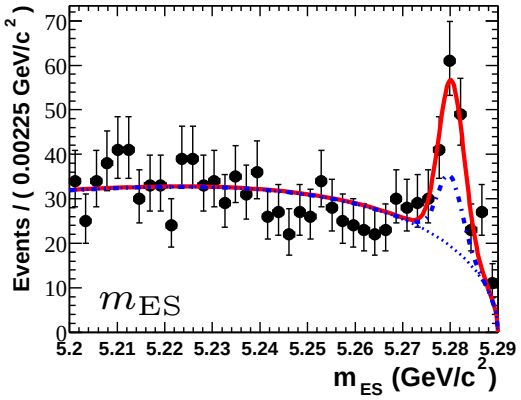
Theory

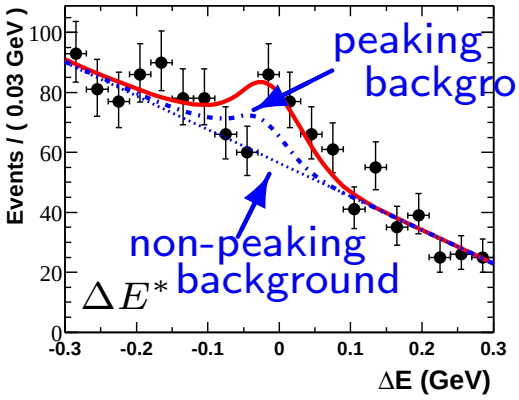
- Non-perturbative hadronic effects complicate theoretical calculations
  $\longrightarrow$ measurements more accurate than predictions
- Theoretical uncertainties reduced in ratios

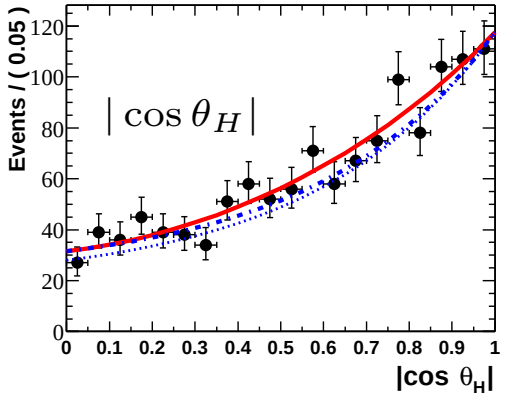
Analysis

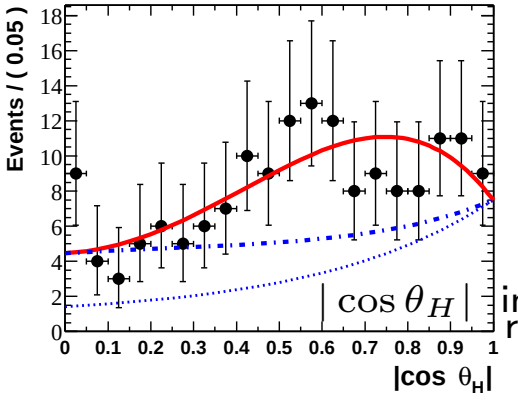
- 4 modes for $K^*\gamma$, 3 modes for $K_2^*(1430)\gamma$
- Major background from $q\overline{q}$
- $B\overline{B}$ Background smaller, for $K_2^*(1430)\gamma$ also bkgd from other $B \to K\pi\gamma$, *e.g.* $K^*(1410)\gamma$
  $\Longrightarrow$ separate via helicity angle

$K_2^*\gamma$ 3-D fit: $m_{\rm ES}$, ΔE^*, helicity angle









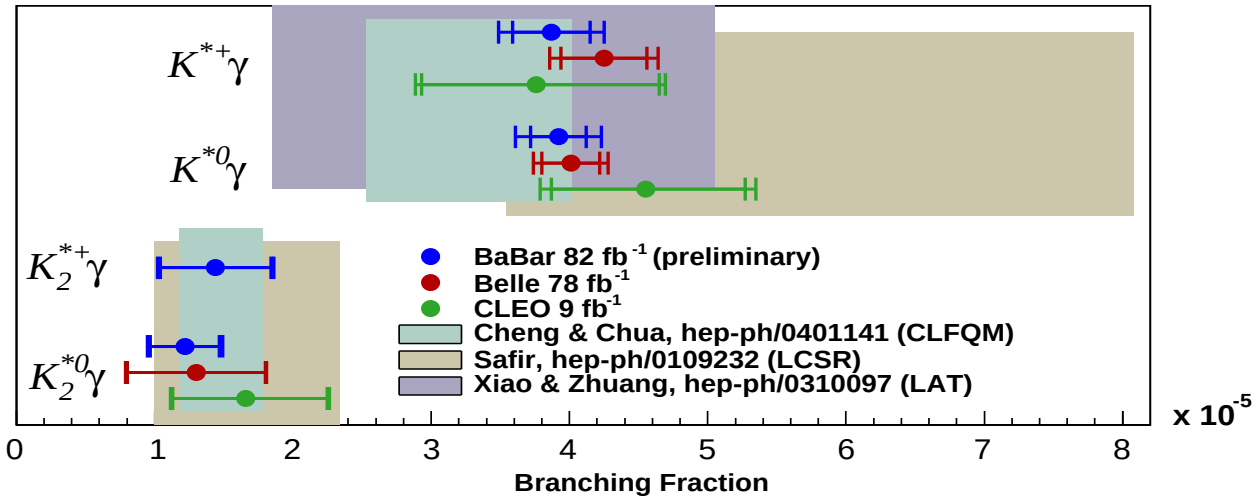
in signal region

$B \to K^*(892)\gamma$ & $B \to K_2^*(1430)\gamma$ (cont.)

Branching Fractions

$K^*\gamma$: 88 M $B\overline{B}$ pairs
$K_2^*\gamma$: 89 M $B\overline{B}$ pairs

$\mathcal{B}$ at $\mathcal{O}(10^{-5})$



Isospin Asymmetry

$$\Delta_{0-} = \frac{\Gamma(\overline{B}^0 \to \overline{K}^{*0}\gamma) - \Gamma(B^- \to K^{*-}\gamma)}{\Gamma(\overline{B}^0 \to \overline{K}^{*0}\gamma) + \Gamma(B^- \to K^{*-}\gamma)}$$

SM: $\quad 6\% < \Delta_{0-} < 13\%$

BABAR: $\quad -4.6\% < \Delta_{0-} < 14.6\%$ @90% C.L.

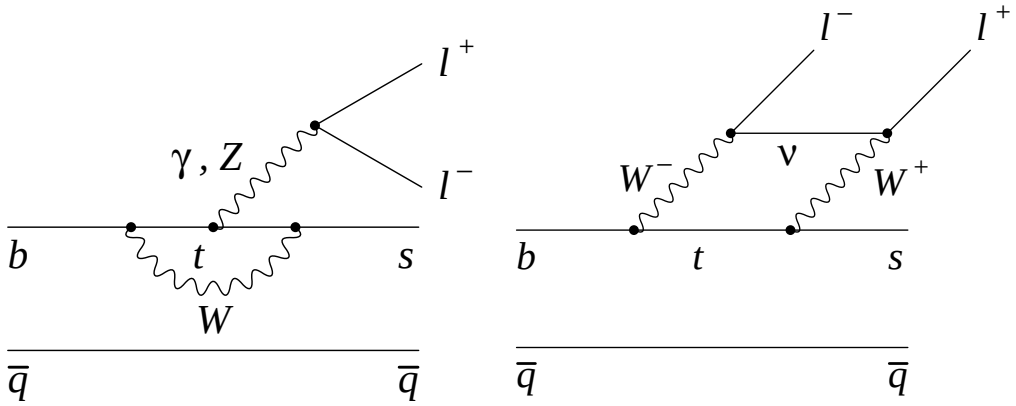
$\Longrightarrow$ all consistent with SM predictions

PRD 70, 112006 (2004), PRD 70, 091105, (2004)

$B^0 \to X_s ll$, $B^0 \to K^{(*)} ll$

Theory

- More complex than $b \to s\gamma$:
  - penguins with γ and Z
  - box-diagram
- Strongly suppressed
- New particles can increase rates



Semi-Inclusive Measurement

- Sum of many exclusive states (89 M $B\overline{B}$ pairs)
- Missing about half of total rate (estimated using JETSET)
- $\mathcal{B}(B \to X_s ll) = (5.6 \pm 1.5 \pm 0.6 \pm 1.1) \times 10^{-6}$ for $m_{ll} > 0.2\,\mathrm{GeV}/c^2$
  SM calculation: $(4.2 \pm 0.7) \times 10^{-6}$ Ali *et al.* hep-ph/0210183 (2002)

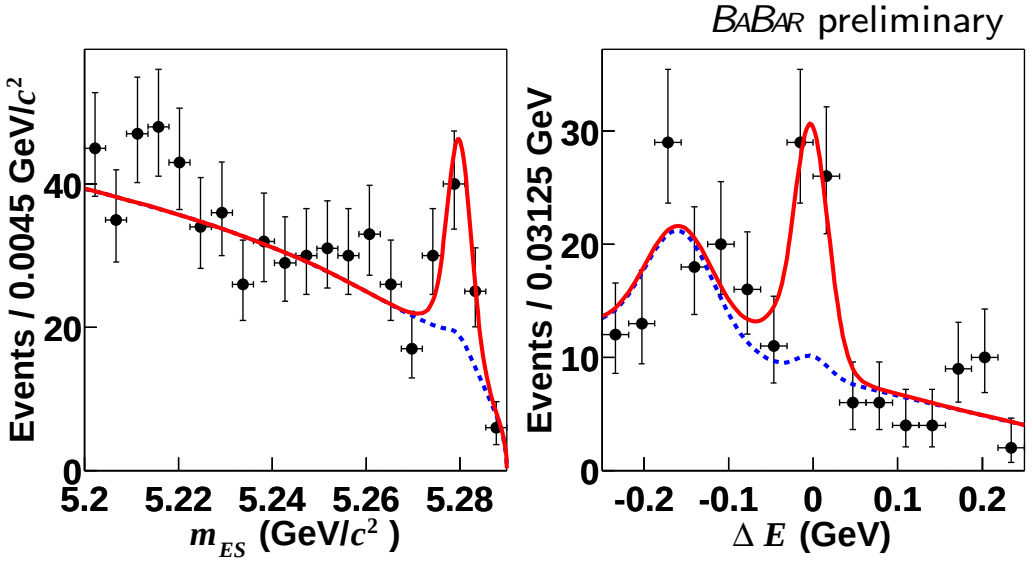
$\Longrightarrow$ agreement with SM (and Belle's result)

PRL **93**, 081802 (2004)

$B^0 \to X_s ll$, $B^0 \to K^{(*)} ll$ (cont.)

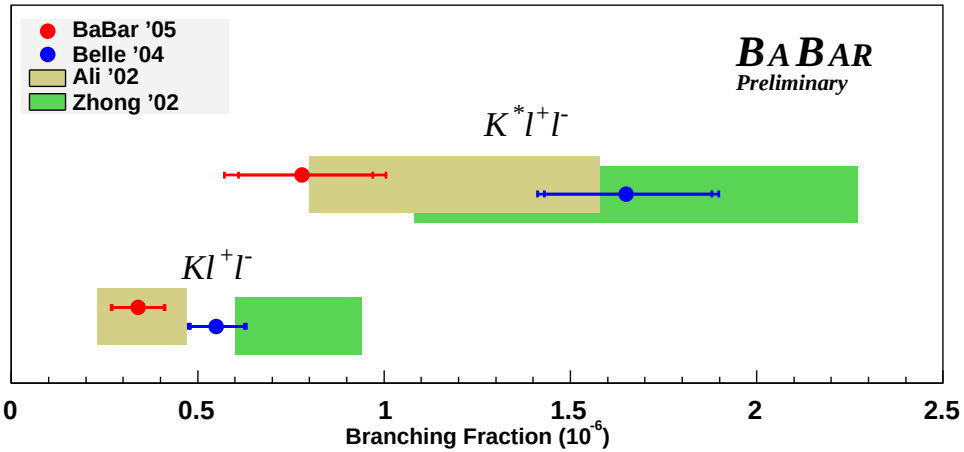
Exclusive Measurements

- $m_{\rm ES}$ and ΔE distributions of Kll in data (229 M $B\overline{B}$ pairs)



- Branching fraction results

  $\Longrightarrow$ agreement with SM



hep-ex/0507005

$B^0 \to \rho\gamma, \omega\gamma$

Theory

- Primarily via penguin diagram,
  partly via W-exchange or W-annihilation
- Contributions from new physics may affect branching faction
- Constraint on $|V_{td}/V_{ts}|$ from

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

ζ: flavor-SU(3) breaking between ρ/ω and K^*
ΔR: W-exchange and W-annihilation diagrams
} from theory

Analysis

- Search in 221 M $B\overline{B}$ pairs
  with modes $\rho^0 \to \pi^+\pi^-$, $\rho^+ \to \pi^+\pi^0$, $\omega \to \pi^+\pi^-\pi^0$
- Background mainly from $q\overline{q}$ continuum
- Maximum likelihood fit to extract signal yield

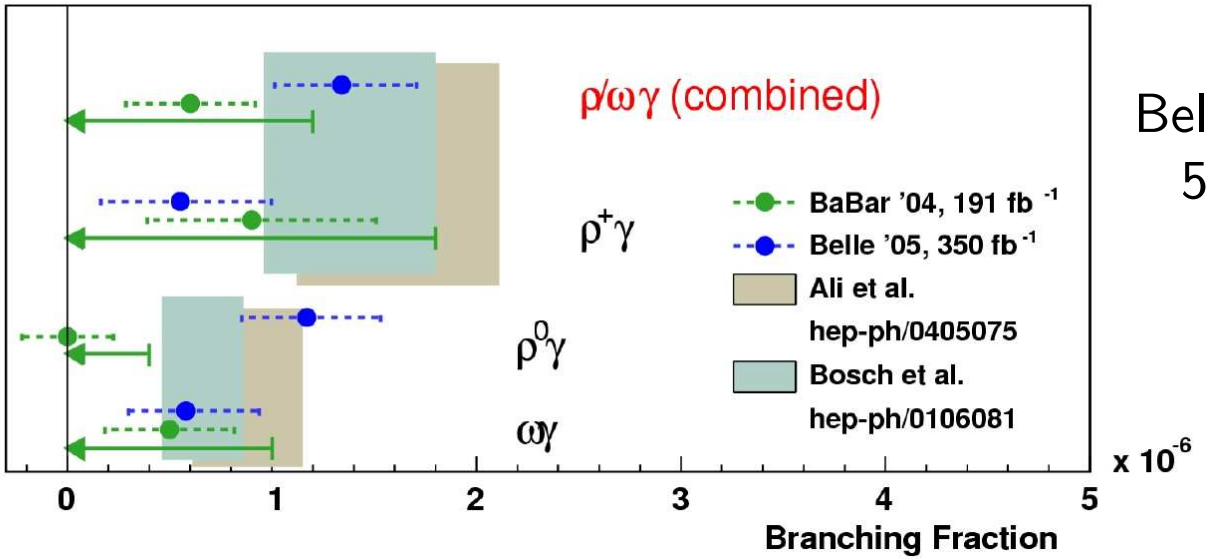
$B^0 \to \rho\gamma, \omega\gamma$ (cont.)

Results

- Combine modes:

$$\mathcal{B}[B \to (\rho/\omega)\gamma] = \frac{1}{2}\left\{\mathcal{B}(B^+ \to \rho^+\gamma) + \frac{\tau_{B^+}}{\tau_{B^0}}\left[\mathcal{B}(B^0 \to \rho^0\gamma) + \mathcal{B}(B^0 \to \omega\gamma)\right]\right\}$$

where τ_{B^+,B^0} = B-meson lifetimes



Belle: seeing mode with 5.5σ significance

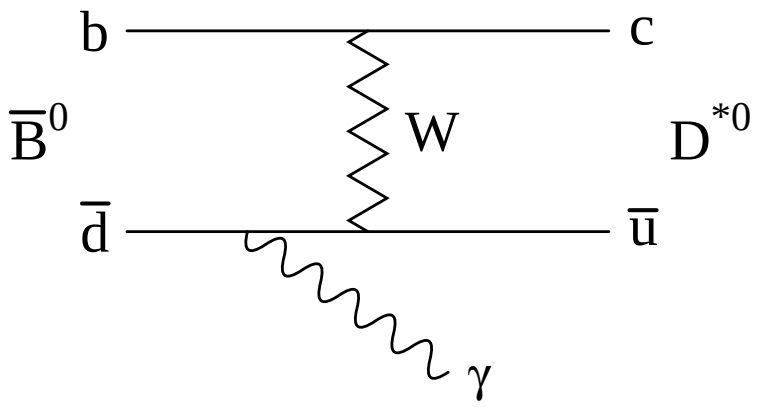
$\Longrightarrow$ agreement with SM

BABAR PRL **94**, 011801 (2005)

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

Theory

- Clean W-exchange decay
- Similar W-exchange also in $B^0 \to \rho\gamma$
- Theoretical estimates about 10^{-6}, but could also be $10\times$ higher



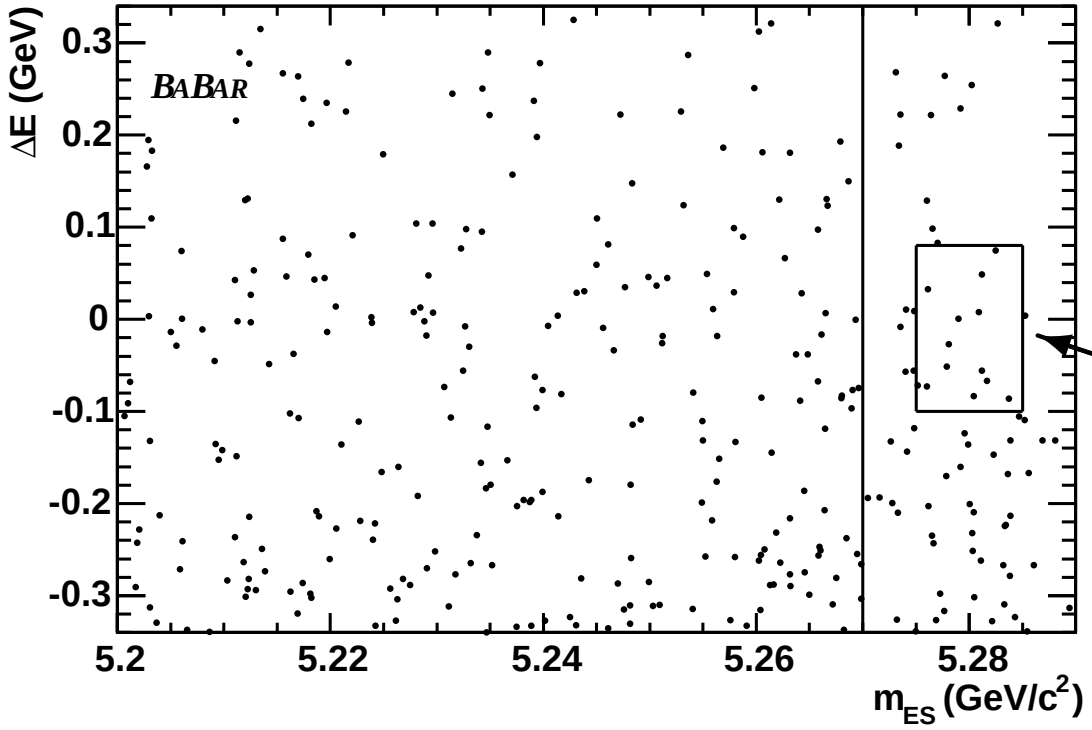
Analysis

- Search among 88 M $B\overline{B}$ pairs in modes $D^{*0} \to (D^0\pi^0, D^0\gamma)$ and $D^0 \to (K\pi, K\pi\pi^0, K\pi\pi\pi)$
- Background mainly from $B\overline{B}$, with biggest from $\overline{B}^0 \to D^{*0}\pi^0$
  $\Longrightarrow$ background has to be taken from MC
- Cut-and-count analysis with signal region

$\overline{B}^0 \to D^{*0}\gamma$ (cont.)

Result

- Expected background 9.4 ± 1.7 events
- Seeing 13 events in signal box



- Branching fraction limit: $\mathcal{B}(\overline{B}^0 \to D^{*0}\gamma) < 2.5 \times 10^{-5}$ (90% C.L.)

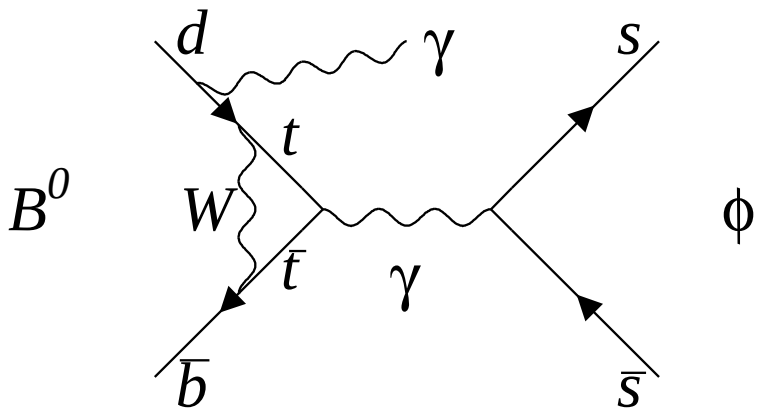
consistent with theoretical estimates

hep-ex/0506070 (accepted by PRD-RC)

$B^0 \to \phi\gamma$

Physics

- Penguin annihilation dominating
- Clean signature, expected to be rare:
  - standard-model prediction:
    $\mathcal{B}(B^0 \to \phi\gamma) = 3.6 \times 10^{-12}$
  - supersymmetric models
    $\mathcal{B}(B^0 \to \phi\gamma) \sim 10^{-9}$ to 10^{-8}



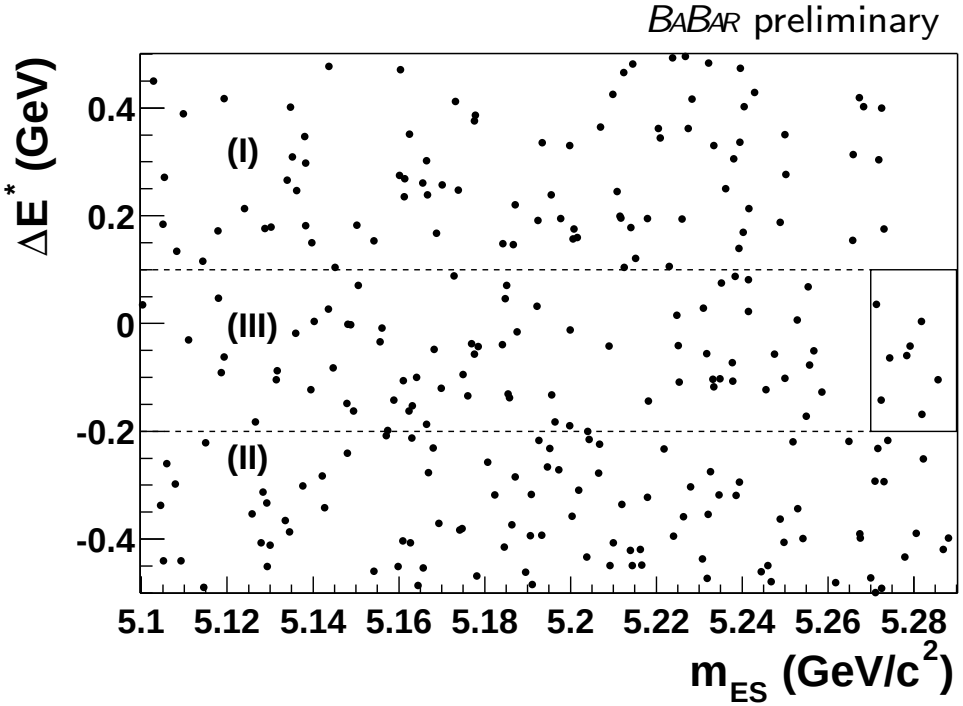
Signal Selection

- Starting with 124 M $B\overline{B}$ pairs
- Reconstruction: $B^0 \to \phi\gamma$ with $\phi \to K^+K^-$
- Cut-and-count analysis with signal region

$B^0 \to \phi\gamma$ (cont.)

Background

- $B\overline{B}$ background from MC $\Longrightarrow < 0.1$ events expected
- Main background from $q\overline{q}$ continuum
- Estimate background from real data sidebands: 6.0 ± 1.0 events expected in signal region



Results

- 8 events in signal box
- No evidence for signal
- Branching fraction limit 8.5×10^{-7} (90% C.L.)

hep-ex/0501038 (submitted to PRD-RC)

Conclusion

- Radiative rare decays are important for test of the Standard Model and searches for new physics
- B-Factories measured branching fractions of several radiative decays and set limits on others
- Only able to show small fraction of decays studied
- So far no hint found for new physics
- Tests will become more stringent:
  - many analyses only on part of existing data sample
  - double the data sample by end of next year
  - more years to come for *BABAR* and Belle