Rare B and D Decays at BaBar

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Representing the BaBar Collaboration at the

46th Rencontres de Moriond: Electroweak Interactions and Unified Theories

> La Thuile, Italy March, 13-20, 2011

BABAR





Rare Decays: Window into New Physics

- New Physics (NP) can be revealed in low-energy flavour processes
- Particularly fruitful areas of investigation are processes with small effects predicted by the Standard Model
 - Rare decays
 - Flavour-changing neutral currents (FCNC)
- Strong constraints on already put on NP from these kinds of decays



Outline

- Direct CP asymmetry in $B \rightarrow X_{(s+d)}\gamma$
- Rare leptonic decays
 - $B^+ \rightarrow \tau^+ \nu$
 - $B \to K \nu \bar{\nu}$
 - $B^+ \rightarrow K^+ \tau^+ \tau^-$
- Very rare decays
 - $B^0 \rightarrow \gamma \gamma$ and
 - $D^0 \rightarrow \gamma \gamma$

BaBar Experiment

- Asymmetric Bfactory: $E_{cms} =$ 10.58 GeV $\Upsilon(4S) \rightarrow B\bar{B}$
- Performed a wide range of flavour physics results in B, charm and T sectors
- General purpose detector:
 - precision tracking
 - photon/electron detection
 - Particle ID
 - muon/K_L identification



Total Dataset:

A_{CP} in B \rightarrow X_(s+d)Y

Direct CP asymmetry in inclusive $B \rightarrow X_s \gamma$

- This mode has been the "workhorse" of radiative B decay physics — the SM branching fraction (PRL 98, 022002 (2007)), is known to 7-8% and deviations from NP can be substantial (arXiv:0805.2141 provides an interesting summary)
- Inclusive measurement:
 - What? no requirements on X_S system, identify events by high-energy photon
 - Why? because smaller theoretical uncertainties
 - **Consequence**: mode studied is actually $B \rightarrow X_{(s+d)}\gamma$
- CP asymmetry is also sensitive to NP. SM A_{CP} ~ 10⁻⁶, while it can be ~ 10% in NP scenarios (Nucl. Phys. B704 (2005) 56-74)



CP Asymmetry

$$A_{CP} = \frac{\Gamma(b \to s\gamma + b \to d\gamma) - \Gamma(\overline{b} \to \overline{s}\gamma + \overline{b} \to \overline{d}\gamma)}{\Gamma(b \to s\gamma + b \to d\gamma) + \Gamma(\overline{b} \to \overline{s}\gamma + \overline{b} \to \overline{d}\gamma)}$$

A_{CP} in inclusive $B \rightarrow X_{(s+d)}\gamma$

Experimental issues:

- High-energy photon: E_Y*>1.5 GeV
- Lepton tag:
 - Electron or muon candidate with p* > 1.05 GeV
 - $E^*_{miss} > 0.7 \text{ GeV}$

 $\cos\theta^*_{\gamma\ell} > -0.7$

- Continuum background
 - subtracted using off-resonance data
- BB background
 - $\text{ mostly } \pi^0 \rightarrow \gamma \gamma, \eta \rightarrow \gamma \gamma \Rightarrow$
 - explicitly vetoed, remaining BG determined from control sample
 - control samples also used for other sizable BB backgrounds

Photon Spectrum (MC)



A_{CP} inclusive $B \rightarrow X_{(s+d)} \gamma$:

- Control regions:
 - continuum: On-Off Data = -100 ± 138 events
 - BB: $1252\pm272\pm841 \Rightarrow 1.4\sigma$ (assumes no signal, where expect 100-400 signal events in low-energy tail)
- A_{CP} is insensitive to photon energy cut: optimize \Rightarrow (2.1-2.8) GeV
- Yields:
 - $N(I+) = 2623 \pm 158$
 - $N(I_{-}) = 2397 \pm 151$

 $\omega = 0.131 \pm 0.0064$

(B⁰ mixing)

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Account for mistag and bias:



$B^+ \rightarrow \tau^+ v$

$B^+ \rightarrow \tau^+ \nu$

- Powerful probe of NP
- Sensitive to charged Higgs boson:

$$B_{NP} = B_{SM} \left(1 - \tan^2 \beta \frac{m_B^2}{m_H^2} \right)^2$$

 Helicity suppression leads to higher BF for τ final state in SM:

$$B(B^+ \to \tau^+ \nu) \sim 1 \times 10^{-4}$$

$$B(B^+ \to \mu^+ \nu) \sim 4 \times 10^{-7}$$

$$B(B^+ \to e^+ \nu) \sim 1 \times 10^{-12}$$



Latest SM Value:

$$B_{SM}(B^+ \to \tau^+ \nu) = (1.20 \pm 0.20) \times 10^{-4}$$

Inputs:

 $|V_{ub}| = (4.32 \pm 0.33) \times 10^{-4}$ $f_B = 190 \pm 13 \text{ MeV}$ $\tau_{B^+} = 1.638 \pm 0.011 \text{ ps}$

$B^+ \rightarrow \tau^+ \nu$: Experimental technique

- Few kinematic handles to reconstruct $B^+ \rightarrow \tau^+ v$
- Reconstruct "other B" completely
 - remove many tracks from further consideration
 - look for signal in remaining tracks and clusters
- Reconstruct 4 τ decay modes:
 - $e_{VV}, \mu_{VV}, \pi_{V}, \rho_{V} \Rightarrow about 72\%$ of total BF
 - Key discriminating variable: **Eextra**: sum of neutral energy not associated with either reconstructed B meson
- $B^+ \rightarrow \tau^+ \nu$ will show an excess of events at Eextra ~ 0.



$$X = n\pi^{\pm} + mK + p\pi^{0} + qK^{0}$$
$$n + m \le 5, \quad m, p, q \le 2$$

Total efficiency, including T BFs: 8×10^{-4}

$B^+ \rightarrow \tau^+ \nu$: results

- Likelihood fit to Eextra variable to extract $B^+ \rightarrow \tau^+ v$ signal
- Signal template of *Eextra* from MC, corrected using double-tagged data
- Background templates:
 - combinatoric: m_{ES} sideband
 - peaking: from B⁺B⁻ MC
- Fit yield: 69 ± 21 events
- Preliminary branching fraction:

$$B(B^+ \to \tau^+ \nu_{\tau}) = (1.80^{+0.57}_{-0.54 \text{ stat}} \pm 0.26_{\text{syst}}) \times 10^{-4}$$





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$B \rightarrow K v \overline{v}$

Search for $B \rightarrow K \nu \nu$



- b→s FCNC, analogous to B → Kl⁺l⁻, and therefore sensitive to NP: unparticles, MSSM, universal extra dimensions, etc.
- Standard Model BF small ~ 3.8 x 10⁻⁶
- NP models predict BF up to a factor of 10 larger

Previous measurements

Mode	Upper Limit (90% CL)	Experiment	Dataset (fb ⁻¹)	Reference
B⁺→ K⁺νν	I.4 x 10 ⁻⁵	Belle	492	PRL 99, 221802 (2007)
B⁺→ K⁺νν	5.2 × 10 ⁻⁵	BaBar	82	PRL 94, 101801 (2005)
B ⁰ → K ⁰ νν	1.6 x 10 ⁻⁴	Belle	492	PRL 99, 221802 (2007)

$B \rightarrow Kvv$: Experimental Techniques

- As for $B^+ \rightarrow T^+ V$, few kinematical constraints on final state \Rightarrow reconstruct "other" B in event in <u>semileptonic</u> B decay
- Look for signal decay among remaining particles of event



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$B \rightarrow Kvv$: Experimental Techniques II



- Suppress high remaining background using multivariate classifier: Bagged Decision Trees (BDT)
- Ensemble of BDTs trained on simulated signal and background events
- Trees use 26 (K⁺) or 38 (K⁰) variables relating to i) missing energy, ii) event shape, iii) signal kinematics and iv) quality of reconstructed tag
- Selection optimized for signal significance: s/(s+b)^{1/2}

	Mode	ϵ (in %)	$N_{ m sgnl}$	N _{bkgd}
	K^+	0.16	2.9 ± 0.4	$17.6 \pm 2.6 \pm 0.9$
	K_S^0	0.06	0.5 ± 0.1	$3.9 \pm 1.3 \pm 0.4$
	low- $q^2 K^+$	0.24	2.9 ± 0.4	$17.6 \pm 2.6 \pm 0.9$
² -dependence	high- $q^2 K^+$	0.28	2.1 ± 0.3	$187 \pm 10 \pm 46$

Expected events

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$B \rightarrow Kvv:$ Results

Observed events

Mode	$N_{ m obs}$	Nobs - NBG
K^+	$19.4^{+4.4}_{-4.4}$	$1.8^{+6.2}_{-5.1}$
K^0	$6.1^{+4.0}_{-2.2}$	$2.2^{+4.1}_{-2.8}$
low- $q^2 K^+$	$19.4_{-4.4}^{+4.4}$	$1.8^{+6.2}_{-5.1}$
high- $q^2 K^+$	164^{+13}_{-13}	-23^{+49}_{-48}



Upper limits

Mode	BF	90% CL	95% CL
	$\times 10^{-5}$	$\times 10^{-5}$	$\times 10^{-5}$
K^+	$0.2^{+0.8}_{-0.7}$	1.3	1.6
K^0	$1.7^{+3.1}_{-2.1}$	5.6	6.7
Comb. K^+ , K^0	$0.5^{+0.7}_{-0.7}$	1.4	1.7
Low- $q^2 K^+$	$0.2^{+0.6}_{-0.5}$	0.9	1.1
High- $q^2 K^+$	$-1.8^{+3.8}_{-3.8}$	3.1	4.6

Phys. Rev. D 82,	112002	(2010)
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Best limits achieved to date

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$B^+ \rightarrow K^+ \tau^+ \tau^-$

Search for $B^+ \rightarrow K^+ \tau^+ \tau^-$

- Relative of $B \rightarrow KI^+I^-$, where I=e or μ
- Standard Model BF smaller due to T mass ~ 4.3 x 10⁻⁷ for $s=m_{ au au}^2/m_b^2>0.6$
- In some models (NMSSM), BF can depend on lepton mass:

$$BF = \left(rac{m_{ au}^2}{m_{\mu}^2}
ight) BF_{SM}$$







$B^+ \rightarrow K^+ \tau^+ \tau^-$: Experimental Techniques

- Hadronic tag on "other B"
- Signal side selections:
 - exactly 3 tracks
 - particle ID
 - q² > 14.23 GeV²
 - thrust angle of signal/tag side decays
 - missing energy
 - extra neutral energy
 - hard track momentum
 - reduce $B^- \rightarrow I^-X BG$



 $\tau \to e \nu \bar{\nu}, \mu \nu \bar{\nu}, \pi \nu$

20





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Extra neutral energy Arbitrary Units 2000 5000 3000 MC Peaking + Data Combinatoric Estimation Signal (Scaled) Signal 1500 1000 BG 500 3 4 4.5 0.5 3.5 Eextra [GeV]

$B^+ \rightarrow K^+ \tau^+ \tau^-$: Results

Expected events: 65±7 Observed events: 47

Primary systematics:

signal efficiency: 15%

background estimation: 17%



Upper limit
(90% CL):
$$B(B^+ \to K^+ \tau^+ \tau^-) < 3.3 \times 10^{-3}$$

first experimental limit

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$B^0 \rightarrow \gamma \gamma$ and $D^0 \rightarrow \gamma \gamma$

Search for $B^0 \rightarrow \gamma \gamma$



- Involves $b \rightarrow d\gamma\gamma$ transition
 - small SM BF ~ $(3.1^{+6.4}_{-1.6}) \times 10^{-8}$ JHEP 08 (2002) 054
- Can be enhanced by NP scenarios
 - extended Higgs sector: Aliev and Iltan, PRD 58, 095014 (1998)
 - SUSY with broken R-parity: Gemintern, Bar-Shalom and Eilam, PRD 70, 035008 (2004)

Best limit to date: $B(B^0 \rightarrow \gamma \gamma) < 6.2 \times 10^{-7}$ (90% CL) Belle, PRD 73, 051107 (2006)

$B^0 \rightarrow \gamma \gamma$: Background suppression

Background sources

- Decays of π^0 and η decays
 - reject with Likelihood ratio based on $m(\gamma \gamma')$ and $E_{\gamma'}$
- out-of-time Bhabha event overlap:
 - rejected with total energy and timing cuts
- Generic continuum events
 - Multivariate classifier (neural network) based on 19 input variables



 $B^0 \rightarrow \gamma \gamma$: Results

467 M BB pairs

- 2-D likelihood fit to m_{FS} and ΔE variables
- Signal yield: 21.3^{+12.8}_{-11.8} events

Likelihood function

90% CL

60

Nsig

70



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20

30

40

50

10

0.8

0.6 L/L₀

0.4

0.2

0

0

$D^0 \rightarrow \gamma \gamma$

(470 fb⁻¹)

 Highly suppressed by GIM mechanism (light down quark sector), but long distance effects can be substantial → SM (PRD 66, 014009 (2002):

 $B(D^0 \to \gamma \gamma) \simeq (3.5^{+4.0}_{-2.6}) \times 10^{-8}$

- SUSY can produce large enhancements, up to 200x (PLB 500, 304 (2001))
- Current limit (PDG): $B(D^0 \rightarrow \gamma \gamma) < 2.7 \times 10^{-5}$



- Tag with $D^{*+} \rightarrow D^0 \pi^+$
- $p(D^*) > 2.85$ GeV, to reject $B \rightarrow D^0 X$
- Main background: $D^0 \rightarrow \pi^0 \pi^0 \Rightarrow$ explicitly reject π^0
- Selection efficiency = 6.1%
- Also measure explicitly $D^0 \rightarrow \pi^0 \pi^0$ and reference mode $D^0 \rightarrow K_s \pi^0$
- Fit to D⁰ mass distribution to extract signal



Signal yield: -6±15 events

Preliminary Upper limit (90% CL):



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Conclusions

- Many rare decay processes are sensitive to New Physics scenarios
- BaBar continues to make measurements of rare processes, especially flavor-changing-neutral-current processes, which are particular powerful in constraining NP models
- In addition to the results I've presented today, we expect to produce updated results for $B(b \rightarrow s\gamma)$ and a suite of measurements using $B \rightarrow K^{(*)}I^+I^-$ in the near future
- We also look forward to many interesting flavour results from LHCb and, looking a bit further down the road, from Belle-2 and SuperB.

Backup slides

BaBar Dataset

Integrated Luminosity [fb⁻¹] BaBar 500 PEP II Delivered Luminosity: 553.48/fb BaBar Recorded Luminosity: 531.43/fb BaBar Recorded Y(4s): 432.89/fb BaBar Recorded Y(3s): 30.23/fb BaBar Recorded Y(2s): 14.45/fb Off Peak Luminosity: 53.85/fb 400 BaBar dataset: 468 M Delivered Luminosity **BB** pairs Recorded Luminosity Recorded Luminosity Y(4s) Recorded Luminosity Y(3s) Recorded Luminosity Y(2s) 300 and 54 fb⁻¹ off-resonance Off Peak data 200 100

As of 2008/04/11 00:00

2007

2008