Rare Decays and New Physics at the B-Factories

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SLAC
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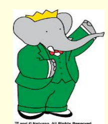
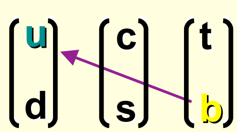


on behalf of the BaBar Collaboration

The Role of Rare Decays

CKM Physics

- Measurement of CKM at B-factories is achieved by
  - Time-dependent CPV
    - Tree-level b->c (beta)
    - Tree-level b->u (alpha)



- b->s,d gluon transitions form “pollution”. No expectation of finding NP in BF’s

Rare Decays

- Searching for NP in electroweak b->s,d (FCNC) transitions requires firm SM prediction
  - Exclusive modes may not be suitable. Use inclusive to avoid uncertainties
  - Or, use angular or direct-CP asymmetries
- Alternatively look for processes that are highly suppressed in SM
  - Leptonic B-decays
  - Lepton Flavor Violation in tau decay
  - Invisible Upsilon Decays

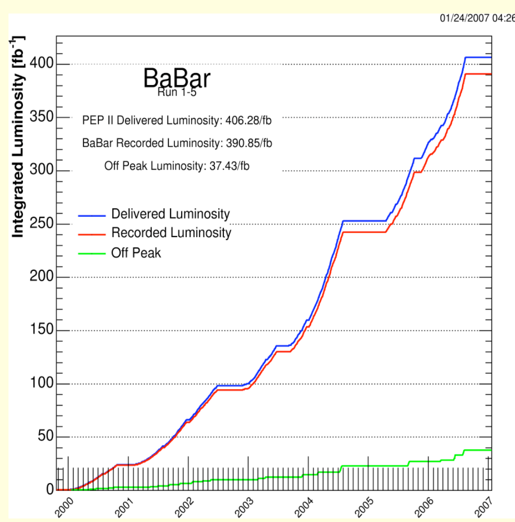
Outline

- PEP-II and BaBar
- Electroweak Penguin B Decays
  - $b \to s\gamma$
  - $B \to \rho\gamma$
  - $B \to K^* l^+ l^-$
  - $B \to \pi l^+ l^-$
- Leptonic B Decays
  - $B^+ \to \tau^+ \nu$
  - $B^+ \to l^+ \nu (l=\mu,e)$
- Lepton Flavor Violation in τ decays
  - $\tau^+ \to l^+ \gamma$
  - $\tau^+ \to l^+ l^+ l^-$, $l^+ h^+ h^-$
  - $\tau^+ \to l^+ h^0 (\pi^0, \eta, \eta')$
- Invisible Upsilon Decay

PEP-II

- Asymmetric storage rings operating near $\Upsilon(4s)$ resonance
- Peak luminosity 1.21×10^{34} cm^2/s $= 12$ nb^{-1}/s $= 1$ fb^{-1}/day
- Produces B's in flight with $<|\Delta z|> = 250$ μm

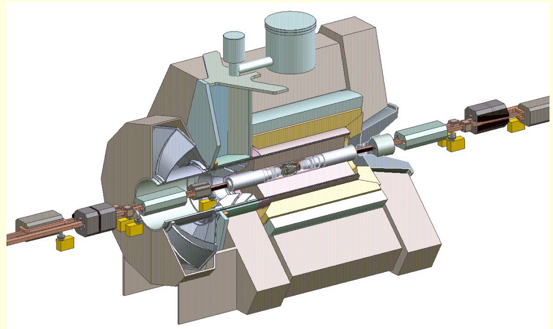
Process	effective σ (nb)
$e^+e^- \to bb$	1.1
$e^+e^- \to cc$	1.3
$e^+e^- \to qq$ (q=u,d,s)	~2.1
$e^+e^- \to \tau^+\tau^-$	0.9



- Anticipated total luminosity of 900 fb^{-1} by Summer '08

BaBar

- 5-layer Silicon Vertex Detector
- 40-layer Drift Chamber for p_t and dE/dx
- Fused Silica Cherenkov Detector for charged particle PID
- CsI (Tl) calorimeter for neutral reconstruction
- Instrumented flux return for muon and K_L ID

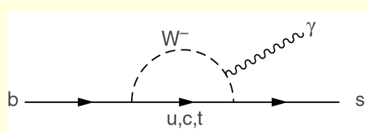


- Over 390 fb^{-1} of data collected
- Recently completed upgrade of IFR

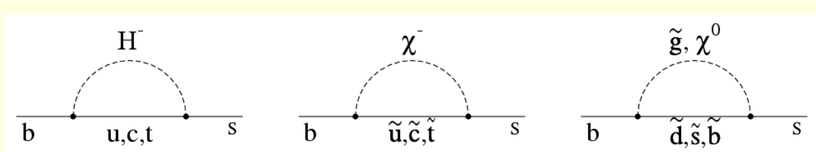
Flavor Changing Neutral Currents

- Within the SM, FCNC's occur through "electroweak penguins"
- Final state contains photon, or lepton pair

SM



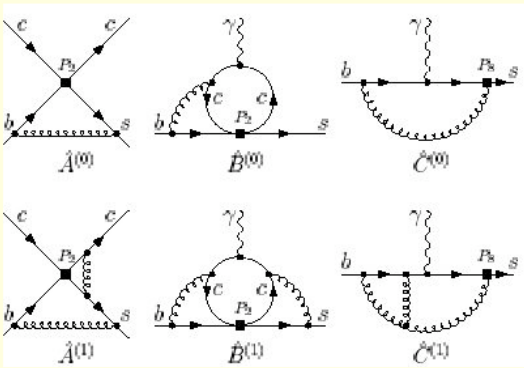
- Beyond SM, many different particles may potentially contribute
- How to disentangle non-SM contribution from SM one?



Non-SM

Inclusive b→sγ SM Theory

- BF(B→X_sγ) = BF(b→sγ), to few% non-perturbative corrections
- In the SM, BF(b→sγ) can be precisely calculated
- But, must first understand QCD effects on SM BF



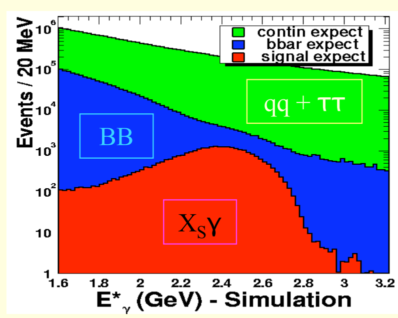
- New in Summer '06, NNLO "Tour de force" calculation involving 1000's of diagrams:

$$BF(b\to s\gamma) = (3.15 \pm 0.23) \times 10^{-4}_{E\gamma>1.6}$$

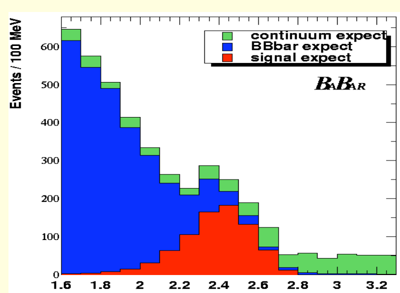
M. Misiak et al., PRL 98(2007) 022002

Inclusive b→sγ Analysis

- BF(b→sγ) extremely important due to theoretical cleanliness
- For a measurement with similar (5%) precision
  - Avoid s-quark fragmentation by only reconstructing the γ
  - Avoid model dependence by pushing E_γ threshold as low as possible

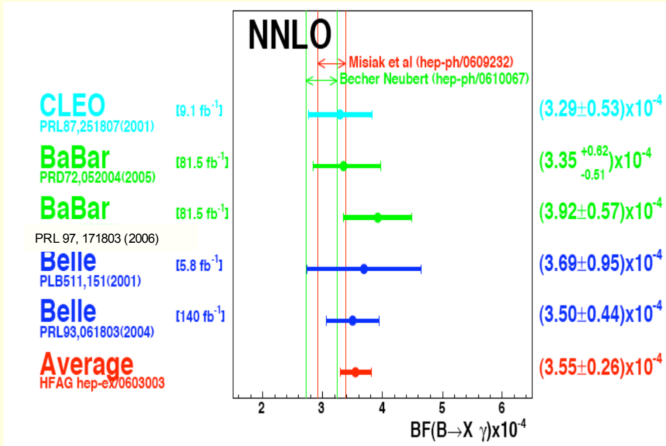


Before cuts



After cuts

Inclusive b→sγ Results

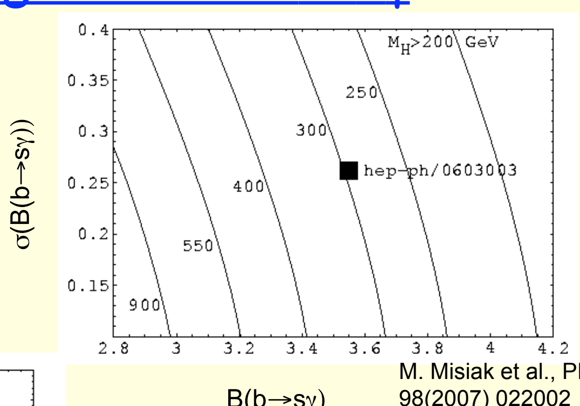


From Nakao,
CKM Workshop 12/06

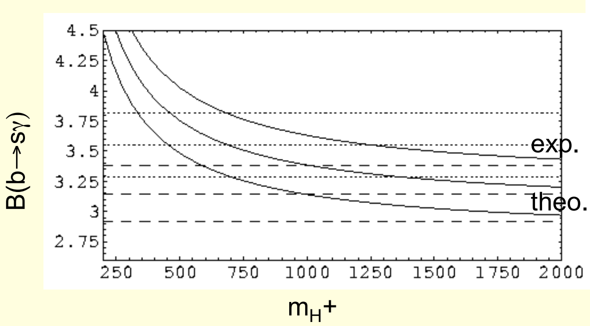
- Comparing to new SM calculation - experiment now sees slight excess
- New experimental results expected soon!

Constraining NP with b→sγ

- b→sγ is useful for constraining many new models of new physics
- As one example, look at 2 Higgs Doublet II (PRD 21, 1393 (1980)) with tanβ =2



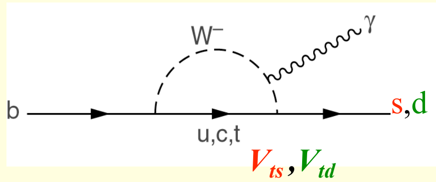
M. Misiak et al., PRL 98(2007) 022002



- Limits currently better than direct searches
- Improvement will be slow if central value stays the same

B→ρ/ω γ

- b→dγ modes similar to b→sγ , but with V_{td} coupling rather than V_{ts}



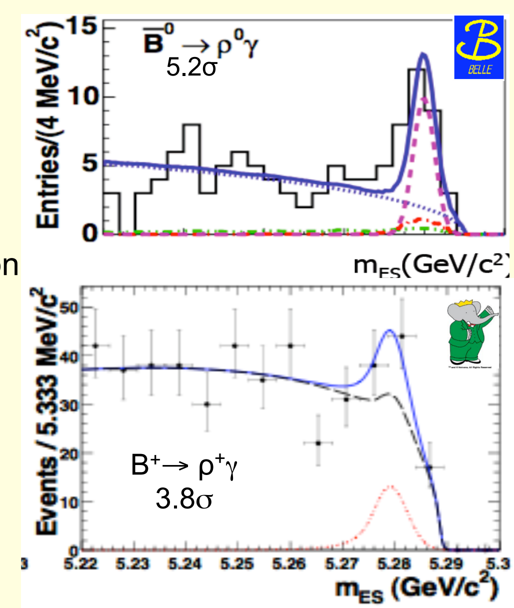
$$\frac{\overline{\mathcal{B}}[B \to (\rho/\omega)\gamma]}{\mathcal{B}(B \to K^*\gamma)} = \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1 - m_\rho^2/M_B^2}{1 - m_{K^*}^2/M_B^2}\right)^3 \zeta^2[1 + \Delta R]$$

Flavour SU(3) breaking (ratio of form factors)
$\zeta = 1.17 \pm 0.09$
Ball and Zwicky, JHEP 0604, 046 (2006);
Ball and Zwicky, hep-ph/0603232

Weak annihilation correction
$\Delta R = 0.1 \pm 0.1$
Ali, Lunghi, Parkhomenko, PLB 595,323 (2004)

B→ρ/ω γ Analyses

- Experimentally challenging
  - Large continuum background
  - Large peaking background from B→K*γ (100x)
- Continuum backround rejection continuously improved
- PID detectors effective at rejection K* γ
- Sophisticated ML fits to pick out tiny signals

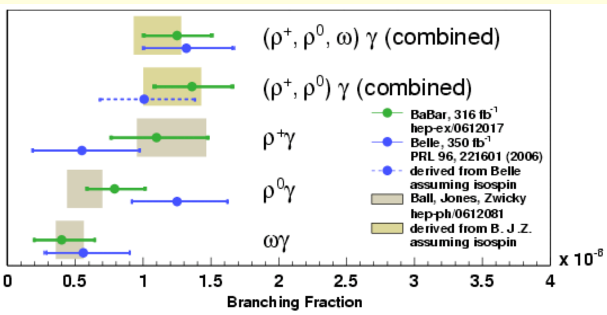


B→ρ/ω γ Results

Mode	N_{signal}	*Significance*	$BF(10^{-6})$
$B^+ \to \rho^+\gamma$	$42.0^{+14.0}_{-12.7}$	3.8σ	$1.10^{+0.37}_{-0.33} \pm 0.09$
$B^0 \to \rho^0\gamma$	$38.7^{+10.6}_{-9.8}$	4.9σ	$0.79^{+0.22}_{-0.20} \pm 0.06$
$B^0 \to \omega\gamma$	$11.0^{+6.7}_{-5.6}$	2.2σ	$0.40^{+0.24}_{-0.20} \pm 0.05$
Combined BF		6.4σ	$1.25^{+0.25}_{-0.24} \pm 0.09$

Isospin Test $\frac{\Gamma(B^+ \to \rho^+\gamma)}{2\Gamma(B^0 \to \rho^0\gamma)} - 1 = -0.35 \pm 0.27$

PRL 98, 151802 (2007)

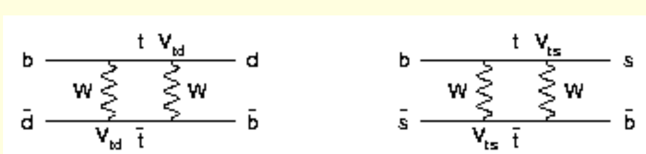


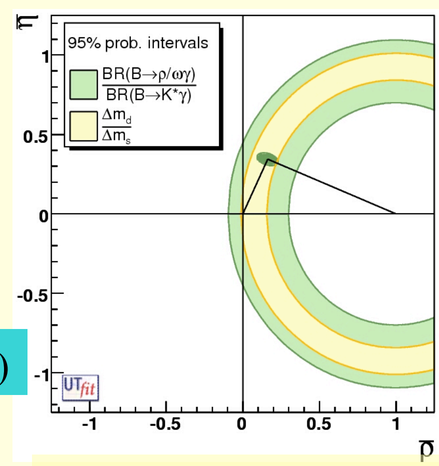
- BaBar and Belle results consistent with each other and SM prediction

Determination of V_{td}/V_{ts}

	B(B→ρ/ω γ)
BABAR	$1.25^{+0.25}_{-0.24} \pm 0.09$
Belle	$1.32^{+0.34+0.10}_{-0.31+0.09}$
Average	$1.28^{+0.20}_{+0.20} \pm 0.06$

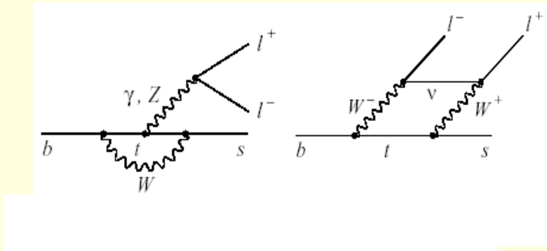
$|V_{td}/V_{ts}|_{\rho\gamma} = 0.202^{+0.017}_{+0.016}\,(exp) \pm 0.015\,(th)$





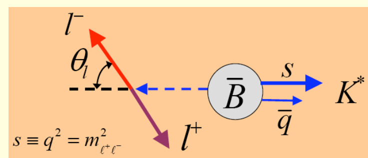
Combination of B_d^0 and B_s^0 mixing measurements
CDF observation:
Phys.Rev.Lett. 97, 242003 (2006)

B→K*l+l-

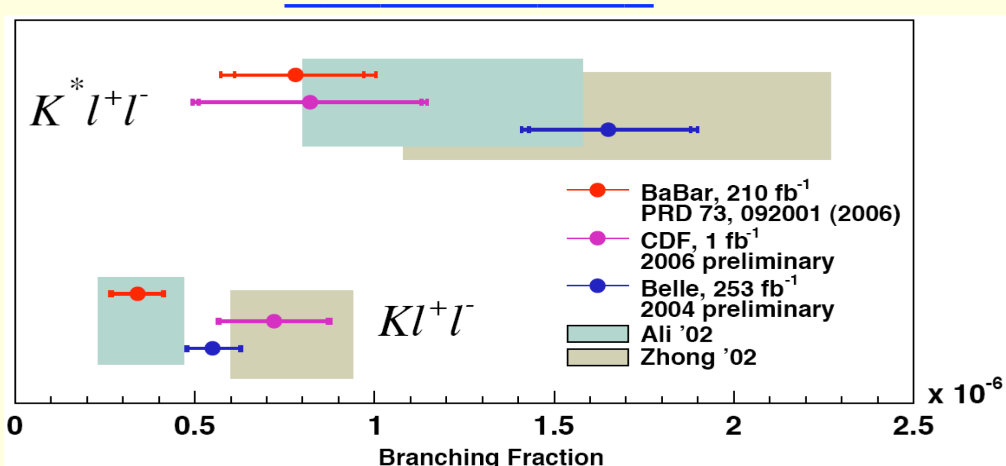


- Interference of two diagrams leads to angular asymmetry, A_{FB}
- A_{FB} varies as a function of m_{ll}
- The zero-crossing point of A_{FB} is a "firm" SM prediction

- b→sll processes receive contributions from two short-distance diagrams
- B→K*ll BF has large (hadronic) theoretical errors



B→K*l+l- BF's



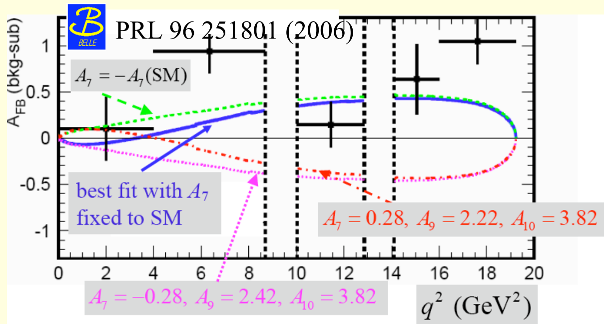
BABAR (209 fb^{-1}) PRD 73, 092001 (2006)

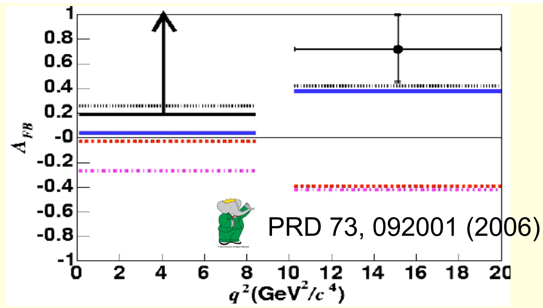
$$B(B\to K l^+ l^-) = (0.34 \pm 0.07 \pm 0.02) \times 10^{-6} \quad (6.6\sigma)$$

$$B(B\to K^* l^+ l^-) = (0.78\,^{+0.19}_{-0.17} \pm 0.11) \times 10^{-6} \quad (5.7\sigma)$$

B→K*l+l- A_{FB}

High A_{FB} at low q^2, not very consistent with SM

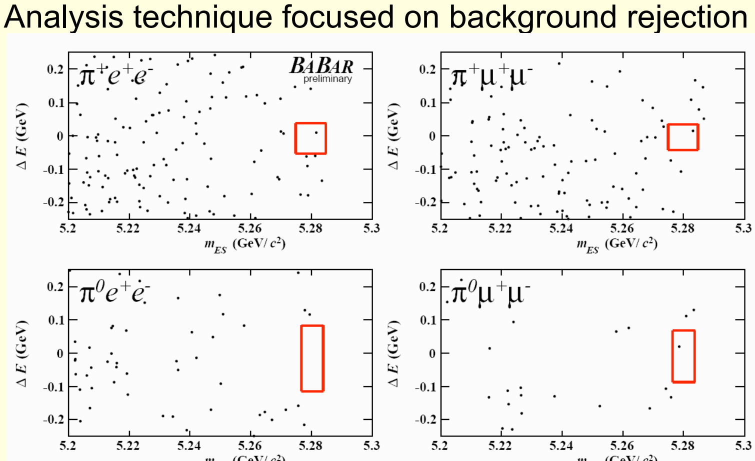




High A_{FB} at high q^2 as predicted in SM

B→πl+l-

- Suppressed relative to B→Kl$^+$l$^-$ by $|V_{td}/V_{ts}|^2$
- Standard Model BF[B→πl$^+$l$^-$] = 3 x 10^{-8}
- Analysis technique focused on background rejection

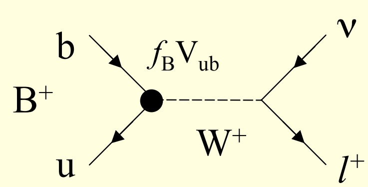


$$\mathcal{B}(B^+ \to \pi^+\ell^+\ell^-) = 2 \times \frac{\tau_{B^+}}{\tau_{B^0}}\mathcal{B}(B^0 \to \pi^0\ell^+\ell^-) < 7.9 \times 10^{-8}$$

hep-ex/0703018

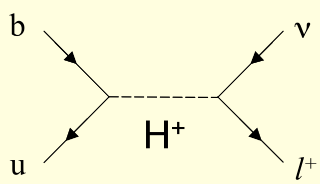
Leptonic B Decays

- SM weak-annihilation diagram leads to:
  - BF($B^+ \to \tau^+ \nu$) = 1×10^{-4}
  - BF($B^+ \to \mu^+ \nu$) = 4×10^{-7}
  - BF($B^+ \to e^+ \nu$)=1×10^{-12}

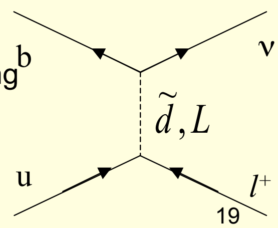


$$\mathcal{B}r(B^+ \to \ell^+ \nu_\ell) = \frac{G_f^2}{8\pi} |V_{ub}|^2 f_B^2 m_B m_\ell^2 \tau_B \left(1 - \frac{m_\ell^2}{m_B^2}\right)^2$$

New physics contributions can arise from diagrams with internal lines containing non-SM particles:

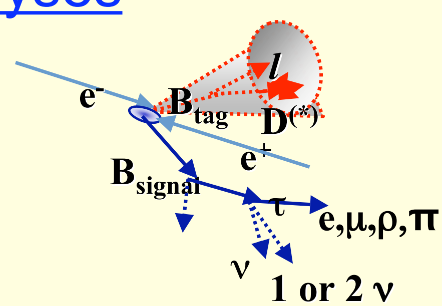


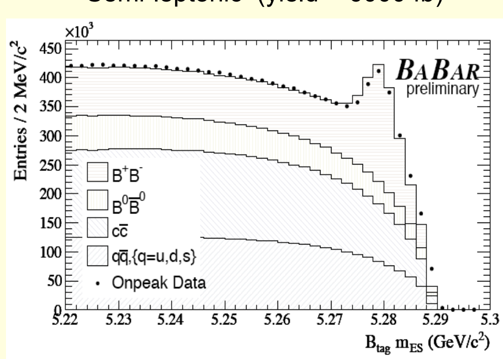
Charged Higgs, R-parity violating SUSY scalar sparticles, Pati-Salam leptoquarks...



$B^\pm \to \tau^\pm \nu$ Analyses

- Multi-neutrino final state difficult to reconstruct
  - Reconstruct $\tau^+ \to (e+,\mu+,\rho+,\pi+)+\nu$'s
  - Provide additional constraints by reconstructing other-side "tag" B in
    - Fully hadronic final state (yield=2700 fb)
    - Semi-leptonic (yield = 6000 fb)

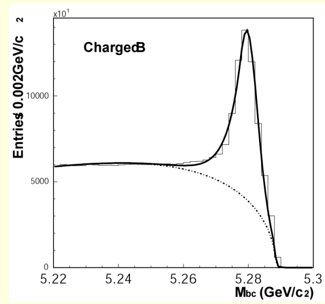


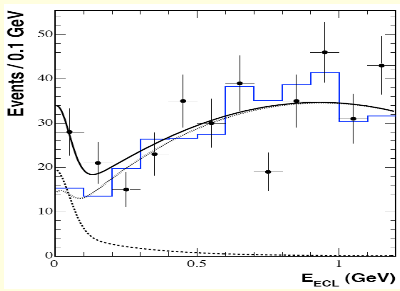


- Tag-side m_{ES} peaks at B-mass
- Trade-off between efficiency and purity

Belle $B^{\pm}\rightarrow\tau^{\pm}\nu$ Results

- First evidence reported based on 414 fb^{-1} of data
- Signal extracted from a fit to E_{ECL} - sum neutral energy not associated with tag or signal candidate (peaks at 0 for signal)





$$\mathcal{B}(B^- \rightarrow \tau^-\bar{\nu}_\tau) = (1.79^{+0.56}_{-0.49}(\mathrm{stat})^{+0.46}_{-0.51}(\mathrm{syst})) \times 10^{-4}$$

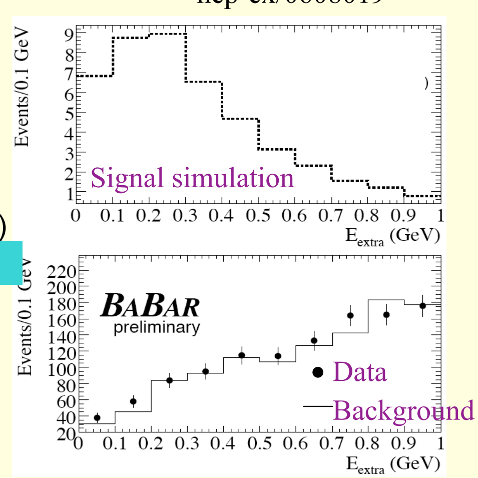
Phys. Rev. Lett. 97, 251802 (2006)

(3.5 σ significance)

BaBar $B^{\pm}\rightarrow\tau^{\pm}\nu$

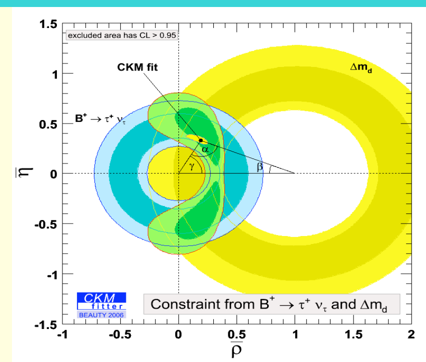
hep-ex/0608019

- Semi-leptonic tag analysis based on 324×10^6 BB pairs
  - Tag efficiency $(6.77 \pm 0.05 \pm 0.10) \times 10^{-3}$
  - Fit to E_{excess} variable to extract signal
  - Double tagged events used to validate E_extra shape
- Slight excess observed (1.3 s significance)
  - $BF(B^+\rightarrow\tau^+\nu) = (0.88 \pm 0.70 \pm 0.11) \times 10^{-4}$
  - $< 1.8 \times 10^{-4}$ @ 90% CL
- Previous BaBar analysis with hadronic tag and smaller dataset
  - $BF < 2.6\times10^{-4}$ PRD 73 057101 (2006)

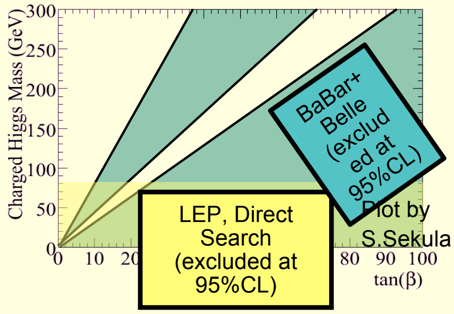


Combined $B^{\pm} \to \tau^{\pm}\nu$ Results

•BaBar/Belle combination $B(B^{+} \to \tau^{+}\nu) = (1.31 \pm 0.48) \times 10^{-4}$ (~2.5 σ)



- Within the SM (with f_B taken from LQCD) can be used to constrain V_{ub}



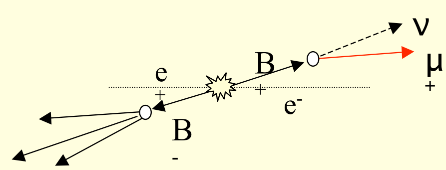
- Beyond the SM, take V_ub from UTFit to get

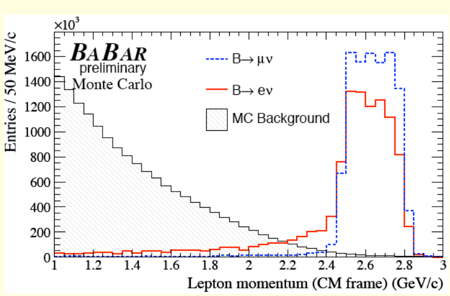
$B(B^{+} \to \tau^{+}\nu)SM = (0.85 \pm 0.13) \times 10^{-4}$

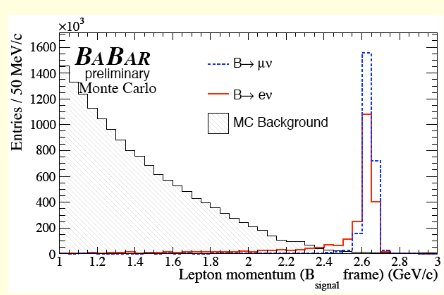
- Constrain NP contributions, e.g. MSSM

Tagged $B^{\pm} \to l^{\pm}\nu$ (l=e,μ)

- Two methods for $B^{+} \to l^{+}\nu$ analysis
  - Similar exclusively reconstructed B tag method used for $B^{+} \to \tau^{+}\nu$
  - Or, use inclusively tagged B
- Signal B rest frame estimated from tag B 4-vector. For exclusive reconstruction signal l is "monochromatic"





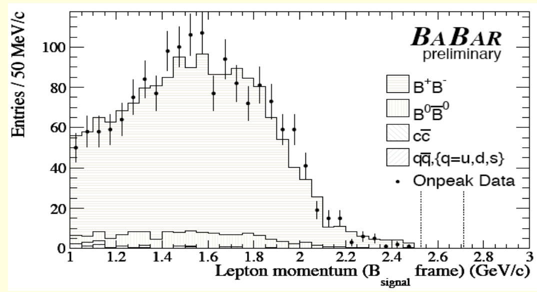


BaBar Exclusive Tag $B^{\pm} \rightarrow l^{\pm} \nu$ Results

- Based on 229x10⁶ BB pairs
- Use same tag as for B->tau v
- 0 signal events observed for both e^+ and μ^+ with expected background of 0.23 and 0.12
- Limits obtained

$B(B^+ \rightarrow \mu^+ \nu) < 6.2 \times 10^{-6}$

$B(B^+ \rightarrow e^+ \nu) < 7.9 \times 10^{-6}$



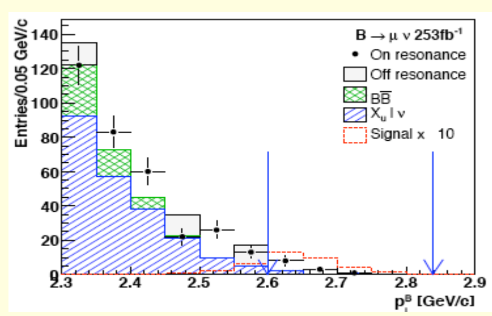
- Very clean experimentally since no systematic related to background
- Limits should improve proportional to Luminosity
- Not yet fully competitive with inclusive analysis

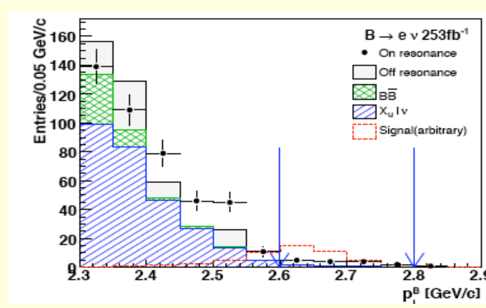
Belle Inclusive $B^{\pm} \rightarrow l^{\pm} \nu$

- Reconstruct "companion" B by 4-vector sum or remaining particles
- Belle analysis on 253 fb^{-1}
  - Lepton momentum cut
    - $2.6 < p_l < 2.84$ (for μ)
    - $2.6 < p_l < 2.8$ (for e)
  - Fit to m_{bc} and ΔE of tag B
  - Signal efficiencies (2.18 ± 0.06)% (μ) and (2.39 ± 0.06)% (e)
  - $BF(B^+ \rightarrow \mu + \nu) < 1.7 \times 10^{-6}$

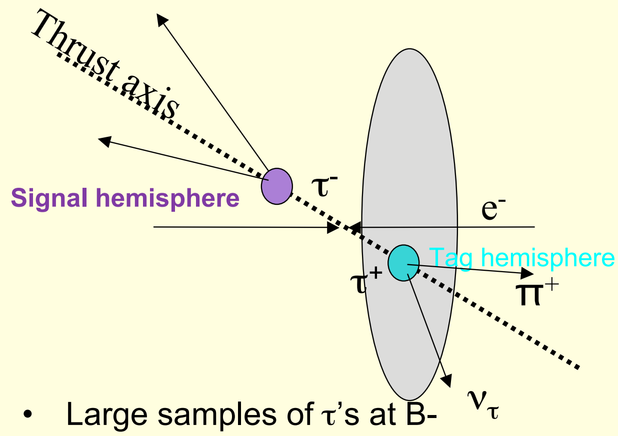
$BF(B^+ \rightarrow e + \nu) < 0.98 \times 10^{-6}$

PLB 647, 67 (2007)

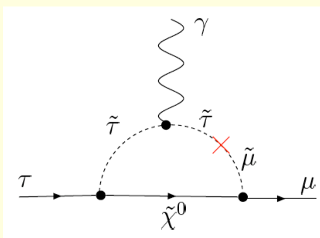




Lepton Flavor Violation in τ decays



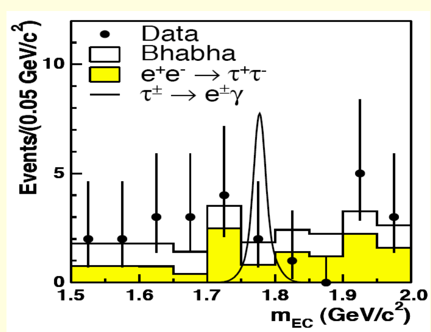
- Lepton Flavor conservation is not associated with any known symmetry
- Can arise naturally and at accessible levels in BSM models

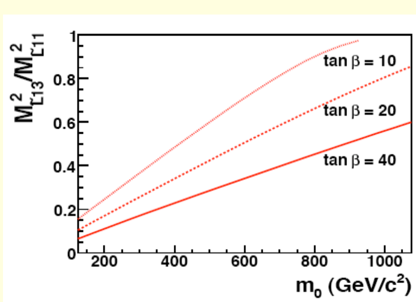


- Large samples of τ's at B-factories
- Neutrinoless τ decays can be completed reconstructed
- Variables analogous to m_{ES} and ΔE can be used

$\tau^\pm \rightarrow l^\pm\gamma$ Results

- Two recent BaBar results using $2.07\text{x}10^8$ τ pairs
  - $B(\tau^+ \rightarrow e^+\gamma) < 1.1\text{x}10^{-7}$ at 90%CL PRL 96, 041801 (2006)
  - $B(\tau^+ \rightarrow \mu^+\gamma) < 6.8\text{x}10^{-8}$ at 90%CL PRL 95, 41802 (2005)
- Belle results (hep-ex/0609049)
  - $B(\tau^+ \rightarrow e^+\gamma) < 1.2\text{x}10^{-7}$ at 90%CL
  - $B(\tau^+ \rightarrow \mu^+\gamma) < 4.5\text{x}10^{-8}$ at 90%CL

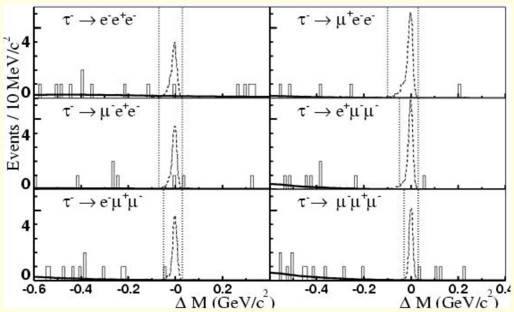




- $\tau^+ \rightarrow e^+\gamma$ interpreted as a bound on off-diagonal (M_{L13}) element of the left-handed slepton mass matrix (mSUGRA model*)
- *A. Brignole and A. Rossi, Nucl Phys B 701, 3 (2004): W. Porod, Comp. Phys. Commun. 153, 275 (2003)

$\tau^{\pm} \rightarrow l^{\pm}l^{\pm}l^{-}$ and $\tau^{\pm} \rightarrow l^{\pm}h^{\pm}h^{-}$ Results

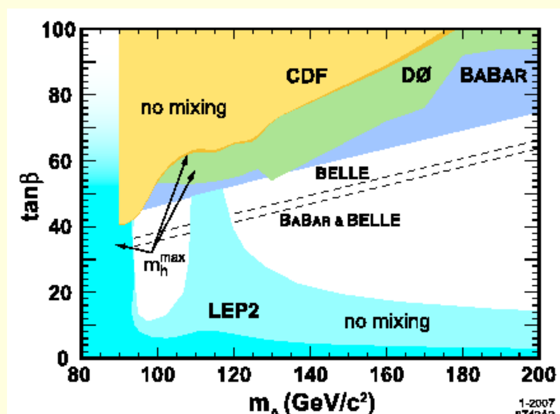
- Search for all permutations of $\tau^{+} \rightarrow l^{+}l^{+}l^{-}$ ($l = \mu$ or e)
  - BaBar analysis based on 91 fb^{-1} find $B<(1\text{-}3)\times10^{-7}$ PRL 91:121801 (2004)
  - Belle analysis based on 87 fb^{-1} finds limits in the range $(2\text{-}4)\times10^{-7}$ PLB 589, 103(2004)



- Search for all permutations of $\tau^{+} \rightarrow l^{+}h{+}h^{-}$ (h= π or K)
  - BaBar analysis based on 224 fb^{-1} find $B<(1\text{-}5)\times10^{-7}$ PRL 95:191801 (2005)
  - Belle analysis based on 158 fb^{-1} finds limits in the range $(2\text{-}8)\times10^{-7}$ PLB 640, 138 (2006)

$\tau^{\pm} \rightarrow l^{\pm}h^{0}(\pi^{0},\eta,\eta')$

- New BaBar results using 339 fb^{-1}. Limits in the range $(1.1\text{-}2.6)\times10^{-7}$ PRL 98, 061803(2007)
- Belle results using 401 fb^{-1} find limits in the range $(0.7\text{-}1.6)\times10^{-7}$ PLB 640, 138 (2006)
- Belle also searches for $\tau^{+} \rightarrow l^{+}K_{s}$ using 281 fb^{-1} PLB 639, 159 (2006)
  - $B(\tau^{+} \rightarrow e^{+}K_{s})<5.6\times10^{-8}$
  - $B(\tau^{+} \rightarrow \mu^{+}K_{s})<4.9\times10^{-8}$



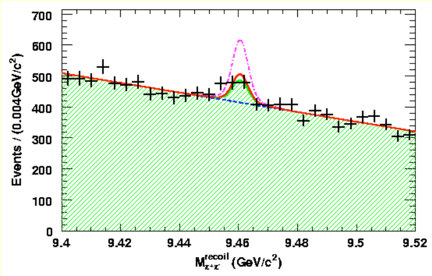
S. Banerjee, Tau '06
hep-ex 0702017

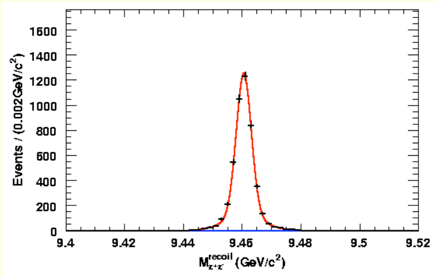
Interpretation of $\tau^{+} \rightarrow \mu^{+}\eta$ in a SUSY seesaw model* (right-handed neutrino mass of 10^{14} Gev/c^2

*M.Sher, PRD 057301 (2002)

Invisible $\Upsilon(1s)$ Decays

- Belle analysis using 2.9 fb^{-1} taken at $\Upsilon(3s)$
- $B(\Upsilon(1s) \to \nu\nu)=(9.9\pm0.5)\times10^{-6}$ (SM)
- $B(\Upsilon(1s) \to \chi\chi)=6\times10^{-3}$ Dark Matter?
- Use $\Upsilon(3s) \to \Upsilon(1s)\pi^+\pi^-$ to tag $\Upsilon(1s)$
- Use $\Upsilon(3s) \to \Upsilon(1s)(\to \mu^+\mu^-)\pi^+\pi^-$ to check $M_{\pi\pi}$ and M_{recoil} distributions





- After subtracting peaking background (133.2 events) data shows small excess (38±39) events
- $B(\Upsilon(1s) \to \text{invisible})<2.5\times10^{-3}$

Conclusions and Outlook

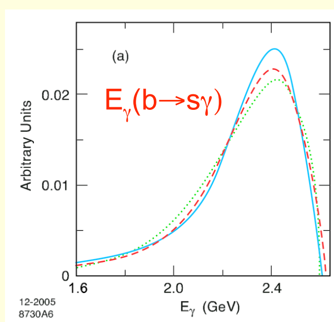
- Rare decays of “low mass” particles continue to provide tight constraints on “high mass” New Physics
  - In many cases these are better, or complementary to those found in direct searches
- The queen of these decays $b\to s\gamma$ is an “acid test” for any new model
- In the era of the LHC, rare decays may help us learn the detailed nature of the New Physics that will be found

Backup Slides

- adf

Shape Functions in Inclusive Decays

- Inclusive B decays offer a clean way to study SM and beyond-SM physics
  - $B \to X_c l\nu$ (V_{cb})
  - $B \to X_u l\nu$ (V_{ub})
  - $B \to X_s\gamma$
- Calculations are done at the b-quark level
- Motion of b-quark within B-meson "smears" kinematic quantities
  - Motion is universal for all B decays
  - Parameterized by "Shape Functions"

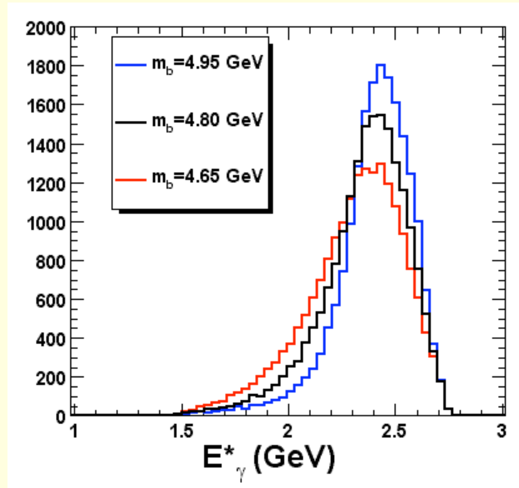


Flaecher and Buchmueller PRD73, 073008 (2006)

Scheme	Parameters	Reference
Kinetic	m_b, μ_π^2, μ_G^2	Benson, Bigi,Uraltsev NPB 710,371(2005)
Shape function	$m_{b\,SF}, \mu_\pi^2{}_{SF}$	Bosch,Lange,Neubert,Paz NPB 699,335(2004)
Kagan-Neubert	Λ, λ_1	Kagan, Neubert EPJ C7, 5(1999)

Shape Functions in b→sγ

- "Two body b decay" b→sγ is perfect for studying shape functions
- Connection between measurements and shape functions is through moments of Eγ distribution
- For BF measurement, must extrapolate below Eγ>1.9 GeV using shape function



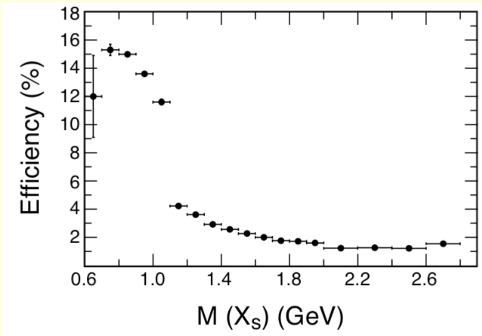
$$\langle E_\gamma \rangle_B \approx \frac{m_b}{2} \qquad \left\langle E_\gamma^2 - \langle E_\gamma \rangle^2 \right\rangle_B \approx \mu_\pi^2$$

"Sum of Exclusive" Overview

- Sum of 38 exclusive modes
  - $K^{(0)}+\leq 4\pi$
  - $K^{(0)}+\eta+\leq 2\pi$
  - $3K^{(0)}+\leq 1\pi$
- Background reduced with π^0 and η vetoes
- Event shape variables used to reduce continuum background
- Fit to m_{ES} distribution in bins of $M(X_s)$
- Uses JETSET to model X_s fragmentation

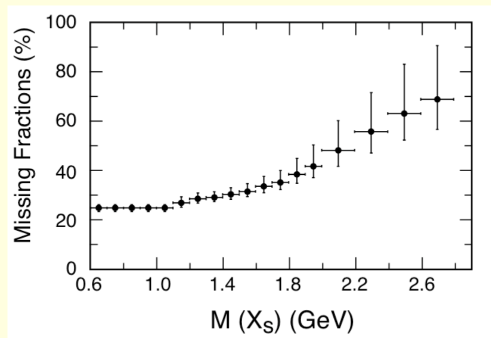
Final States	Data/Monte Carlo
$K^-\pi^+$, $K^0_S\,\pi^-$ $K^-\pi^0$, $K^0_S\,\pi^0$	0.50 ± 0.07 0.19 ± 0.12
$K^-\pi^+\pi^-$, $K^0_S\,\pi^+\pi^-$ $K^-\pi^+\pi^0$, $K^0_S\,\pi^-\pi^0$	1.02 ± 0.14 1.34 ± 0.24
$K^-\pi^+\pi^-\pi^+$, $K^0_S\,\pi^+\pi^-\pi^-$ $K^-\pi^+\pi^-\pi^0$, $K^0_S\,\pi^+\pi^-\pi^0$	2.67 ± 0.96 1.29 ± 0.61
$K^-\pi^0\pi^0$, $K^0_S\,\pi^0\pi^0$ $K^-\pi^+\pi^0\pi^0$, $K^0_S\,\pi^-\pi^0\pi^0$	1.89 ± 1.33
$K^-\pi^+\pi^-\pi^+\pi^-$, $K^0_S\,\pi^+\pi^-\pi^+\pi^-$ $K^-\pi^+\pi^-\pi^+\pi^0$, $K^0_S\,\pi^+\pi^-\pi^-\pi^0$ $K^-\pi^+\pi^-\pi^0\pi^0$, $K^0_S\,\pi^+\pi^-\pi^0\pi^0$	$1.32^{+1.55}_{-1.32}$
$K^-\eta$, $K^0_S\,\eta$, $K^-\eta\,\pi^+$ $K^0_S\,\eta\,\pi^-$, $K^-\eta\,\pi^0$, $K^0_S\,\eta\,\pi^0$ $K^-\eta\,\pi^+\pi^-$, $K^0_S\,\eta\,\pi^+\pi^-$ $K^-\eta\,\pi^+\pi^0$, $K^0_S\,\eta\,\pi^-\pi^0$	$0.83^{+1.00}_{-0.83}$
$K^-K^+K^-$, $K^-K^+K^0_S$ $K^-K^+K^-\pi^+$, $K^-K^+K^0_S\,\pi^-$, $K^-K^+K^-\pi^0$, $K^-K^+K^0_S\,\pi^0$	$0.27^{+0.54}_{-0.27}$

“Sum of Exclusive” Efficiency



Efficiency decreases with M(X_s)

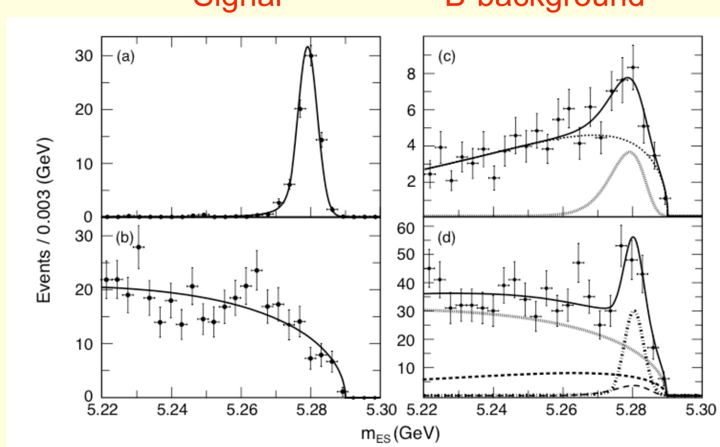
Missing modes fraction increases with M(X_s)



“Sum of Exclusive” $b \to s\gamma$ Fitting

- Fits to m_{ES} in bins of M(X_s)
- Peaking background subtracted in each bin
- Example at right si for 1.4<M(X_s)<1.5. Other bins are similar

Signal B-background



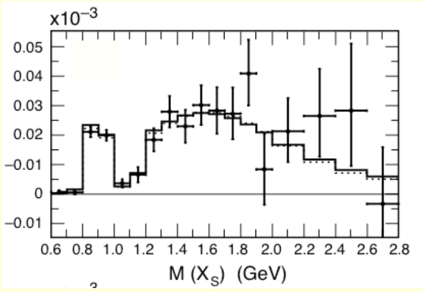
Continuum Data

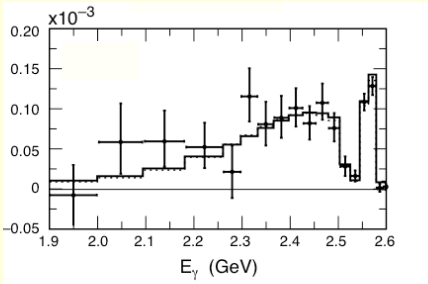
1.4<M(X_s)<1.5

"Sum of Exclusive" Results

- $BF(E_\gamma > 1.9\ GeV) = (3.27 \pm 0.18\ ^{+0.55}_{-0.40}\ ^{+0.04}_{-0.09}) \times 10^{-4}$
- Extrapolated to $BF(E\gamma > 1.6) = (3.35 \pm 0.19\ ^{+0.56}_{-0.41}\ ^{+0.04}_{-0.09}) \times 10^{-4}$
- $\Delta_{0-} = 0.006 \pm 0.058 \pm 0.009 \pm 0.024$
- E_γ Moments $E\gamma > 1.9$ GeV
  - First moment = $2.321 \pm 0.038\ ^{+0.017}_{-0.038}$ GeV
  - Second moment = $0.0253 \pm 0.0101\ ^{+0.0041}_{-0.0028}$ GeV^2

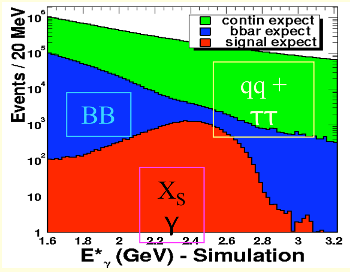
PRD 72, 052004 (2005)

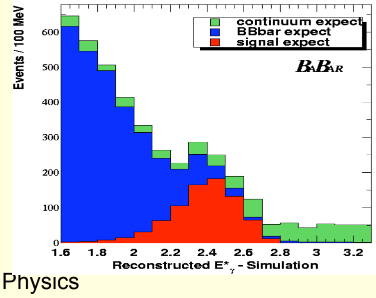




Fully Inclusive b→sγ Overview

- Require $E_\gamma^* > 1.9$. Lowest possible $E\gamma$ cut is preferred to minimize model dependence
- Veto π^0 and η backgrounds
- Dramatically reduce continuum background with opposite-side lepton tag and event shape variables
- Subtract continuum background with off-peak data

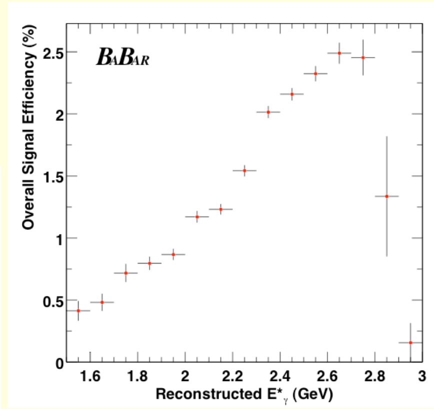




Fully Inclusive b→sγ Details

- B-background is largest systematic
- Use control samples to limit B-background systematics

Truth-match	Parentage	Fraction of $B\overline{B}$ background ($2.0 < E_\gamma^* < 2.7\,\mathrm{GeV}$)
Photon	π^0	0.640
	η	0.174
	ω	0.024
	η'	0.011
	FSR	0.007
	J/ψ	0.008
	Other	0.001
	Total	0.865
π^0 (merged)	Any	0.001
Electron	Any	0.036
$\overline{n}$ (n)	Any	0.077
$\overline{p}$ (p)	Any	0.005
K_L^0	Any	0.001
$\pi^\pm$ or $K^\pm$	Any	0.001
Unidentified		0.015

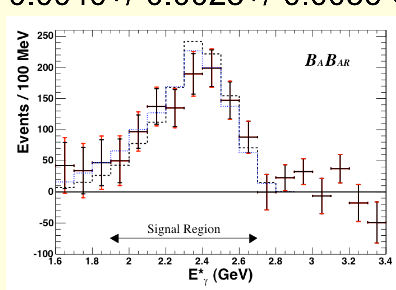


- E_γ* efficiency reduced at low E_γ*

Fully Inclusive Results

- BF(Eγ>1.9 GeV)= $(3.67\pm0.29\pm0.34\pm0.29)\mathrm{x}10^{-4}$
  - Extrapolate to BF(E_g>1.6 GeV)= (3.94±0.31±0.36±0.21)x10-4
- Moments for E_γ>1.9 GeV
  - First moment = 2.28±0.025±0.017±0.15 GeV
  - Second moment = 0.0328+/-0.0040+/-0.0023+/-0.0036 GeV^2
  - m_b=4.44±0.08±0.14 GeV
  - μ_π^2=0.64±0.13±0.24 GeV^2
- A_{CP}=-0.110±0.115±0.017

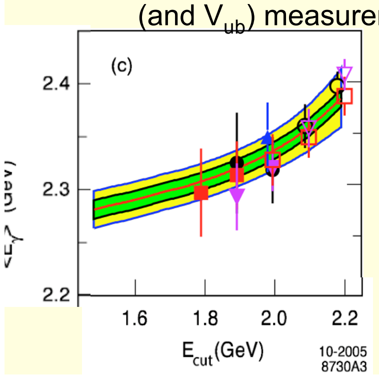
hep-ex/0607071

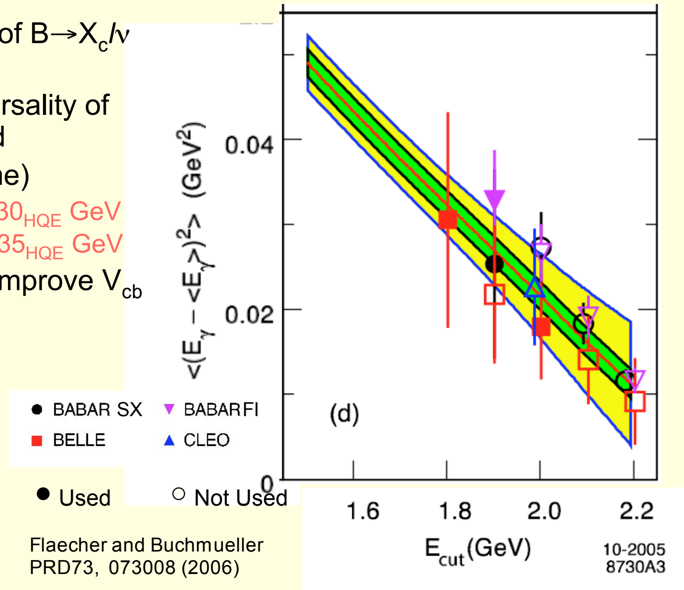


Eγ spectrum (not corrected for efficiency)

HQE Parameters from $b \to s\gamma$ Moments

- Combined fit to moments of $B \to X_c l\nu$ and moments of E_γ
- Agreement is good. Universality of shape functions confirmed
- Fit finds (in Kinetic Scheme)
  - m_b=4.590±0.025$_{exp}$±0.030$_{HQE}$ GeV
  - μ_π^2=0.401±0.019$_{exp}$±0.035$_{HQE}$ GeV
- Use $b \to s\gamma$ information to improve V_{cb} (and V_{ub}) measurements





Flaecher and Buchmueller
PRD73, 073008 (2006)