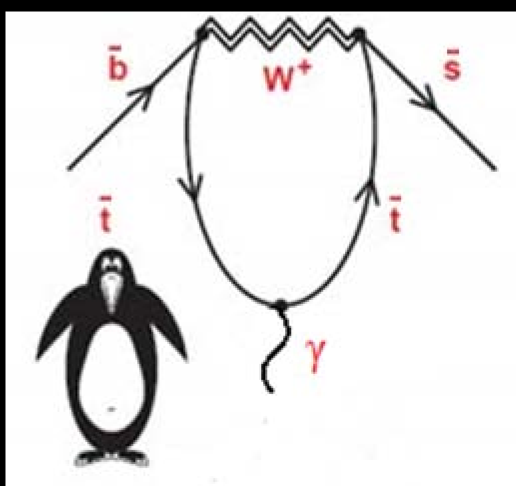
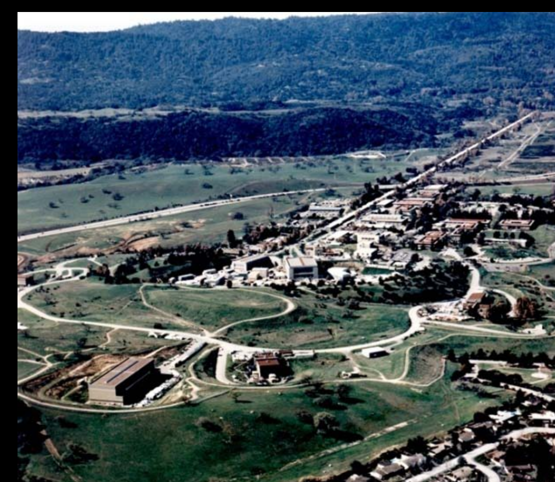
Radiative Penguin *B* Decays at *BaBar*



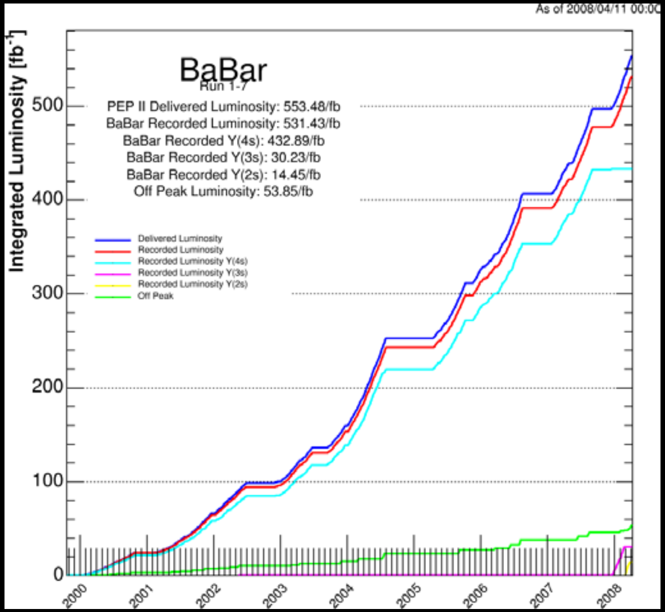
David Doll

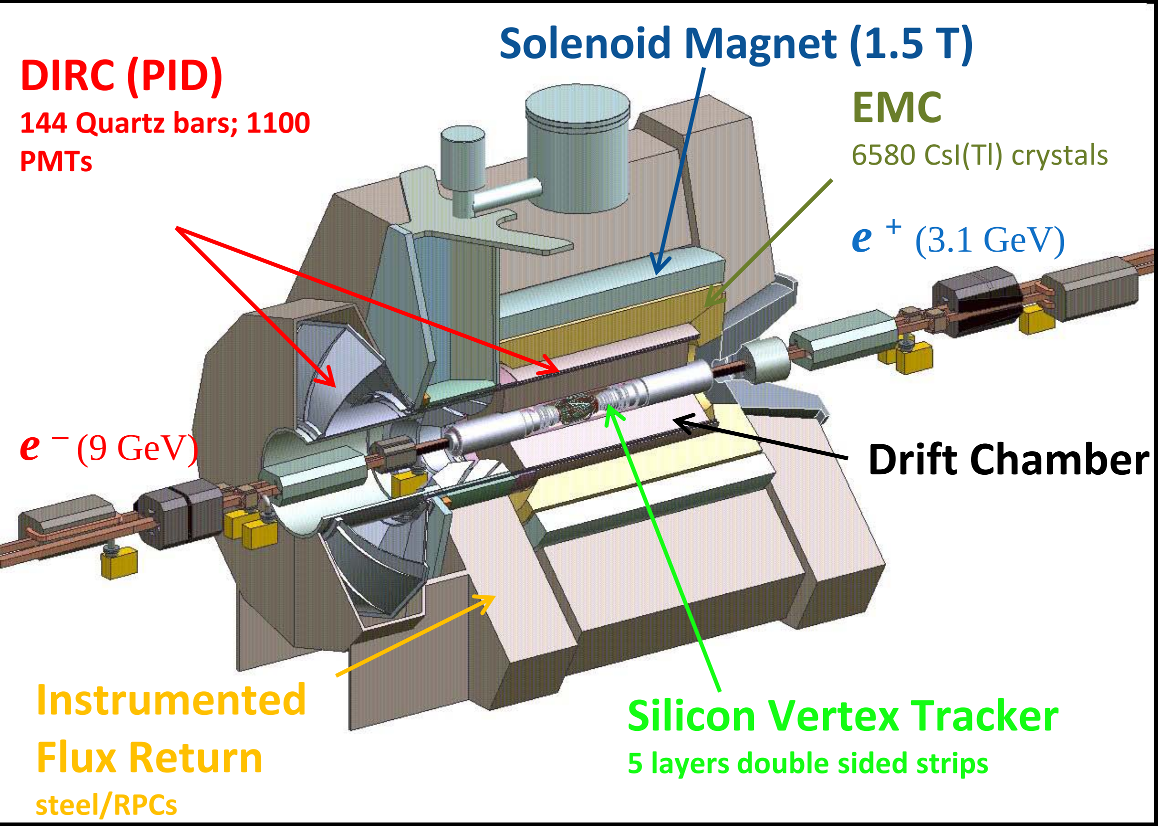


Today’s Talk

2 recent results presented using entire dataset:

- $b \rightarrow d\gamma$ transitions
- $B^{+} \rightarrow K^{+}\tau\tau$





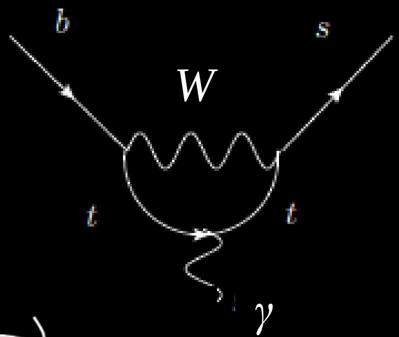
Final Dataset

433 fb^{-1} at $\Upsilon(4S)$

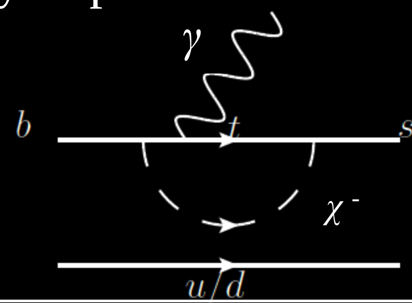
470 x 10^{6} BB pairs

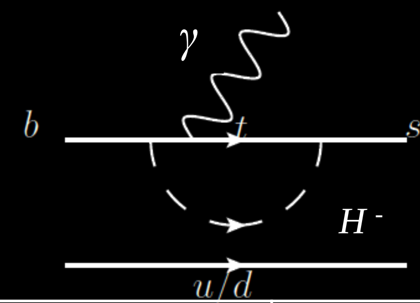
54 fb^{-1} at 40 MeV below $\Upsilon(4S)$

Radiat"ing" decays at *BaBar*



- $b \to s\gamma$ and $b \to d\gamma$ transitions
- FCNC decays – opportunity to place constraints on NP
- Many Analysis Strategies





Method	Current *BABAR* results	Luminosity (fb^{-1})
Inclusive $B \to X_s\gamma$	$A_{CP(s+d)}$ = -0.11±0.115±0.017	81.5
B. Aubert *et al.*, Phys. Rev. Lett. 97, 171803 (2006)	BF(E_γ >1.6 GeV)* = $(3.94 \pm 0.31 \pm 0.36 \pm 0.21) \times 10^{-4}$	81.5
Sum of Exclusives $B \to X_s\gamma$	A_{CP} = -0.011±0.030±0.014	343.5
B. Aubert *et al.*, Phys. Rev. **D72**, 052004 (2005) B. Aubert *et al.*, Phys. Rev. Lett. 101, 171804 (2008)	BF(E_γ >1.6 GeV) = $(3.35 \pm 0.19^{+0.56}_{-0.41}{}^{+0.04}_{-0.09}) \times 10^{-4}$	81.9
Recoil Reconstruction $B \to X_s\gamma$	BF(E_γ >1.6 GeV) = $(3.91 \pm 0.91 \pm 0.64) \times 10^{-4}$	210
B. Aubert *et al.*, Phys. Rev. **D77**, 051103 (2008)	$A_{CP(s+d)}$ =0.10±0.18±0.05	210
Sum of Exclusives $B \to X_d\gamma$ B. Aubert *et al.*, arXiv:1005.4087 (2010)	--This Talk--	429.1

*Results reported depend on photon spectrum model

$B \to X_d\gamma$ Analysis

- $b \to d\gamma$ suppressed by a factor ~20 w.r.t. $b \to s\gamma$
- "Sum of exclusives":

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

X_s and X_d related by kaon-pion substitution

Charge conjugation implied throughout

- Analysis measures $b \to s\gamma$ as well to extract a value for $|V_{td}/V_{ts}|$
  - independent check of value from B_s vs. B_d mixing
  - Lower theoretical uncertainties than ratio of specific final states*

$$\frac{BF(B \to (\rho,\omega)\gamma)}{BF(B \to K^*\gamma)} \Rightarrow \frac{|V_{td}|}{|V_{ts}|} = 0.199^{+0.022}_{-0.025}(\text{exp}) \pm 0.014(\text{th})\ \dagger$$

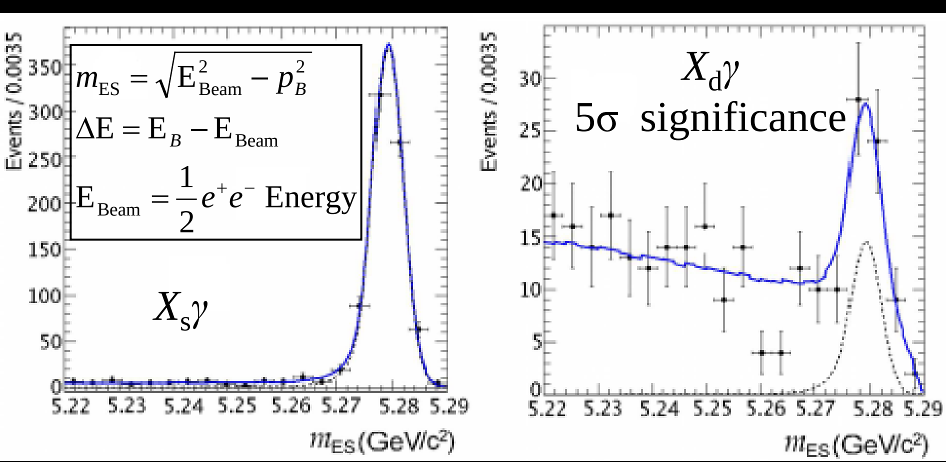
lower with inclusive determination

*A. Ali, H. Asatrian and C. Greub, Phys. Lett. **B429** 87 (1998)
† P. Ball, G. Jones and R. Zwicky, Phys. Rev. **D75**, 054004 (2007)

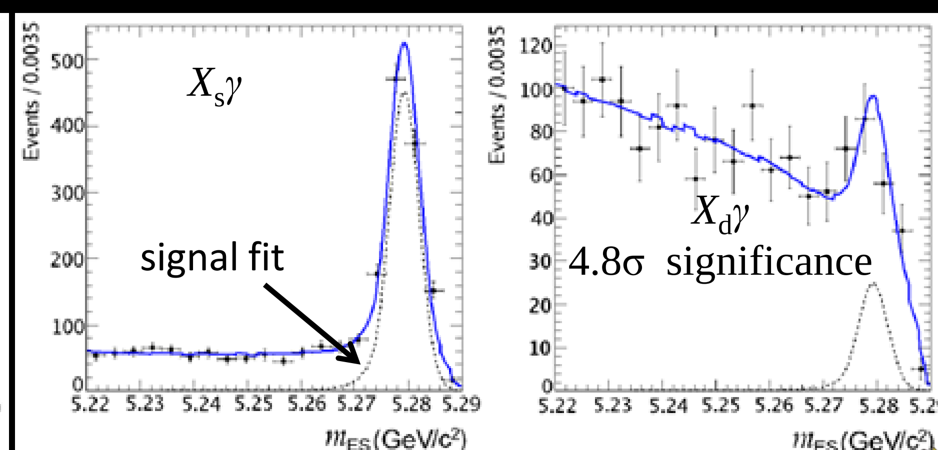
Analysis Overview

- $X_{d/s}$ mass spectrum split into two bins (4 total yields measured)
  - $0.5 < M(X_{d/s}) < 1.0$ GeV/c^2 – low mass bin
    - Modeled exclusively by $\rho/\omega\gamma$ ($K^*(892)\gamma$) MC for the X_d (X_s) signal events – though all 7 final states reconstructed
  - $1.0 < M(X_{d/s}) < 2.0$ GeV/c^2 – high mass bin
    - final state composition modeled "generically" via phase space in JETSET – no explicit resonances
- Background levels suppressed through use of a neural net as well as requirements on event shape and X-candidate variables
- Fit for signal yield and correct for missing modes and spectrum
  - Yield determined from simultaneous fit to m_{ES} (below) and ΔE

low mass bin



high mass bin



Systematic Errors

Systematic Error Source	$M(X_s)$ 0.5-1.0	$M(X_s)$ 1.0-2.0	$M(X_d)$ 0.5-1.0	$M(X_d)$ 1.0-2.0
Track selection	0.3%	0.4%	0.3%	0.4%
Photon reconstruction	1.8%	1.8%	1.8%	1.8%
π^0/η reconstruction	0.9%	1.1%	1.4%	1.6%
Neural network	1.1%	4.9%	1.1%	4.9%
B counting	0.6%	0.6%	0.6%	0.6%
PID (*)	2.0%	2.0%	2.0%	2.0%
Fit bias (*)	0.1%	0.9%	4.9%	6.5%
PDF shapes (*)	2.3%	0.6%	3.7%	3.4%
Histogram binning (*)	0.8%	0.2%	1.8%	1.8%
Background (*)	0.8%	1.2%	5.9%	7.0%
Fragmentation (*)	-	3.3%	-	5.1%
Signal model	-	5.8%	-	6.0%
Error on partial $\mathcal{B}$	4.0%	9.0%	9.3%	14.2%
Missing ≥ 5 body		9.6%		18.2%
Other missing states		7.5%		15.3%
Spectrum Model		1.8%		1.6%
Error on inclusive $\mathcal{B}$	4.0%	15.2%	9.3%	27.7%

- Obtained through MC/data comparison
- For the partial branching fractions, largest sources are fit bias, background estimation, fragmentation and signal model
- The entire mass range requires accounting for both unreconstructed modes and the spectrum model of $X_{s/d}$-mass

$B \to X_d \gamma$ Results

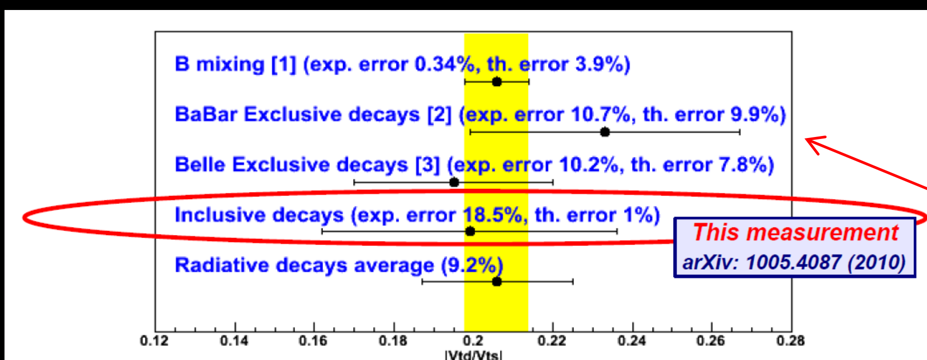
- Consistent with previously measured results

	Branching Fraction
$b \to s\gamma$ low mass	$3.83 \pm 0.16 \pm 0.15 \times 10^{-5}$
$b \to s\gamma$ high mass	$19.2 \pm 0.8 \pm 1.7 \pm 2.3 \times 10^{-5}$
$b \to s\gamma$ ($m_{had} < 2.0\,\mathrm{GeV}/c^2$)	$23.0 \pm 0.8 \pm 1.9 \pm 2.3 \times 10^{-5}$
$b \to d\gamma$ low mass	$1.25 \pm 0.32 \pm 0.12 \times 10^{-6}$
$b \to d\gamma$ high mass	$7.90 \pm 1.98 \pm 1.12 \pm 1.88 \times 10^{-6}$
$b \to d\gamma$ ($m_{had} < 2.0\,\mathrm{GeV}/c^2$)	$9.15 \pm 2.01 \pm 1.24 \pm 1.88 \times 10^{-6}$
$\frac{B\to(\rho,\omega)\gamma}{B\to K^*\gamma}$	$0.033 \pm 0.009 \pm 0.003$
$\frac{b\to d\gamma}{b\to s\gamma}$ ($m_{had} < 2.0\,\mathrm{GeV}/c^2$)	$0.040 \pm 0.009 \pm 0.005 \pm 0.010$

World Average (HFAG):

$$BF(B \to K^*\gamma) = (4.21 \pm 0.18) \times 10^{-5}$$

$$BF(B \to (\rho,\omega)\gamma) = (1.30 \pm 0.19) \times 10^{-6}$$



D. Bard – ICHEP 2010

Measurement for the entire mass range considered

$BF(b \to d\gamma) = (9.15 \pm 2.01 \pm 1.24 \pm 1.88) \times 10^{-6}$

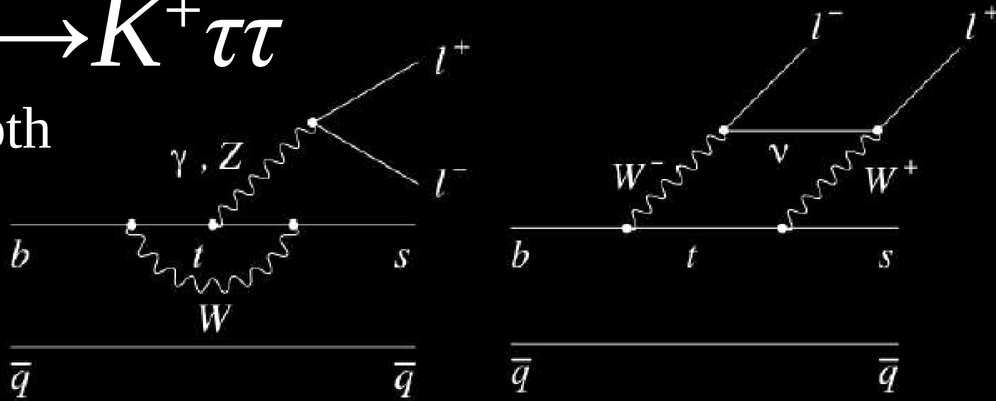
$$\frac{BF(B \to (\rho,\omega)\gamma)}{BF(B \to K^*\gamma)} \Rightarrow \frac{|V_{td}|}{|V_{ts}|} = 0.233^{+0.025+0.022}_{-0.024-0.021}$$

B. Aubert *et al.*, Phys. Rev. **D78** 112001 (2008)

$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.199 \pm 0.022(stat.) \pm 0.012(syst.) \pm 0.027(extrap.) \pm 0.002(th.)$$

$B^+ \to K^+\tau\tau$

- FCNC – occurs in SM through both box and penguin processes

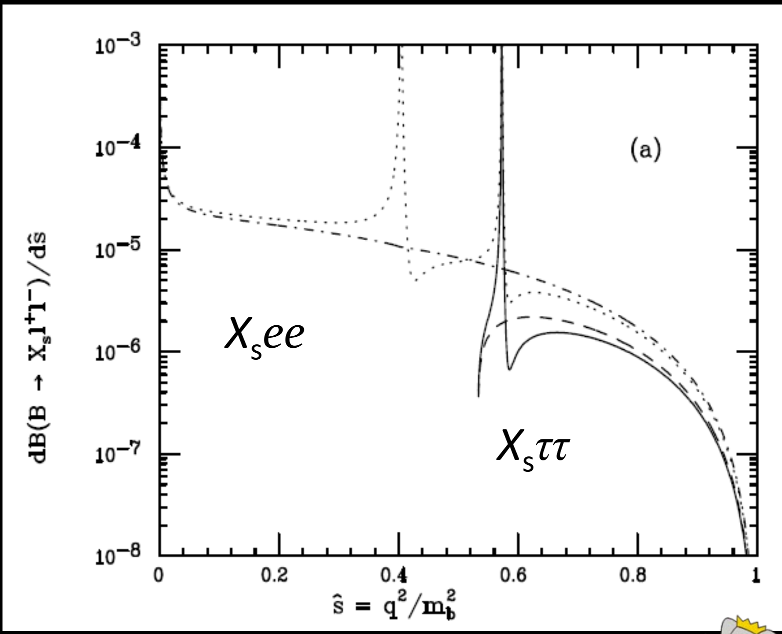


- BF($B^+ \to X_s\tau\tau$) comparable to BF($B^+ \to X_s ll$) (l={e,μ}) at high momentum transfer, q^2
  - Exclusive mode, $B^+ \to K^+\tau\tau$, is 50-60% of the entire rate

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

- New Physics couplings proportional to mass squared, could enhance BF($B^+ \to X_s\tau\tau$) over BF($B^+ \to X_s ll$) levels*

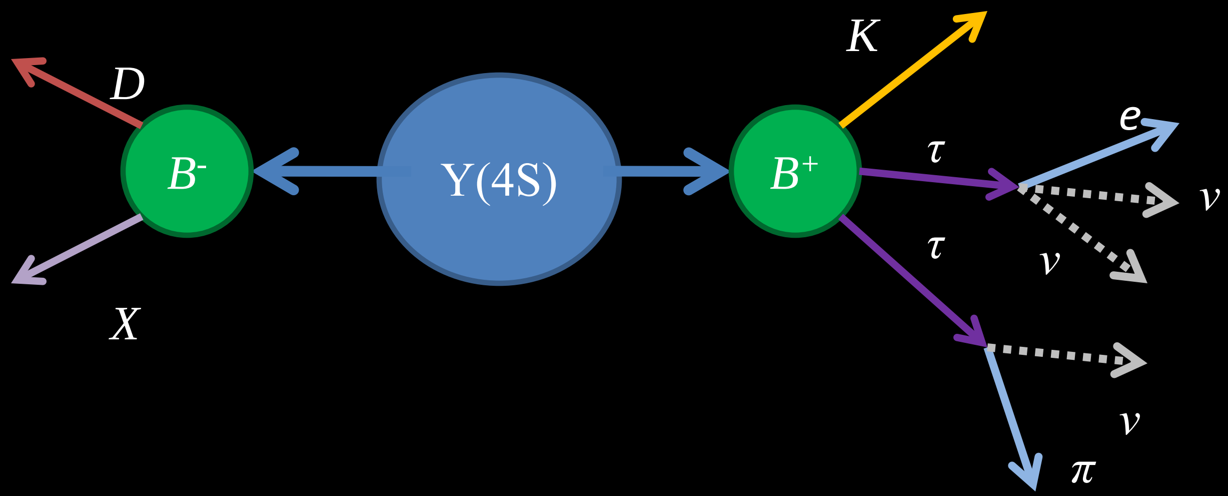
* G. Hiller, Phys. Rev. **D70** 034018 (2004)



J.L. Hewett, Phys. Rev. **D53**, 4964 (1996)

Analysis Overview

- "Tagged Analysis" – reconstruct the recoiling *B*
  - 2-4 neutrinos in the final state
  - Use Hadronic final states to reconstruct "tag *B*"



Analysis Overview

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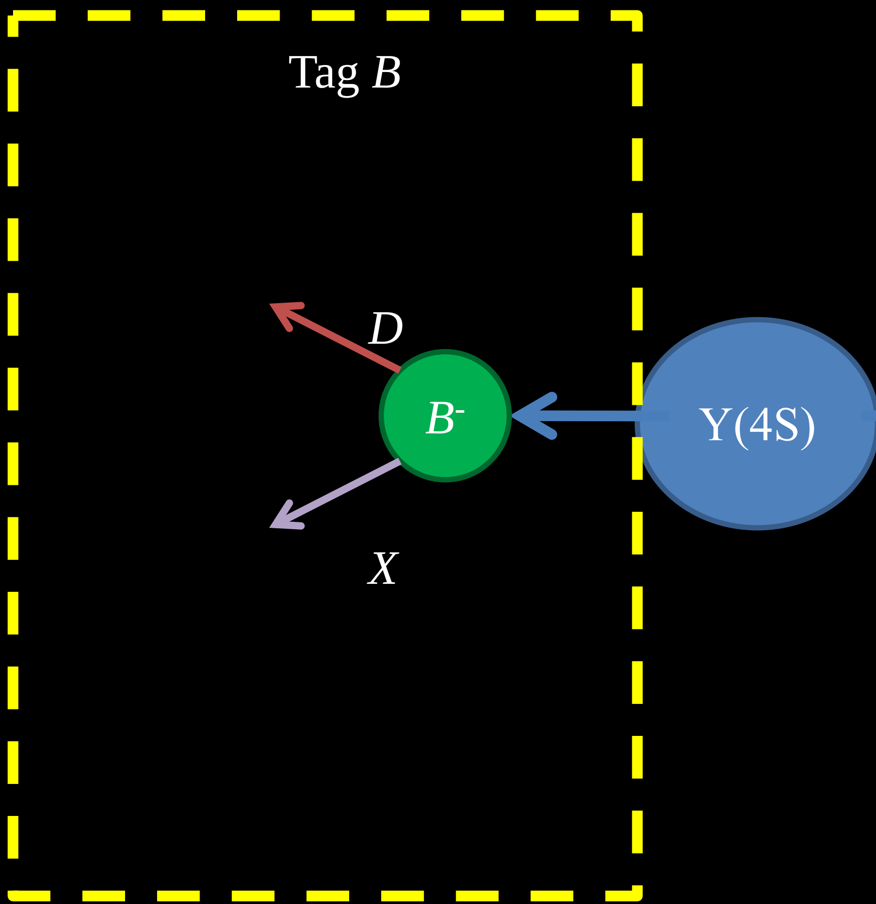


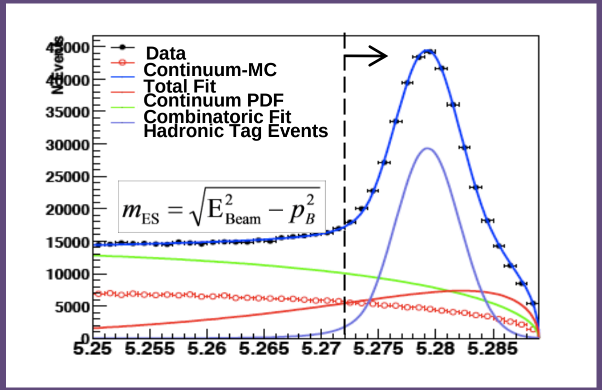
Modes Reconstructed:

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

X can be up to 6 extra hadrons $\{K, K_s, \pi, \pi^0\}$

$D^{(*)}$ is reconstructed in several final states

Tag efficiency ~0.2%



Analysis Overview

- "Tagged Analysis" – reconstruct the recoiling *B*
  - 2-4 neutrinos in the final state
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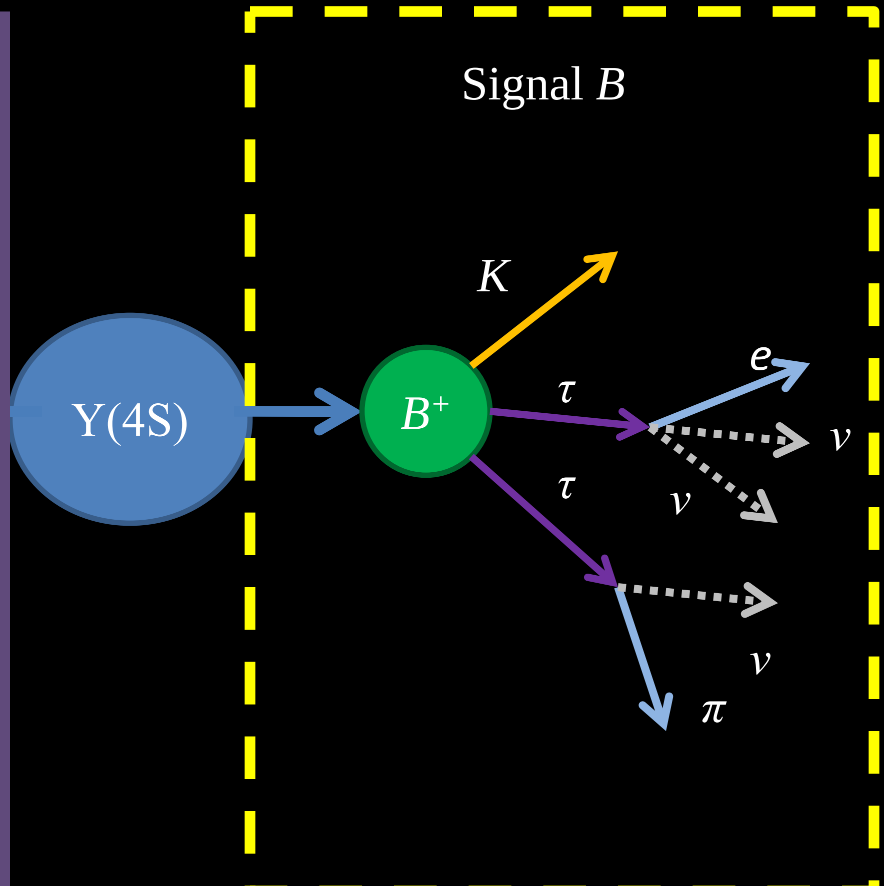
Signal Modes:
$\tau \longrightarrow \{e\nu\nu, \mu\nu\nu, \pi\nu\}$

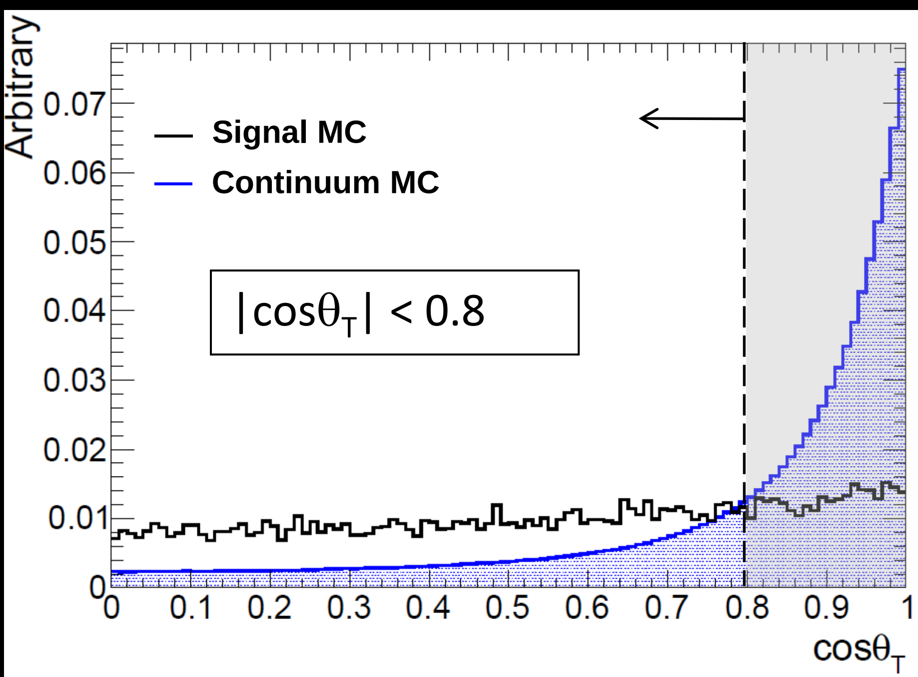
~46% of τ final states

Always 3 charged particles on the signal side



Signal Selection

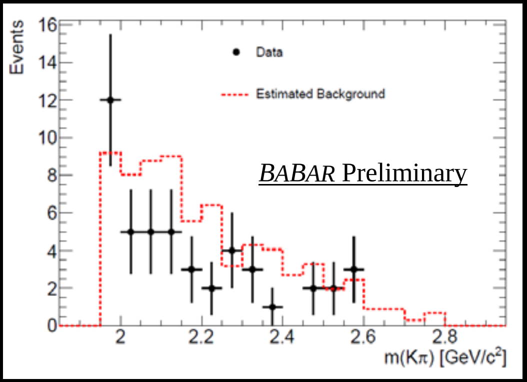
$|\cos\,\theta_T| < 0.8$, the angle between the tag-*B*'s thrust and the thrust of the signal side, is used to reject continuum backgrounds – the only tag-side variable cut on after tag identification



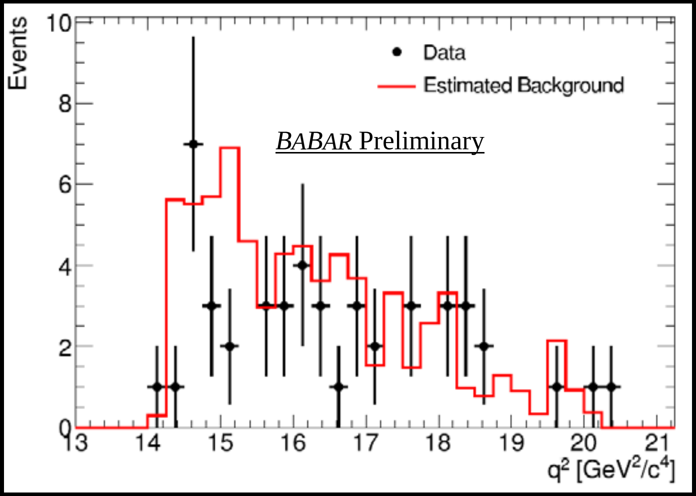
- Exactly 3 charged Tracks
- One K^+ from Particle ID
  - $0.44 < p_K < 1.40$ GeV/c
  - Charge opposite tag-*B*
- One neutral pair of $\{e, \mu, \pi\}$
  - $p^* < 1.59$ GeV/c
  - $M_{pair} < 2.89$ GeV/c^2
- $q^2 = (p_{Y4S} - p_{tag} - p_K)^2 > 14.23\ (\mathrm{GeV/c})^2$
- 1.39 < Missing Energy < 3.38 GeV - calculated from 4-vectors of detected particles
- Extra neutral energy < 0.74 GeV

$B^+ \to K^+ \tau\tau$ Results

- Largest source of background in $b \to sll$ is $B \to DX$
  - Suppressed by requiring $m(K\pi) > 1.96\ \mathrm{GeV/c^2}$



- "Cut and Count" procedure to establish an upper limit



Number of events expected = 64.7
Number of events seen =47

BF($B^+ \to K^+ \tau\tau$) < 3.3×10^{-3} (90% CL)

Summary

- Two recent results involving Flavor Changing Neutral Currents presented
- Both use the entire *BABAR* dataset
  - Further improvement only possible at a Super *B* factory
- BF($b \rightarrow d\gamma$) (m_{Hadron}<2.0 GeV/c^2)=(9.15±2.01±1.24±1.88) × 10^{-6}

$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.199 \pm 0.022(stat.) \pm 0.012(syst.) \pm 0.027(extrap.) \pm 0.002(th.)$$

- BF($B^+ \rightarrow K^+ \tau\tau$) < 3.3 × 10^{-3} (90% CL)

Bonus Material

Systematic Errors

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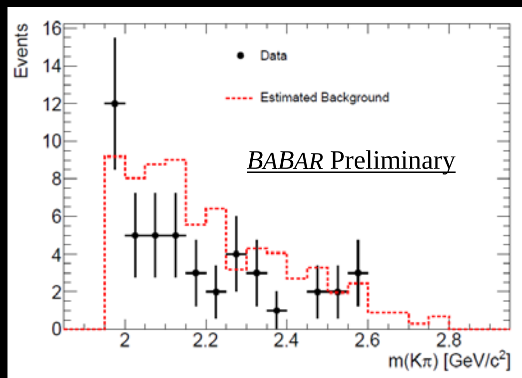
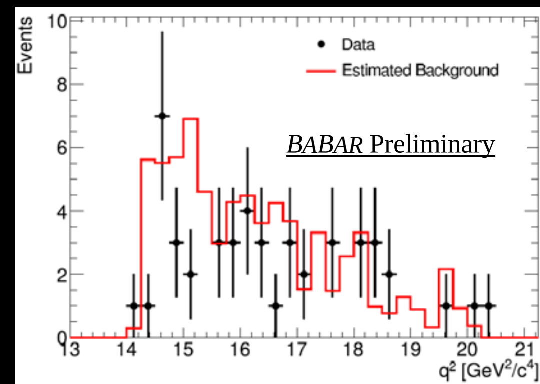
- Obtained through MC/data comparison
- For the partial branching fractions, largest sources are fit bias, background estimation, fragmentation and signal model
- Last two do not contribute to the low mass bin
  - exclusively resonant decays expected
  - "signal model" not used in this bin

- Extrapolating to entire mass range requires accounting for both unreconstructed modes and mass range
- Use "Kagan-Neubert" model for X_s mass spectrum with parameters (m_b=4.65, μ_π^2=0.52) [7]
  - assume X_d mass spectrum identical

$B^+ \to K^+\tau\tau$ Results

- Largest source of background in $b \to sll$ is $B \to DX$
  - Suppressed by requiring $m(K\pi) > 1.96$ GeV/c^2





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