Recent Results in Rare Decays at BaBar

Colin Jessop

University of Notre Dame

Representing the BaBar Collaboration

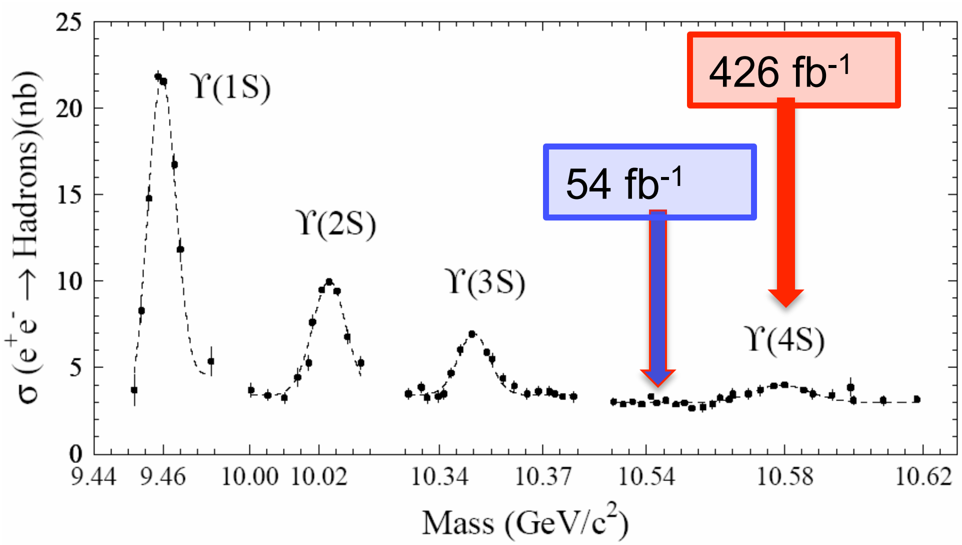
At the Xth International Conference on Heavy Quarks and Leptons

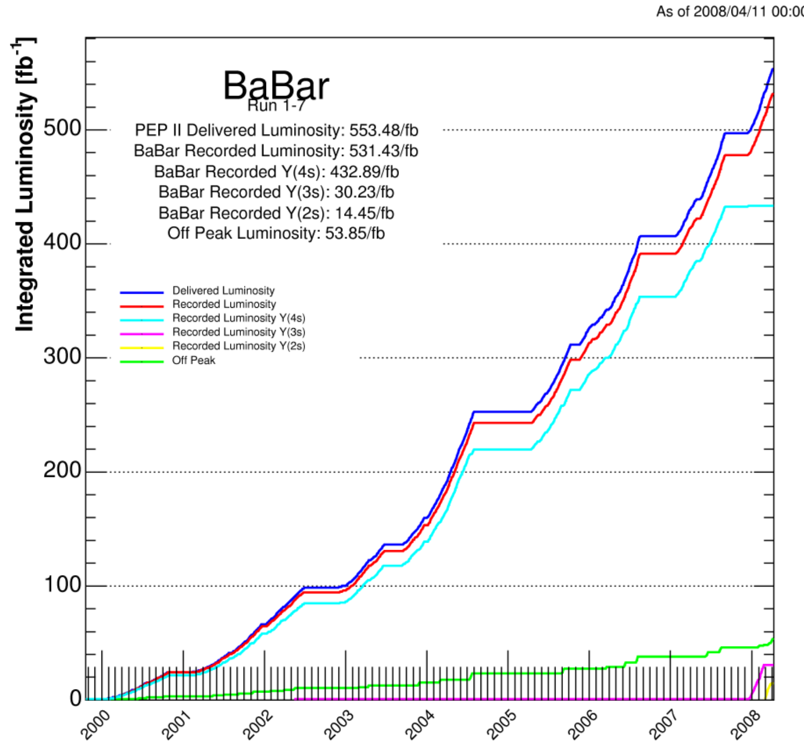
Rare Decay Searches

Motivation: To search for rates enhanced over SM predictions that may arise from new virtual heavy mass particles in quantum loops

1. Search for $B \to K \nu \bar{\nu}$
2. Search for $B \to K^+ \tau^+\tau^-$
3. Search for $B^0 \to \gamma\gamma$
4. Measurement of $B \to X_d\gamma$

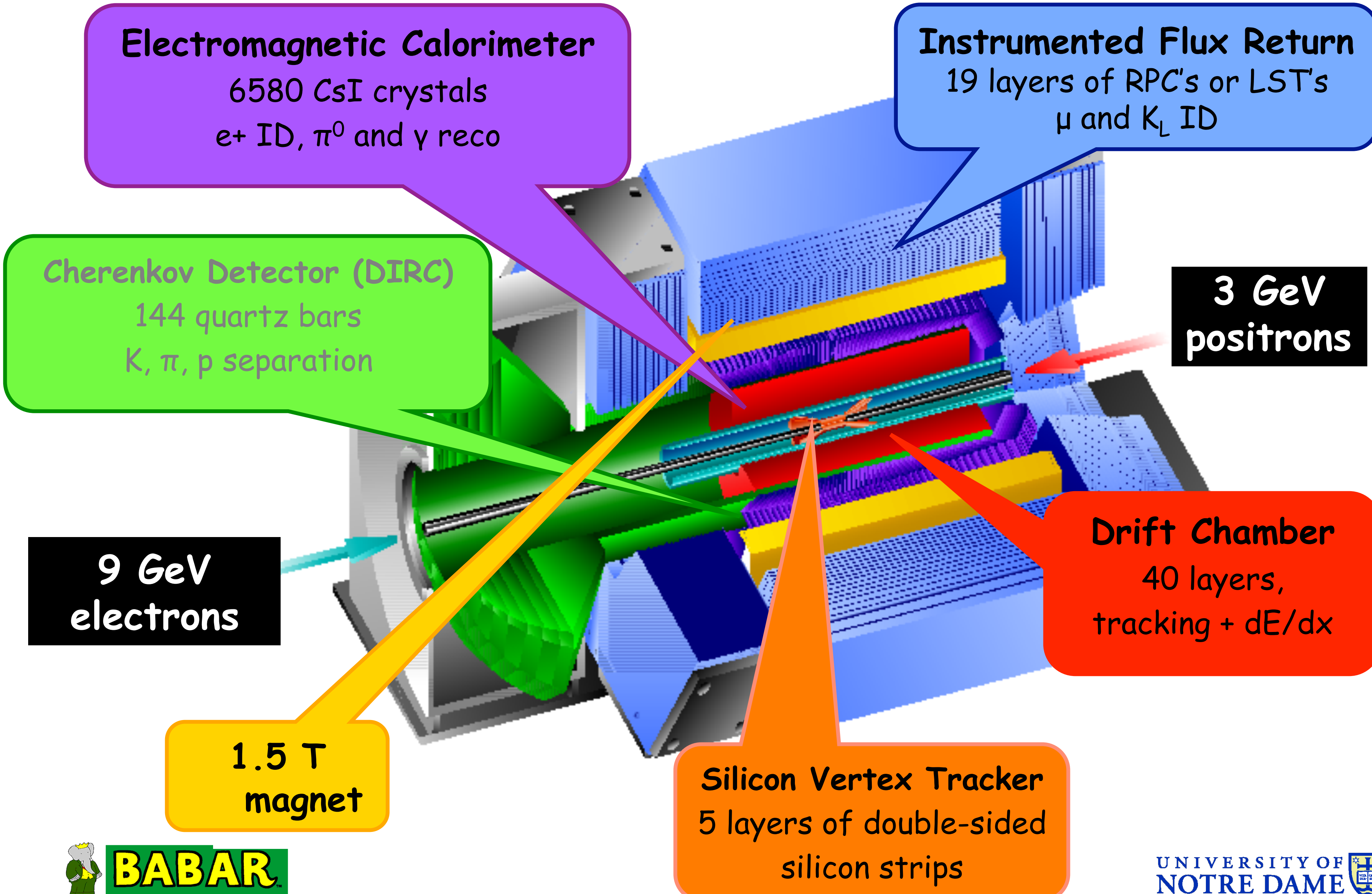
The BaBar Dataset





BaBar collected *468 M BB* pairs between 2000-2007 and 54 fb^{-1} off-resonance data

The BaBar Detector



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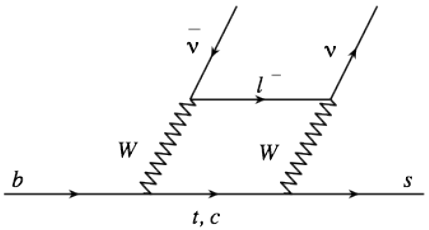
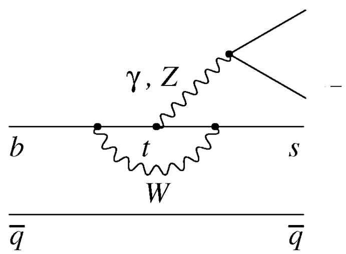
Search for B → $K\nu\bar{\nu}$

Standard Model



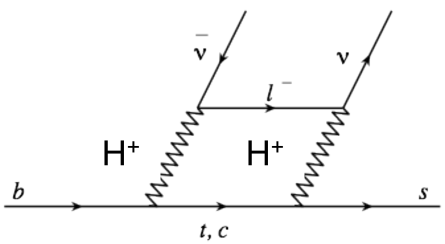


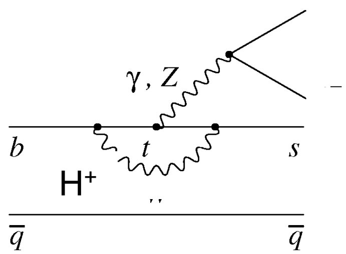
$B(B^0 \rightarrow K\nu\bar{\nu}) \sim 3.2\text{-}5.2 \times 10^{-6}$

Altmannshofer,Buras,Straub,Wick JHEP 0904, 02 (2009)

Buchalla,Hiller,Isidori 63 014015 (2000)

Physics Beyond Standard Model





$B(B^0 \rightarrow K\nu\bar{\nu}) \sim O(10^{-5})$

(MSSM,unparticles,extra dimensions)

Yamada PRD 77 014025,Aliev etal JHEP 07(072

Colangeo etal PRD 73 115006

Previous Measurements

Experiment	BF (90% CL)	Dataset	*Reference*
Belle	$< 1.4 \times 10^{-5}$	*492 fb^{-1}*	*Chen etal PRL 99 221802, 2007*
BaBar	$< 5.2 \times 10^{-5}$	*82 fb^{-1}*	*Aubert et al. 94 1018011*

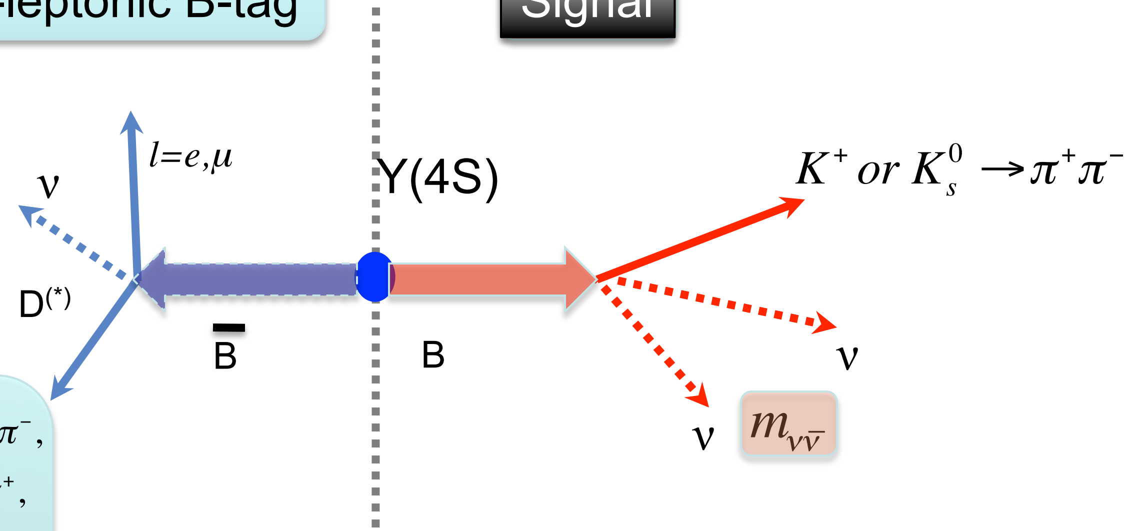
Search for $B \to K\nu\bar{\nu}$: Experimental Technique

Identify BB events by tagging with semi-leptonic $B \to D^{(*)} l \nu$ decays

Semi-leptonic B-tag

Signal

$\varepsilon_{tag} \approx 1\%$



$$D \to K^-\pi^+, K^-\pi^+\pi^+, K^-\pi^+\pi^+\pi^-,$$
$$K^-\pi^+\pi^0, (K^0_s \to \pi^+\pi^-)\pi^+,$$
$$(K^0_s \to \pi^+\pi^-)\pi^+\pi^-$$
$$D^{*+} \to D^0\pi^+, D^+\pi^0$$
$$D^{*0} \to D^0\pi^0$$

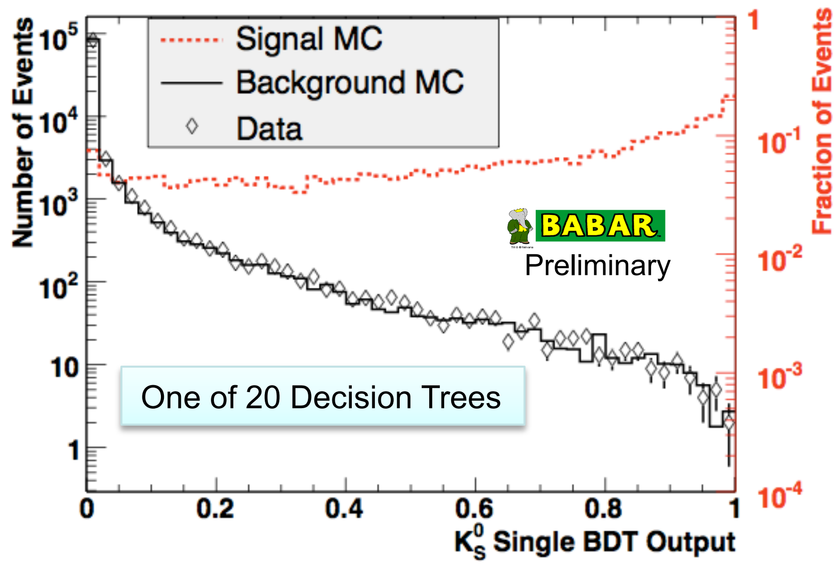
Some new physics would enhance rate in $(q^2 = m^2_{\nu\bar{\nu}}) > 0.4 m^2_B$ *region*

Search for $B \to K\nu\bar{\nu}$:Background Suppression

Bagged Decision Tree (BDT)

Ensemble of 20 Decision Trees trained on MC signal and background

Each Decision Tree constructed from 26 Variables broadly classified as either E_{miss}, Event Properties, Signal side kinematics , and B_{tag} reconstruction quantities



N_{obs} is from on-resonance data, N_{bkg} is expected from MC, ε is signal efficiency derived from MC

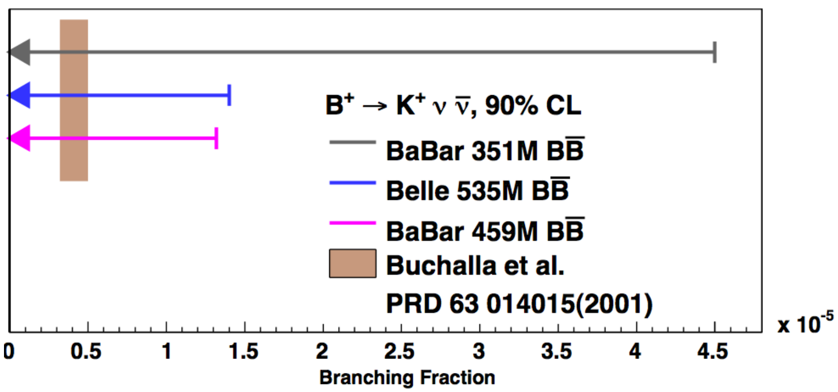
Mode	$\epsilon(\%)$	N_{sig}	N_{bkg}	N_{obs}	N_{excess}
K^+	0.16	2.9 ± 0.4	$17.6 \pm 2.6 \pm 0.9$	$19.4^{+4.4}_{-4.4}$	$1.8^{+6.2}_{-5.1}$
K^0_s	0.06	0.5 ± 0.1	$3.9 \pm 1.3 \pm 0.4$	$6.1^{+4.0}_{-2.2}$	$2.2^{+4.1}_{-2.8}$
low-q^2	0.24	2.9 ± 0.4	$17.6 \pm 2.6 \pm 0.9$	$19.4^{+4.4}_{-4.4}$	$1.8^{+6.2}_{-5.1}$
high-q^2	0.28	2.1 ± 0.3	$187 \pm 10 \pm 46$	164^{+13}_{-13}	-23^{+49}_{-48}

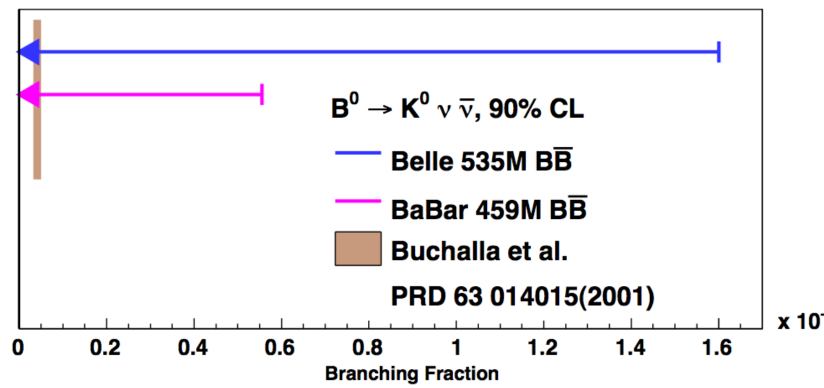
Search for $B \to K\nu\bar{\nu}$:Results

arXiv:1009.1529

Category	Uncertainty
Signal efficiency	14%
K^+ background prediction	5%
High-q^2 K^+ background prediction	25%
K_S^0 background prediction	10%

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

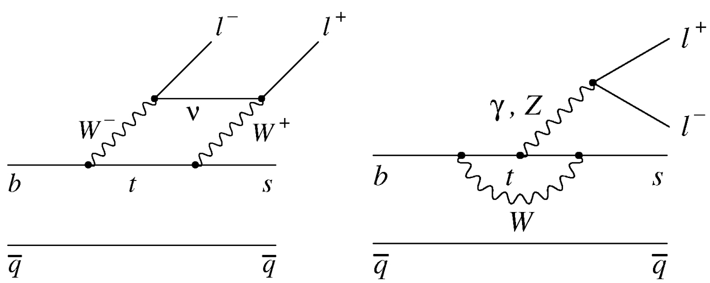


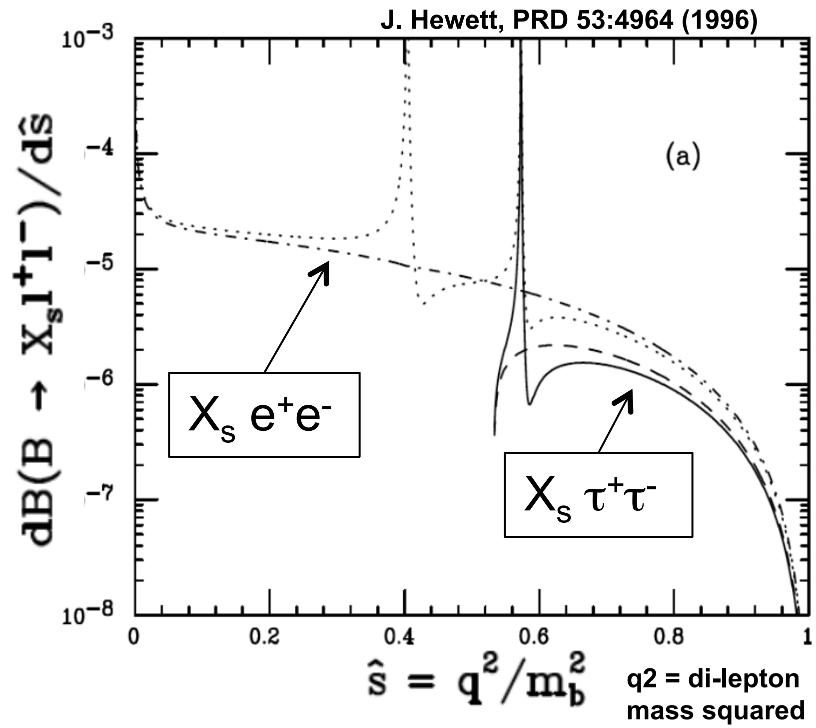


No signal observed but most stringent limits to date are set

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

Standard Model





$$B(B \rightarrow X_s l^+ l^-)$$

Lepton	$0.6 \leqslant \hat{s} \leqslant 1$
Electron	8.5×10^{-7}
Muon	8.5×10^{-7}
Tau	4.3×10^{-7}

$B^+ \rightarrow K^+\tau^+\tau^-$ ~50% of total inclusive rate

Standard Model rate comparable to $\mu^+\mu^-$ or e^+e^- channels but new physics with a mass dependent coupling such as a Higgs in the Next-to-MSSM could enhance by $(m_\tau/m_\mu)^2$ ~280 (G.Hiller PRD 70 034018 (2004))

Search for $B^+ \to K^+\tau^+\tau^-$ Analysis Technique

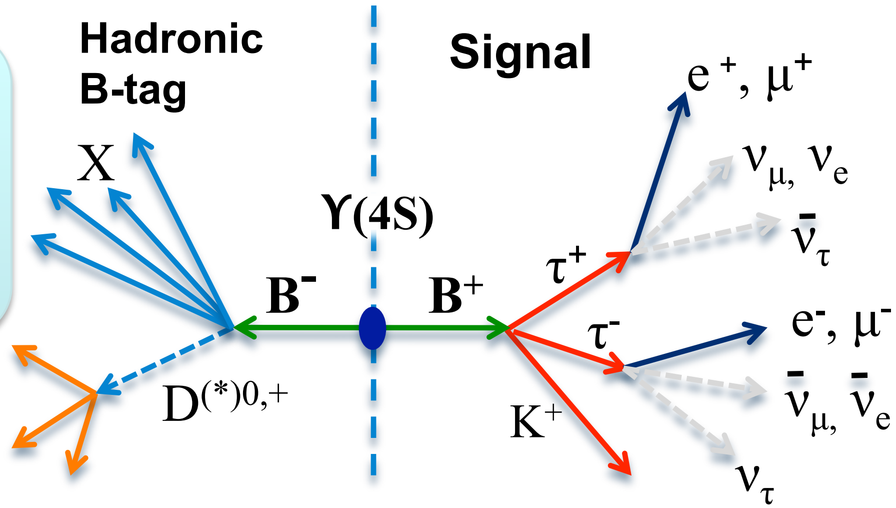
$B \to D^{(*)}X$

$X = m\pi^{\pm} + nK^{\pm} + pK_s^0 + q\pi^0$

$0 \le m,n,p \le 2$

$0 \le m+n+p+q \le 6$

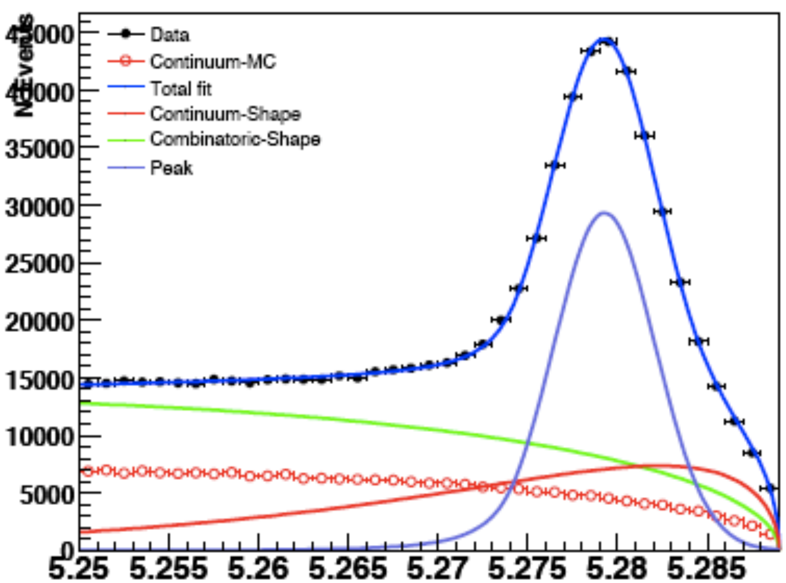
$\varepsilon_{tag} \approx 0.2\%$



$\tau \to \mu\nu_\mu\nu_\tau$

$\tau \to e\nu_e\nu_\tau$

$\tau \to \pi\nu_\tau$



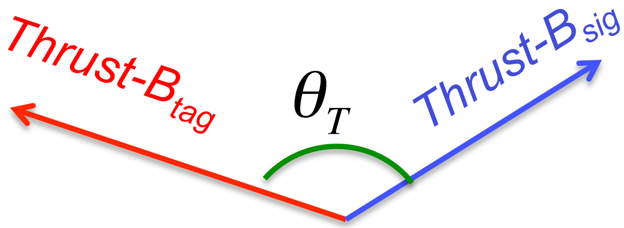
$M_{ES} = \sqrt{\left(E_{beam}^{*2} - p_B^{*2}\right)}$

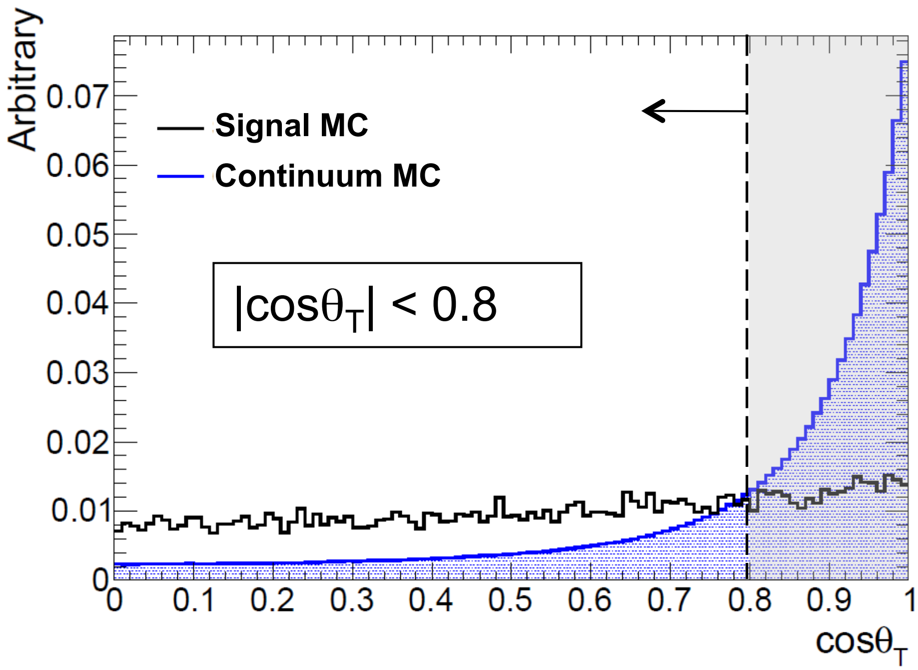
Missing Energy from Neutrinos
$1.39 < E_{miss} < 3.8$ GeV

Restrict to kinematically accessible region and away from ψ pole $q^2 > 14.23$ GeV^2
$(q^2 = (p_{\Upsilon(4s)} - p_{tag} - p_K)^2\ GeV^2)$

Neutral energy not associated with B_{tag} or B_{sig} < 0.74 GeV

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



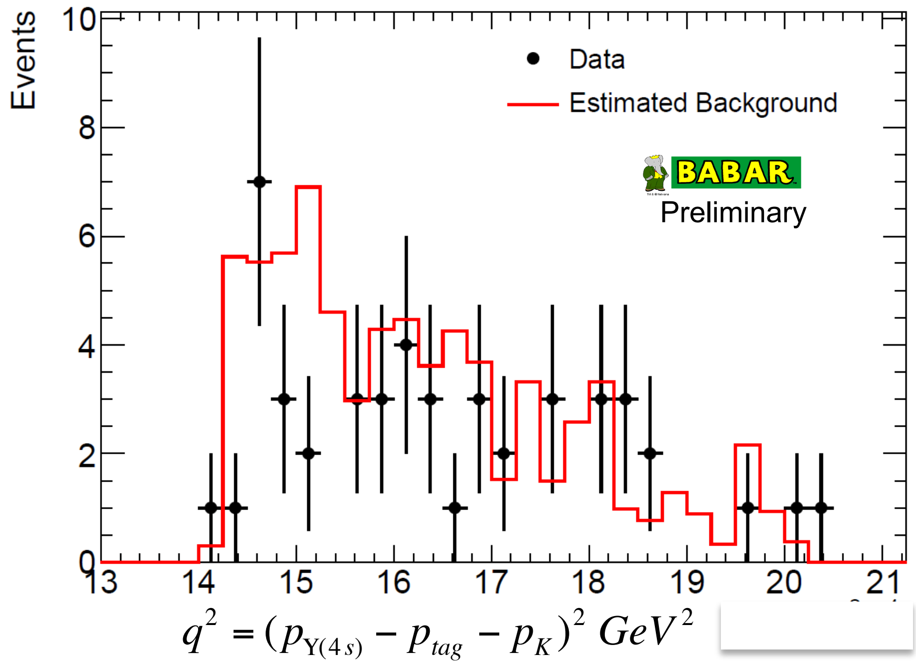


Continuum Suppression with $cos\theta_T$

Dominant Background for B_{sig} is $B \rightarrow D^+ l^- \nu$ with $D^+ \rightarrow K^- l^+ \nu$

Suppress with p_{lepton} < 1.96 GeV

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



Systematic	%
B Counting	1.1
Tag Efficiency	3.2
Signal Efficiency	14.8
Background Estimation	17.3

Expected Bkgd: 64.7 +/- 7.3

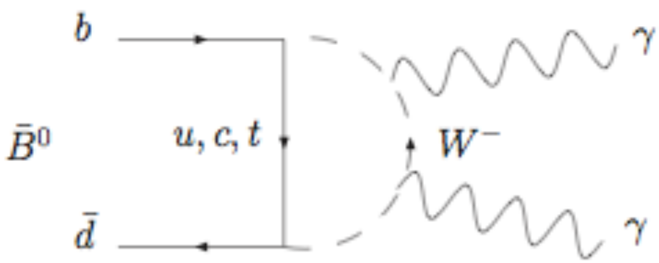
Data Events: 47

B **($B^+ \rightarrow K^+\tau^+\tau^-$) < 0.0033 (90% CL)**

(First limit to date)

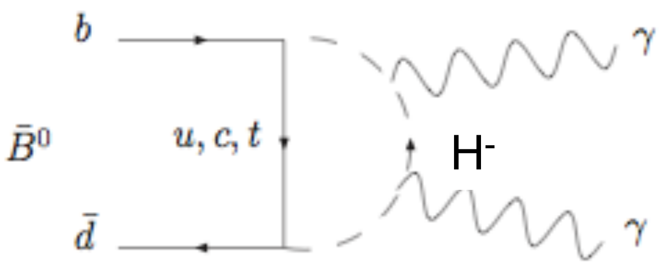
Search for $B^0 \to \gamma\gamma$

Standard Model



$B(B^0 \to \gamma\gamma)$ ~ 3 x 10^{-8}
(Bosch and Buchalla,,JHEP 0208:054 (2002))

Physics Beyond Standard Model



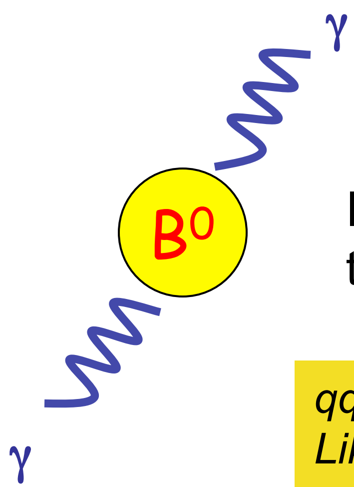
$B(B^0 \to \gamma\gamma)$ ~ $O(10^{-7})$
Aliev and Turin, PRD 58 095014
(2HDM models or R-parity violating SUSY)

Experimental constraints from $b \to d\gamma$ experiment

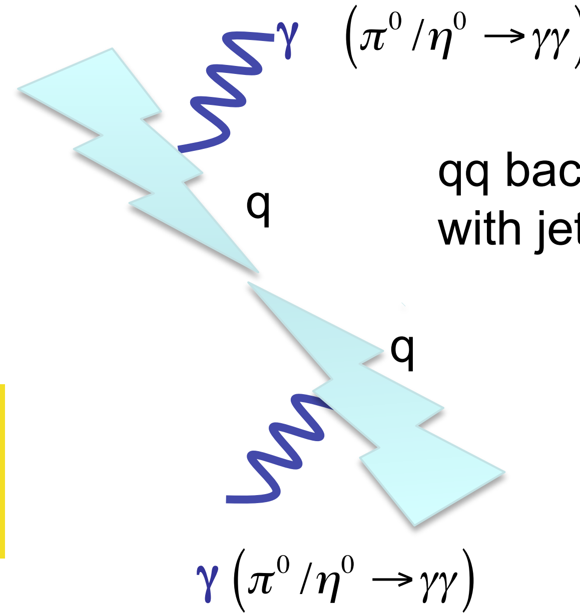
Previous Measurements

Experiment	BF (90% CL)	Dataset	*Reference*
L3	< 1.9 x 10^{-5}	2.95x10^{6} ($Z \to$had)	*Acciarri et al. Phys. Lett. B, 363, 1995*
BaBar	< 1.7 x 10^{-6}	19 fb^{-1}	*Aubert et al. PRL 87, 24, 2001*
Belle	< 6.1 x 10^{-7}	104 fb^{-1}	*Villa et al. PRD 73, 2006*

$B^0 \rightarrow \gamma\gamma$ Backgrounds

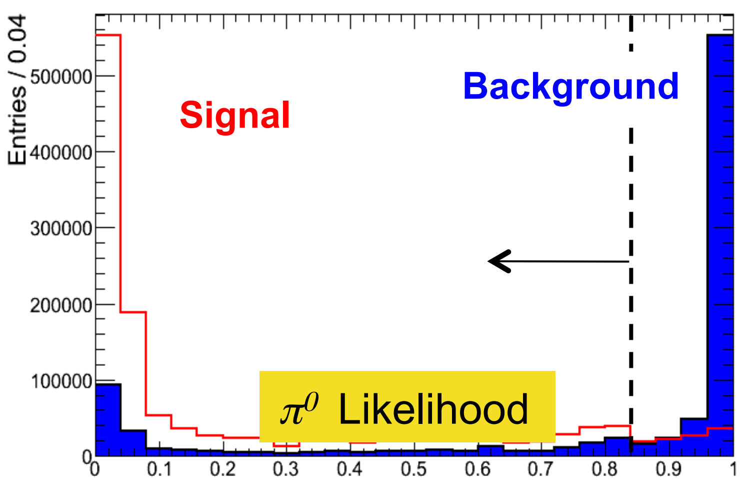


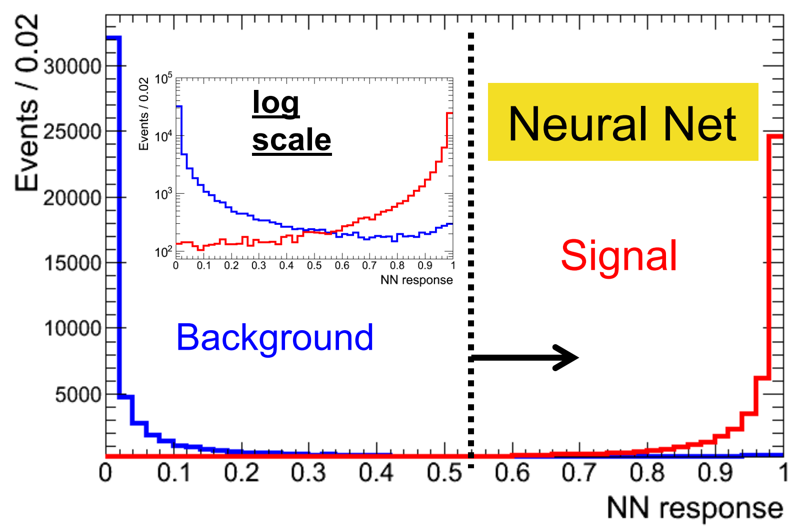
Isotropic signal topology



qq background with jet topology

qq backgrounds suppressed with π/η Likelihood and a Neural Net of event topology variables

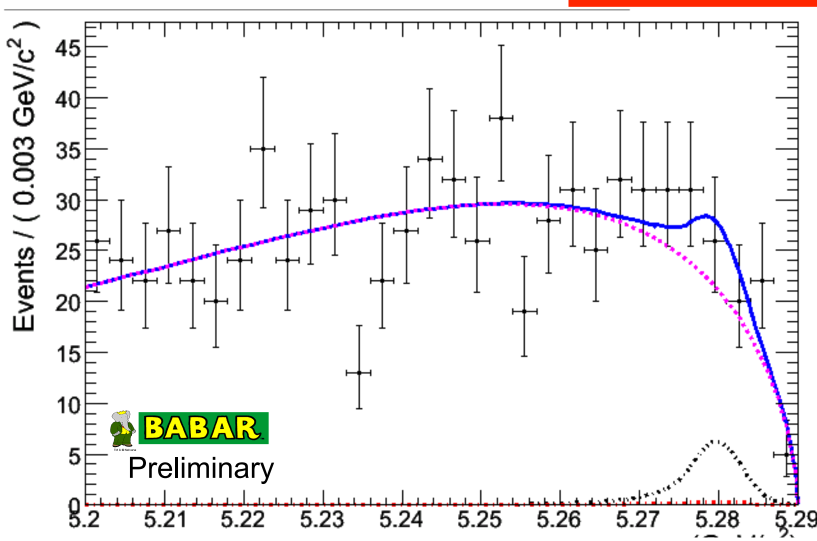




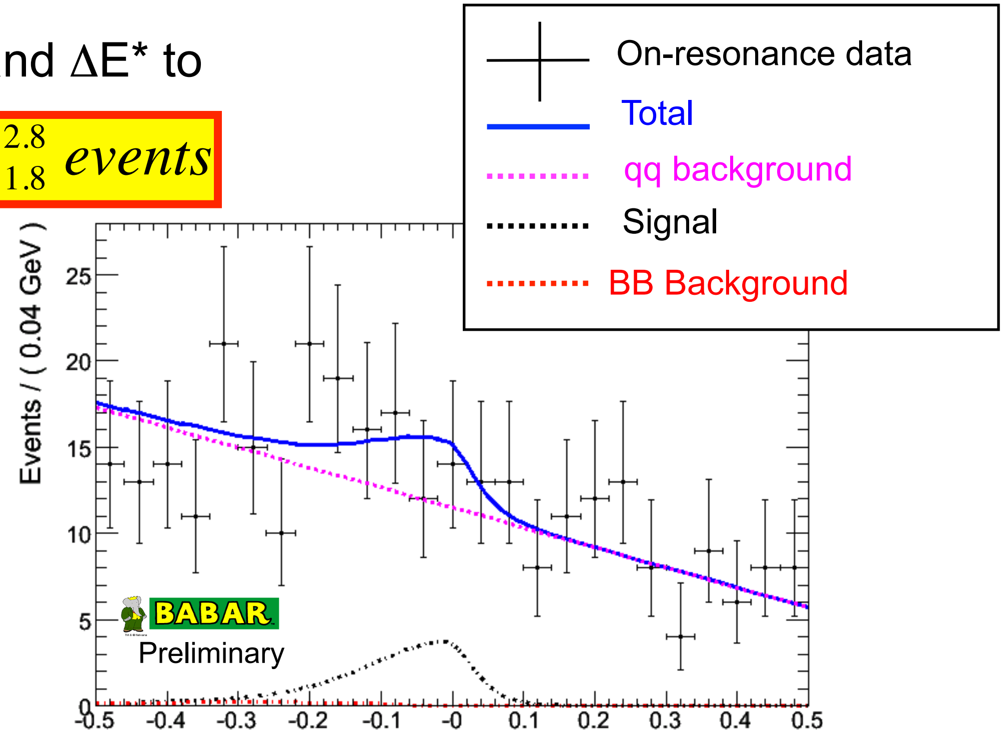
Search for $B^0 \to \gamma\gamma$ Results

Unbinned Max Likelihood fit in M_{ES} and ΔE^* to extract signal

$$N_{sig} = 21.3^{+12.8}_{-11.8}\ events$$



$$M_{ES} = \sqrt{\left(E^{*2}_{beam} - p^{*2}_{B}\right)}$$



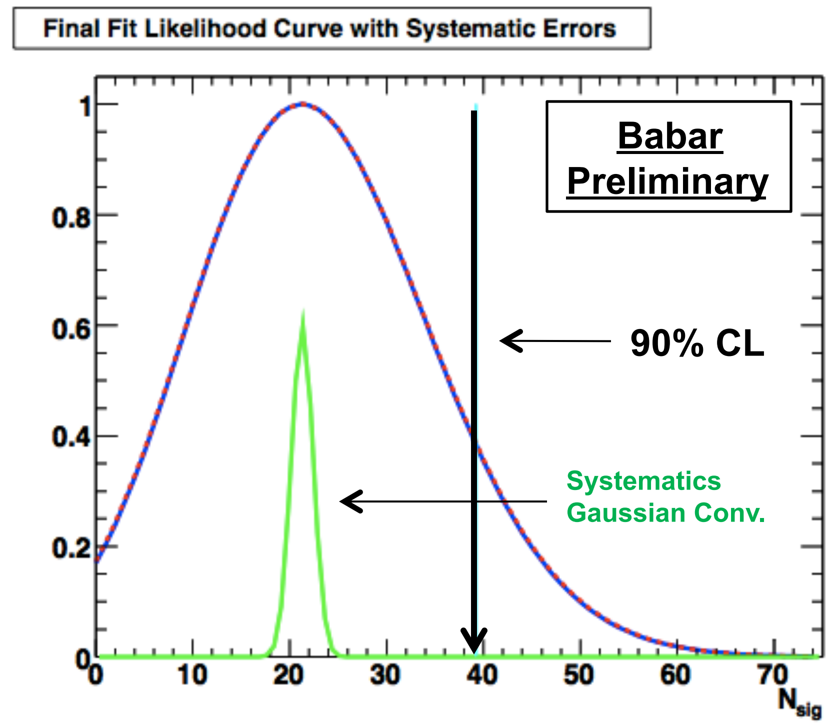
$$\Delta E^* = E^*_B - E^*_{beam}$$

$$B(B \to \gamma\gamma) = \left(1.7 \pm 1.1(stat.) \pm 0.2(sys.)\right) \times 10^{-7} \qquad (1.9\sigma\ significance)$$

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

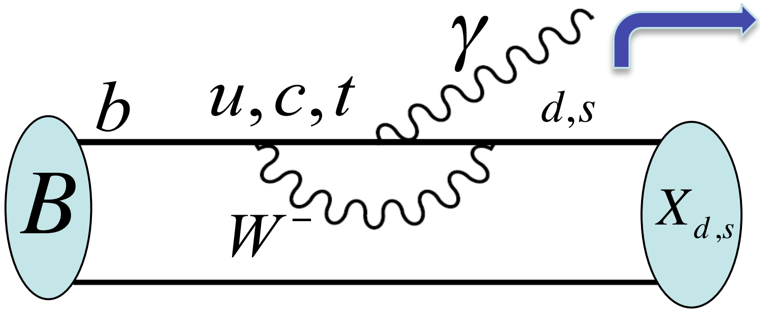
arXiv:1010.2229

Source	Uncertainty on $N_{\rm sig}$ (%)
$B^0\overline{B}^0$ counting	1.7
Tracking efficiency	0.2
Track multiplicity	3.4
Photon efficiency	4.0
Cluster time	0.7
L_{π^0} and L_η	2.8
Neural network	3.0
Fit uncertainty	9.9
Sum in quadrature	12.1

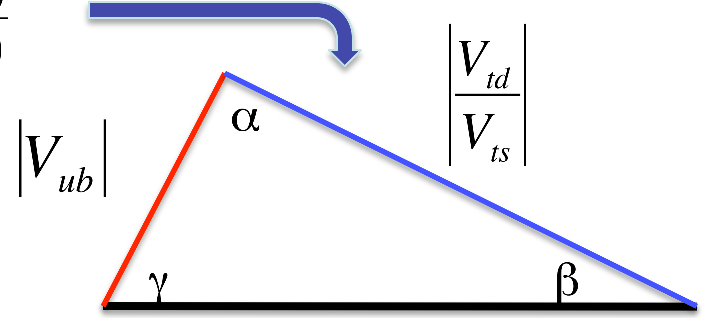


$$B(B \rightarrow \gamma\gamma) < 3.3 \times 10^{-7} \ at \ \ 90\% \ C.L.$$

Measurement of $B \to X_d\gamma$ and Extraction of $|V_{td}/V_{ts}|$



$$\frac{\Gamma(B \to X_d\gamma)}{\Gamma(B \to X_s\gamma)}$$



$\left|\frac{V_{td}}{V_{ts}}\right|$ is most precisely measured with B_d/B_s mixing

Measurement with penguins to search for New Physics

Previously used ratio of exclusives ($\rho,\omega\gamma/K^*\gamma$) but limited by form factor uncertainty

Inclusive method is theoretically cleaner

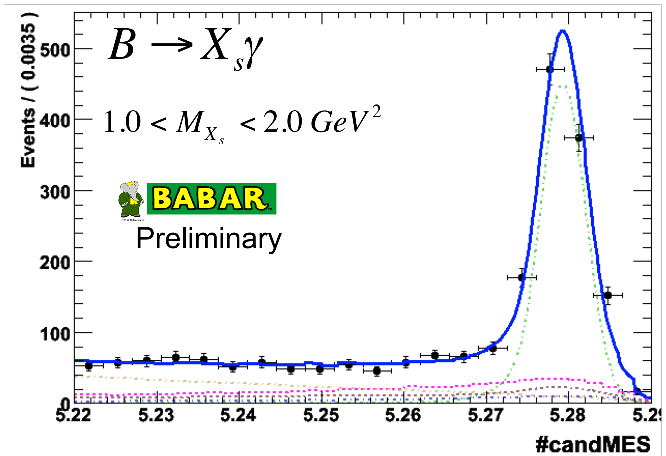
Use the sum-of-exclusives technique

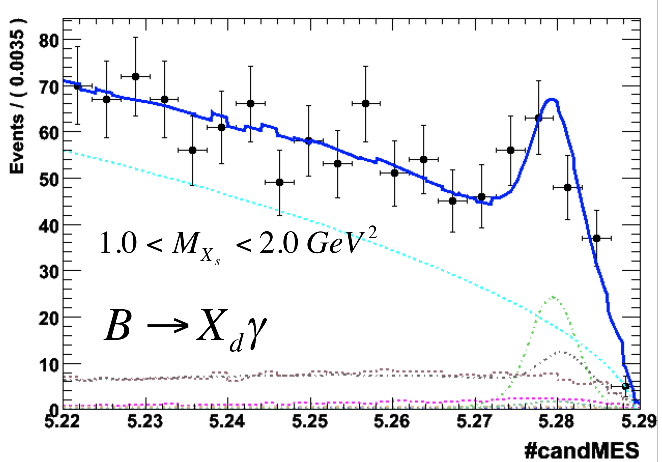
(~50% of modes covered. Largest systematic from missing modes)

$B \to X_d\gamma$	$B \to X_s\gamma$
$B^0 \to \pi^+\pi^-\gamma$	$B^0 \to K^+\pi^-\gamma$
$B^+ \to \pi^+\pi^0\gamma$	$B^+ \to K^+\pi^0\gamma$
$B^+ \to \pi^+\pi^-\pi^+\gamma$	$B^+ \to K^+\pi^-\pi^+\gamma$
$B^0 \to \pi^+\pi^-\pi^0\gamma$	$B^0 \to K^+\pi^-\pi^0\gamma$
$B^0 \to \pi^+\pi^-\pi^+\pi^-\gamma$	$B^0 \to K^+\pi^-\pi^+\pi^-\gamma$
$B^+ \to \pi^+\pi^-\pi^+\pi^0\gamma$	$B^+ \to K^+\pi^-\pi^+\pi^0\gamma$
$B^+ \to \pi^+\eta\gamma$	$B^+ \to K^+\eta\gamma$

Measurement of $B \to X_d\gamma$ and Extraction of $|V_{td}/V_{ts}|$

$471M\ B\overline{B}$





Measure for $M_{X_{d,s}} < 2.0\ GeV^2$

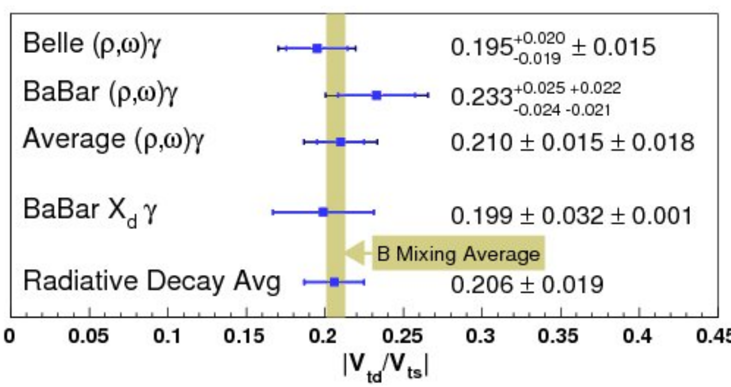
$$\frac{\Gamma(B \to X_d\gamma)}{\Gamma(B \to X_s\gamma)} = 0.040 \pm 0.009(stat.) \pm 0.010(sys.)$$

Correct for unmeasured $M_{X_{d,s}} > 2.0\ GeV^2$ using Kagan & Neubert (PRD 58 094012) spectrum with

$m_b = 4.65 \pm 0.05$ $\mu_\pi^2 = -0.52 \pm 0.08$ ($HFAG$)

Extract $\left|\frac{V_{td}}{V_{ts}}\right|$ using the calculations of Ali, Asatrian & Greub using β as input rather than (ρ,η) (Phy. Lett. B 429 87 (1998))

$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.199 \pm 0.022(\text{stat.}) \pm 0.024(\text{sys.}) \pm 0.002(\text{th.})$$



arXiv 1005.4087v1
PRD 82:051101 2010

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Conclusions

BaBar continues to mine its dataset for evidence of physics beyond the Standard Model in rare B decays:

Most stringent limits presented for

$B(B \to K \nu \nu) < 1.4 \times 10^{-5}$

$B(B \to K^+ \tau^+\tau^-) < 3.3 \times 10^{-3}$

$B(B^0 \to \gamma\gamma) < 3.3 \times 10^{-7}$

Measurement of $$\frac{\Gamma(B \to X_d \gamma)}{\Gamma(B \to X_s \gamma)} = 0.040 \pm 0.009(stat.) \pm 0.010(sys.)$$

$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.199 \pm 0.022(\text{stat.}) \pm 0.024(\text{sys.}) \pm 0.002(\text{th.})$$

Techniques developed will hopefully be used to observe these modes at SuperB !