Leptonic B Decays at BaBar

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On the behalf of the BaBar collaboration

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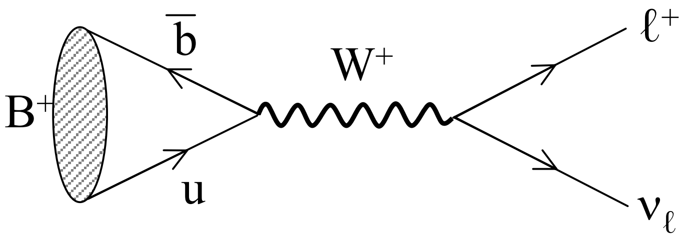
Outline

Recent results from the BaBar collaboration

- $B \rightarrow \tau\nu$
  - Semileptonic tag analysis
  - Hadronic tag analysis
- $B \rightarrow K\tau\mu$
- $B \rightarrow \ell^+\ell^-\gamma$

$B \rightarrow \ell \nu$ decays

In the Standard Model



$$\mathcal{B}_{SM}(B \rightarrow \tau\nu) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

$f_B = 216 \pm 22$ MeV

(Lattice QCD)

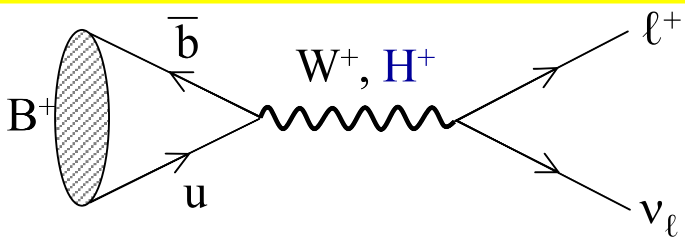
$|V_{ub}| = (4.31 \pm 0.30)\mathrm{x}10^{-3}$

(Semilep. B decays)

$\mathcal{B}_{SM}(B \rightarrow \tau\nu) = (1.6 \pm 0.4)\mathrm{x}10^{-4}$

Strong helicity suppression for $B \rightarrow e(\mu)\,\nu$ decays

Beyond the Standard Model



- Charged Higgs mediated amplitude occurs in two Higgs doublet extensions
  - W.Hou, Phys. Rev. D. 48, 2342
- Branching Fraction could be enhanced or suppressed
- Possibility to constraint the (m_{H+},tanβ) parameter space

$$\mathcal{B}(B \rightarrow \tau\nu) = \mathcal{B}_{SM}(B \rightarrow \tau\nu) \times \left(1 - \tan^2\beta \frac{m_{B^\pm}^2}{m_{H^\pm}^2}\right)^2$$

ratio of vacuum expectation values for two Higgs doublets.

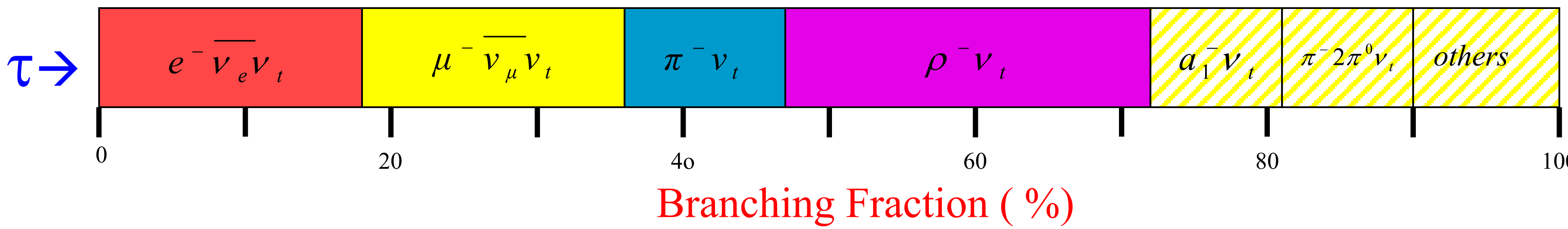
Charged Higgs mass

$B \to \tau\nu$ experimental challenges

$\mathcal{B}^{SM}(B \to \tau\nu) \sim 10^{-4}$
$\mathcal{B}^{SM}(B \to \mu\nu) \sim 10^{-7}$
$\mathcal{B}^{SM}(B \to e\nu) \sim 10^{-10}$

$B \to \tau\nu$ helicity favored but experimentally more difficult

Main τ decay modes:



- $\sim$ 71% of the total τ width
- Final state contains:
  - 1 track (+ 1 π^0 in the ρ channel)
  - 2-3 neutrinos
- Weak kinematical constraints
- Need to clean the experimental enviroment
- Reconstruct the other B (tag B) of the event

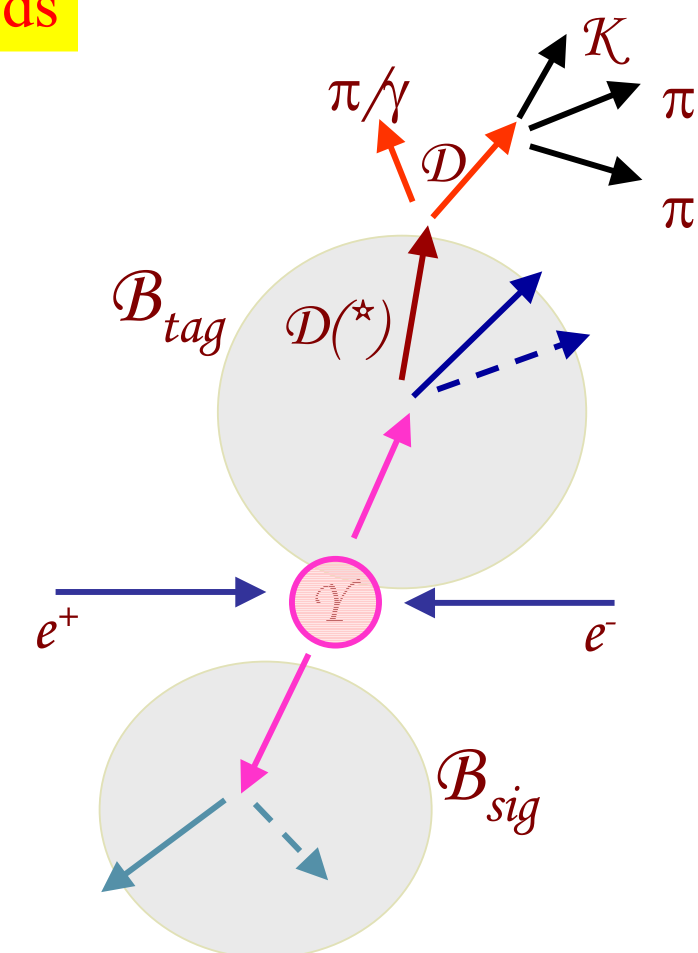
Tag technique

Two tag methods

- Hadronic:
  - $B^- \to D^{(*)0}\ n_1\pi^\pm\ \ n_2K^\pm\ \ n_3K^0_s\ n_4\pi^0$

    $(n_1 + n_2 <= 5;\ n_3<=2;\ n_4<=2)$
  - Full reconstruction
  - Use of beam energy constraints to build discriminating variables

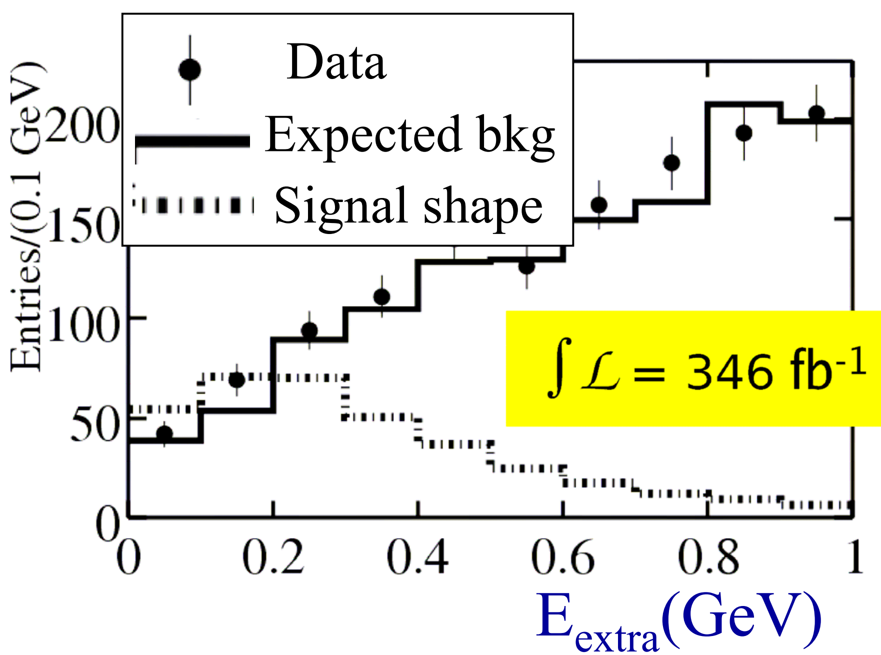
    $$m_{ES} = \sqrt{(E^*_{beam})^2 - (p^*_B)^2}$$
    $$\Delta E = E_B - E^*_{beam}$$
  - Higher purity/lower statistics
- Semileptonic:
  - $B^- \to D^{(*)0}\ell\nu(\ell = e, \mu)$
  - Take advantage of the high semileptonic BFs
  - Partial reco (additional neutrino)
  - Higher statistics/lower purity



- Look for signal in the rest of the event

$B \rightarrow \tau\nu$ with semileptonic tag

- Tag efficiency: 0.66%
- Most discriminating variable E_{extra}: ΣE (extra neutral clusters and tracks)
- Mode dependent selection:
  - $E_{extra} < 0.25$-0.48 GeV
- Tag efficiency and E_{extra} model validated in double tagged events
- Expected background evaluated by extrapolating data in E_{extra} sidebands with same ratio as in MC

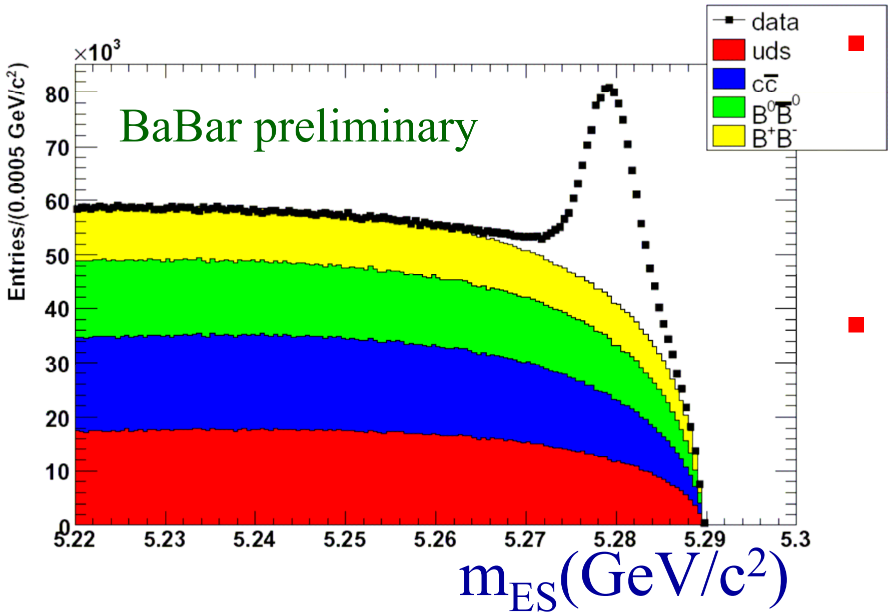


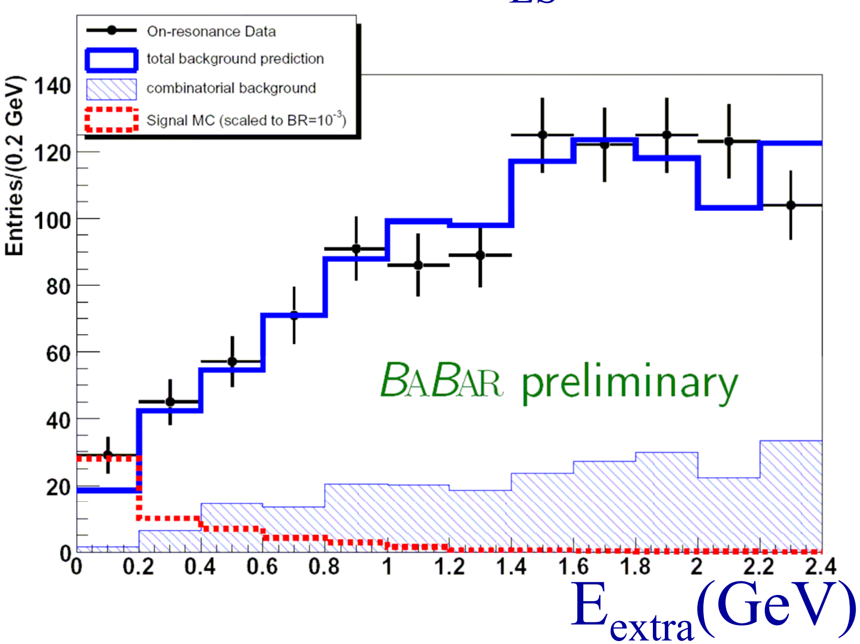
τ decay mode	Expected background events	Observed events in on-resonance data
$\tau^+ \rightarrow e^+\nu\bar{\nu}$	44.3 ± 5.2	59
$\tau^+ \rightarrow \mu^+\nu\bar{\nu}$	39.8 ± 4.4	43
$\tau^+ \rightarrow \pi^+\bar{\nu}$	120.3 ± 10.2	125
$\tau^+ \rightarrow \pi^+\pi^0\bar{\nu}$	17.3 ± 3.3	18
All modes	221.7 ± 12.7	245

Submitted to PRD: **arXiv:0705.1820**

$B \to \tau\nu$ with hadronic tag

$\int \mathcal{L} = 346\ fb^{-1}$





- Tagged 5.9×10^5 fully reconstructed B mesons ($\varepsilon^{tag} = 0.15\%$)
  - Use m_{ES} to discriminate combinatorial background
- Mode dependent selection:
  - Veto on extra charged tracks
  - Particle identification
  - $E_{extra} = \Sigma E$ (extra neutral clusters)
    - $E_{extra} < 0.1\text{-}0.29$ GeV

BaBar preliminary

τ decay mode	Expected background	observed
$\tau \to e\nu\nu$	1.5 ± 1.4	4
$\tau \to \mu\nu\nu$	1.8 ± 1.0	5
$\tau \to \pi\nu$	6.8 ± 2.1	10
$\tau \to \pi\pi^0\nu$	4.2 ± 1.4	5
All modes	14.3 ± 3.0	24

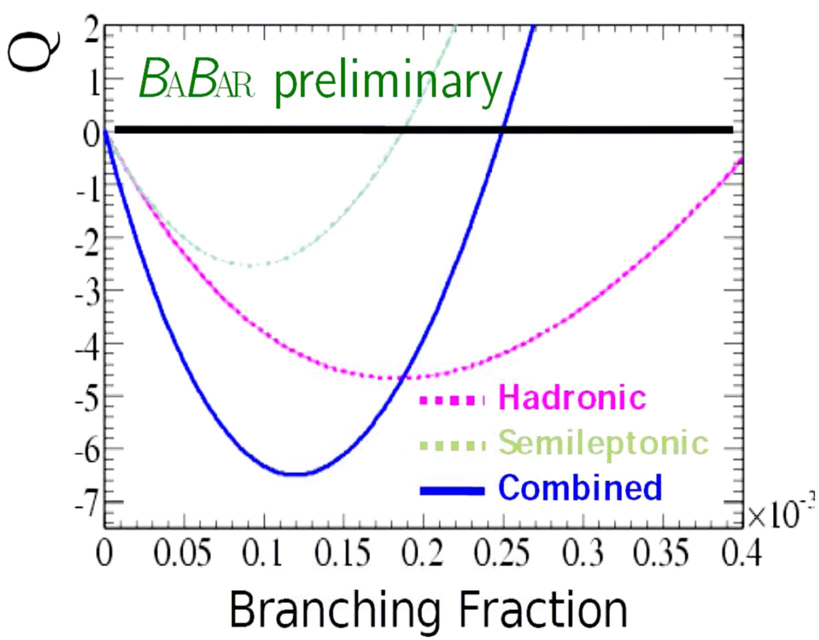
$B \rightarrow \tau\nu$ Branching Fraction

- Use the background predictions and the number of observed events to obtain the BF confidence interval.
- Build likelihood combining poissonian probabilities of all the τ channels

$$\mathcal{L}(s+b) = \prod_{i=1}^{4} \frac{e^{-(s_i + b_i)}(s_i + b_i)^{n_i}}{n_i} \qquad s_i = N_B \varepsilon_i \mathcal{B}$$

$$Q(\mathcal{B}) = -2\ln(\mathcal{L}(s+b) / \mathcal{L}(b))$$

Signal significance: $\sqrt{-Q_{min}}$



Semileptonic tag analysis:
$\mathcal{B}(B \rightarrow \tau\nu) = (0.9 \pm 0.6 \pm 0.1) \times 10^{-4}$ [1.3σ]

Hadronic tag analysis: BaBar preliminary
$\mathcal{B}(B \rightarrow \tau\nu) = (1.8^{+1.0}_{-0.9} \pm 0.3) \times 10^{-4}$ [2.2σ]

Combined Result: BaBar preliminary [2.6σ]
$\mathcal{B}(B \rightarrow \tau\nu) = (1.2 \pm 0.4^{stat} \pm 0.3^{bkg} \pm 0.2^{eff}) \times 10^{-4}$

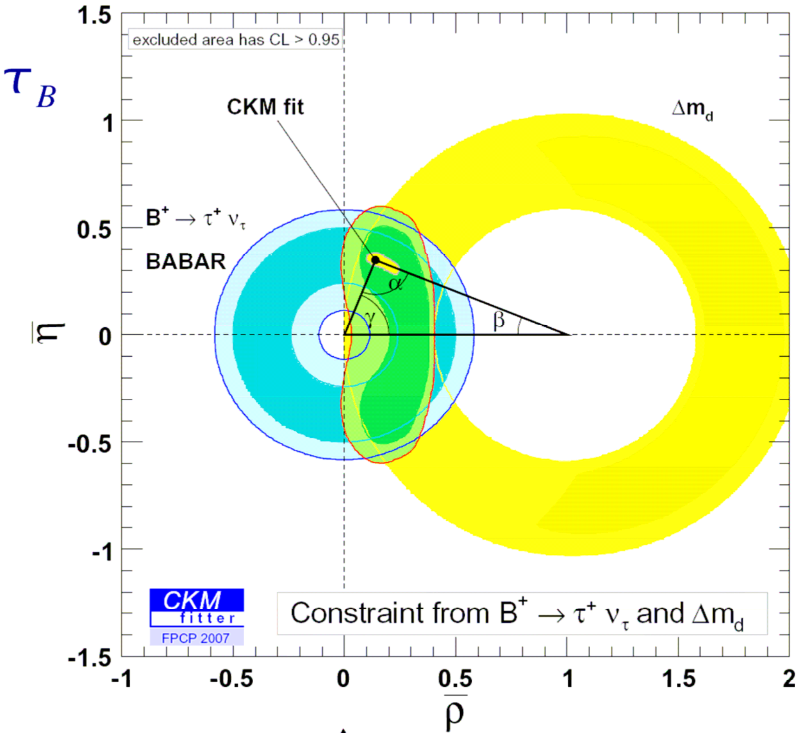
SM prediction: $\mathcal{B} = (1.6 \pm 0.4) \times 10^{-4}$

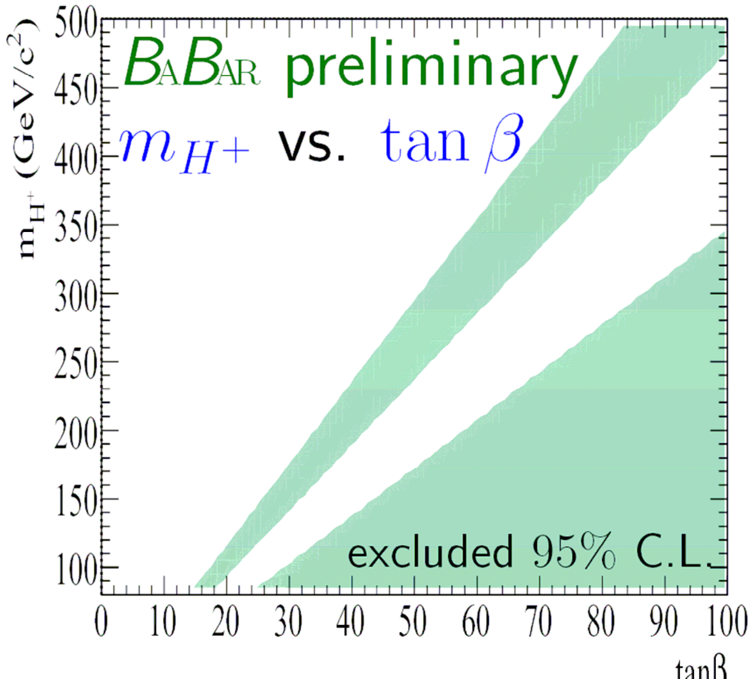
Belle result: $\mathcal{B} = (1.79^{+0.56}_{-0.49}{}^{+0.46}_{-0.51}) \times 10^{-4}$ [3.5σ]

Interpreting the result

$$\mathcal{B}_{SM}(B\to\tau\nu) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1-\frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

Using $f_B = 223 \pm 15 \pm 26$ (lattice QCD) the BF measurement provides a constraint on the ρ-η plane



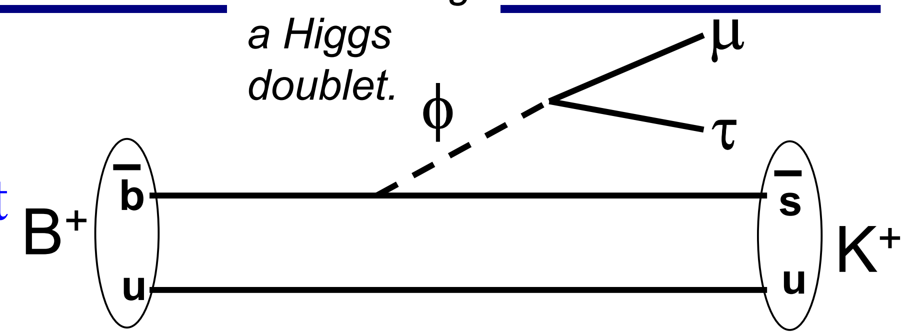


The comparison between the SM expectation and the BaBar combined result allows to exclude regions on the (m_{H+},tanβ) plane

Shown above the limit set by direct search at LEP: $m_{H+}>78.5$ GeV @95% CL

$$\mathcal{B}(B\to\tau\nu) = \mathcal{B}_{SM}(B\to\tau\nu)\times\left(1-\tan^2\beta\frac{m_{B^\pm}^2}{m_{H^\pm}^2}\right)^2$$

B→Kτμ



- Not allowed in the SM
  - Flavor changing neutral current
  - Lepton flavor violation

- NP with extended Higgs sector may introduce tree level FCNC mediated by a new scalar particle
- "Most natural" values for lepton couplings are proportional to

$$\eta_{ij} = \sqrt{m_i m_j}/m_\tau$$

- Transitions involving third generation of both quark and leptons are favored in this framework

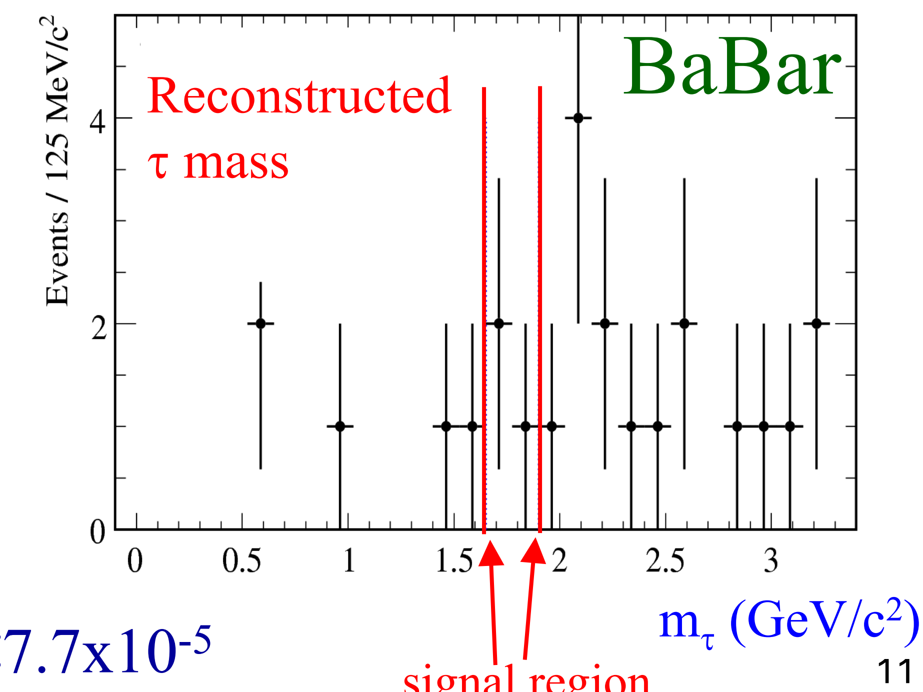
$\eta_{ee} = 0.0003$ $\eta_{e\mu} = 0.004$ $\eta_{e\tau} = 0.02$ $\eta_{\mu\mu} = 0.06$ $\boxed{\eta_{\mu\tau} = 0.24}$

Sher and Yuan, Phys. Rev. D44, 1461 (1991)

$B \rightarrow K\tau\mu$

- Search based on 346 fb^{-1}
- Look for signal on the recoil of hadronic tag Bs
- $B \rightarrow D^0(K\pi)\mu\nu$ events: control sample to normalize the signal BF
- Signal divided into three channels based on tau daughter: **electron**, **muon**, and **pion**.
- τ four momentum obtained by subtraction:
  - $p_\tau = p_{Btag} - p_K - p_\mu$

Events in signal window	*Expected background*
$N_e = 1$	$b_e = 0.5 \pm 0.3$
$N_\mu = 0$	$b_\mu = 0.6 \pm 0.3$
$N_\pi = 2$	$b_\pi = 1.8 \pm 0.6$



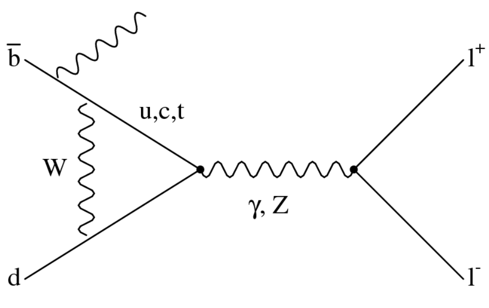
First search ever done for this channel

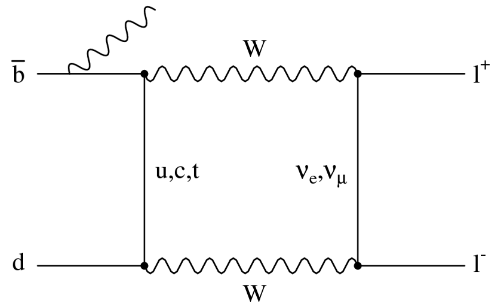
No evidence of signal

Upper limit (90%CL): $\mathcal{B}(B \rightarrow K\tau\mu) < 7.7 \times 10^{-5}$

$B \to \ell^+\ell^-\gamma$

Submitted to PRL: **arXiv:0706.2870**



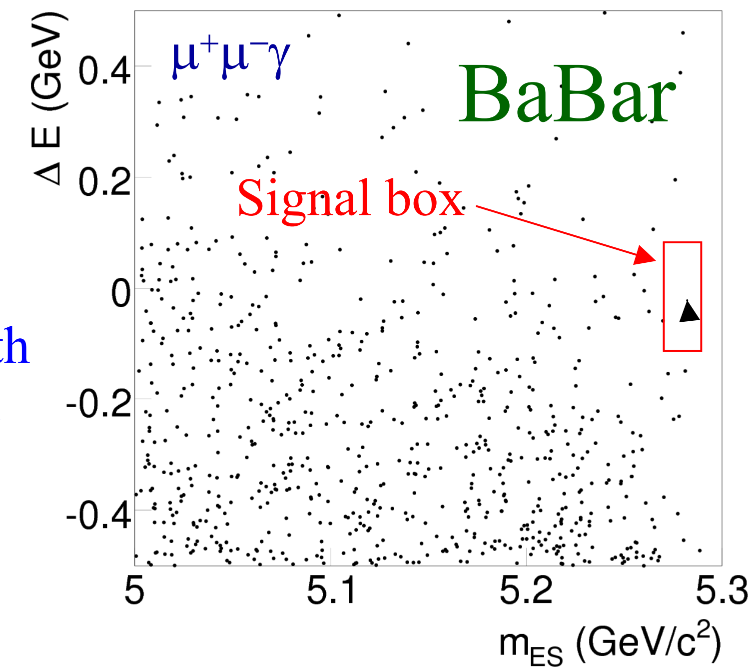


- FCNC processes
  - Suppressed in the SM
  - BR ~ 10^{-10}
  - Can be enhanced by new physics

First search ever done for these channels

- Search based on 320×10^6 BB pairs
- Construct B^0 candidates from two leptons (electrons or muons) and a photon
- Constrain the B candidate to be consistent with the production at the Y(4S) using m_{ES} and ΔE

Events in signal window	*Expected background*
$N_e = 1$	$b_e = 1.75 \pm 1.38$
$N_\mu = 1$	$b_\mu = 2.66 \pm 1.40$

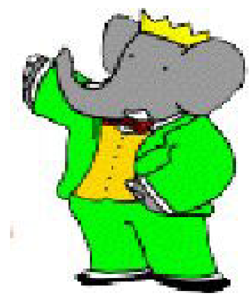


$\mathcal{B}(B \to e^+e^-\gamma) < 1.2\times10^{-7}$, $\mathcal{B}(B \to \mu^+\mu^-\gamma) < 1.5\times10^{-7}$ @90% CL

Summary

- $B \rightarrow \tau\nu$
  - $\mathcal{B} = (1.2 \pm 0.4^{stat} \pm 0.3^{bkg} \pm 0.2^{eff}) \times 10^{-4}$
  - 2.6σ significance (3.2σ stat.)
  - Set constraints on New Physics parameters
- $B \rightarrow K\tau\mu$
  - First search ever done
  - No evidence of signal
  - $\mathcal{B} < 7.7 \times 10^{-5}$ @90% CL
- $B \rightarrow \ell^+\ell^-\gamma$
  - First search ever done
  - $\mathcal{B}(B \rightarrow e^+e^-\gamma) < 1.2 \times 10^{-7}$ @90% CL
  - $\mathcal{B}(B \rightarrow \mu^+\mu^-\gamma) < 1.5 \times 10^{-7}$ @90% CL

Recent BaBar results



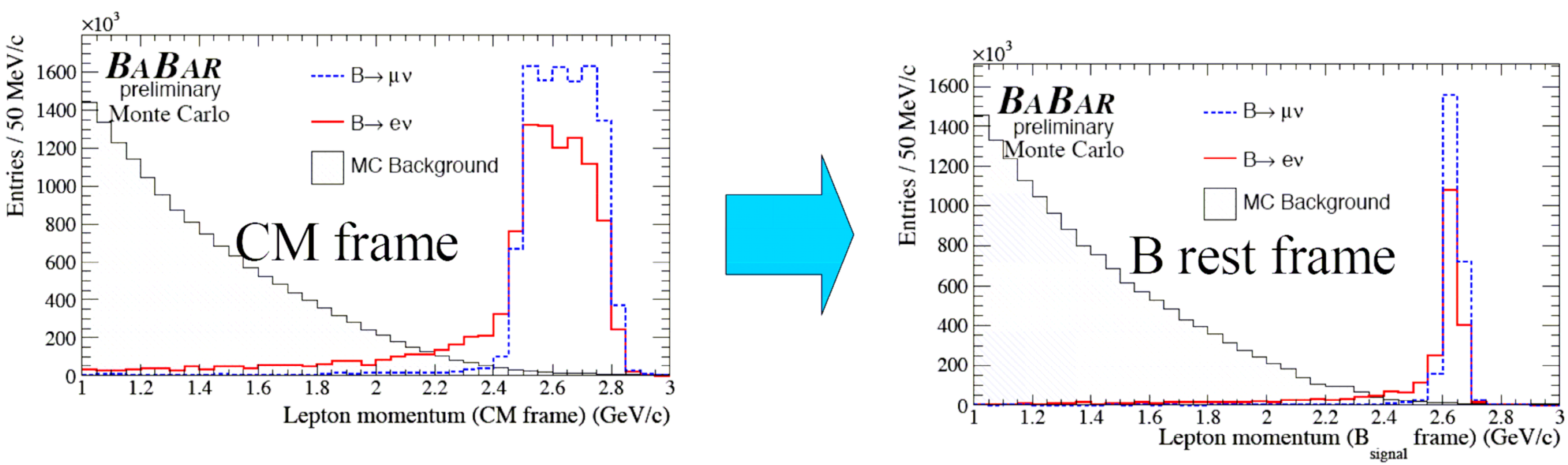
Backup slides

B→e/μν

BR helicity suppressed

- $BR_{SM}(\mu\nu)=(4.7 \pm 0.7)\times10^{-7}$
- $BR_{SM}(e\nu)=(11.1 \pm 0.1)\times10^{-11}$

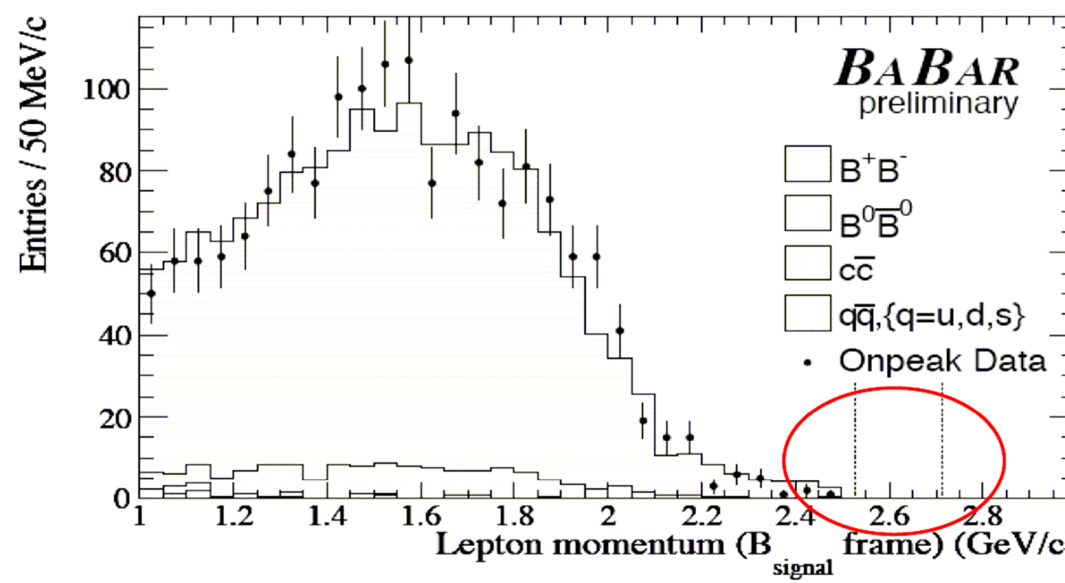
- Search for signal on the recoil of hadronic tagged events
- Only one neutrino→ reconstruction of tag B completely constraints kinematics
- Signal B rest frame estimated from tag B 4-vector, allowing to exploit 2-body signal kinematics.



$B \rightarrow e/\mu\nu$

- Analysis based on 209 fb^{-1}
- Observed 0 events in each of e and m channels with expected backgrounds of 0.23 and 0.12 events respectively

$B(B^+ \rightarrow e^+\nu) < 7.9 \times 10^{-6}$
$B(B^+ \rightarrow \mu^+\nu) < 6.2 \times 10^{-6}$
at 90% CL



- Method free from experimental issues related to backgorund modeling but currently statistically limited

$B \rightarrow \ell \nu \gamma$

- Presence of photon removes helicity suppression
  - BR enhanced
  - Universality of leptonic branching fraction recovered
  - Measuring the BF in a limited phase space region provide information on the QCD parameter λ_B

$$\Delta\mathcal{B} = \alpha \frac{G_F^2 |V_{ub}|^2}{32\pi^4} f_B^2 \tau_B m_B^3 \left[a + bL + cL^2\right]$$

$L = (m_B/3)(1/\lambda_B + 1/(2m_b))$. *a*, *b*, *c*: (model independent) computable constants

λ_B : first inverse moment of B light cone distribution amplitude (enters calculations of BF of hadronic *B* decays) $\sim \Lambda_{QCD}$

SM expectation for the full BR

$B(B \to l\nu\gamma) \sim (1\text{-}5) \times 10^{-6}$ (Korchemsky, Pirjol and Yan Phys Rev D61, 114510, 2000)

$B \to \ell \nu \gamma$

232M BB arXiv:0704.1478

- Measure partial BF in the phase space region:

$1.875 < E^*_{\ell} < 2.850$GeV, $0.45 < E^*_{\gamma} < 2.35$GeV, $\cos\theta_{\ell\gamma} < -0.36$

- Identify lepton and signal photon and perform an inclusive reconstruction (i.e. 4-vector sum) of the other B
- Neutrino 4-vector obtained from missing momentum vector
- Extract signal from ML fit to m_{ES} and neutrino E-|p| in signal and sideband regions

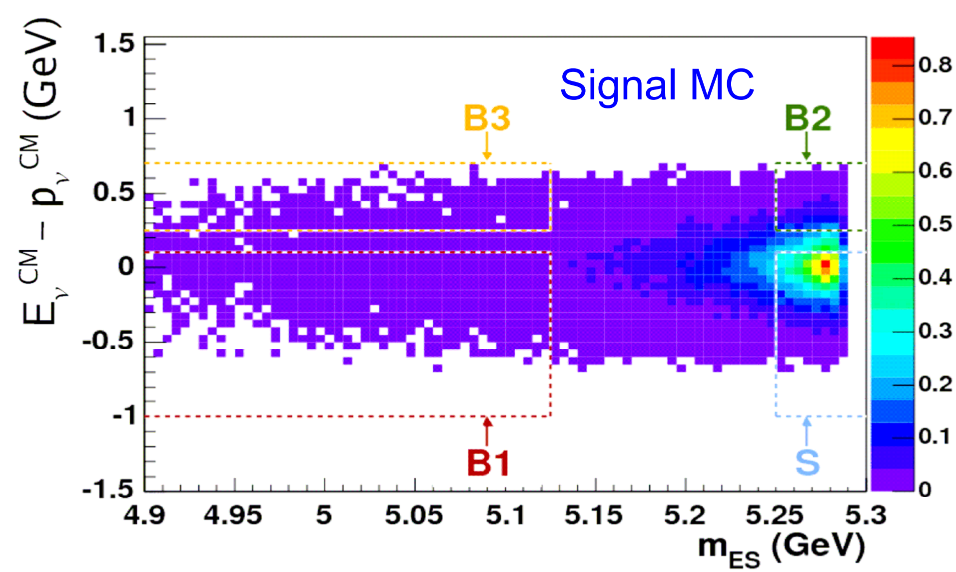
No evidence of signal set UL at 90% CL

$\Delta B(B \to \gamma \mu \nu_{\mu}) < 2.1\times10^{-6}$
$\Delta B(B \to \gamma e \nu_{e}) < 2.8\times10^{-6}$
$\Delta B(B \to \gamma \ell \nu_{\ell}) < 2.3\times10^{-6}$

(Bayesian limits with flat prior in BF)

With some input from theory, joint fit translates to:

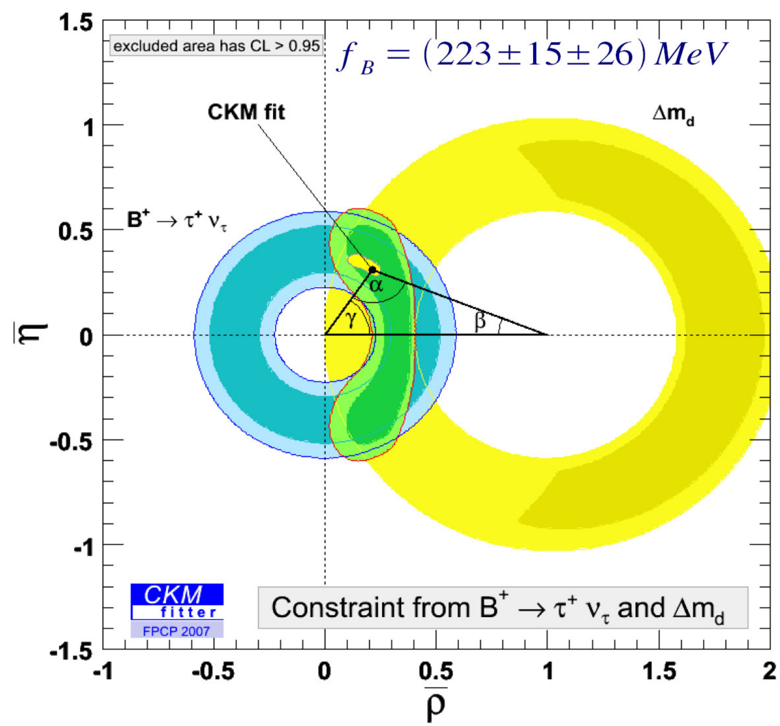
$BF(B \to \gamma \ell \nu_{\ell}) < 5.0 \times 10^{-6}$ (90% CL)



Approaching the SM prediction

Combined BaBar+Belle $B \to \tau\nu$

- BaBar combined (346 fb^{-1}): Preliminary
  - $\mathcal{B}(B \to \tau\nu) = (1.2 \pm 0.4^{stat} \pm 0.3^{bkg} \pm 0.2^{eff}) \times 10^{-4}$
- Belle had tag (414 fb^{-1}): PRL 97,251802 (2006)
  - $\mathcal{B}(B \to \tau\nu) = (1.79^{+0.56}_{-0.49}{}^{+0.46}_{-0.51}) \times 10^{-4}$
- BaBar+Belle (Gaussian weighted average)
  - $\mathcal{B}(B \to \tau\nu) = (1.41 \pm 0.43) \times 10^{-4}$



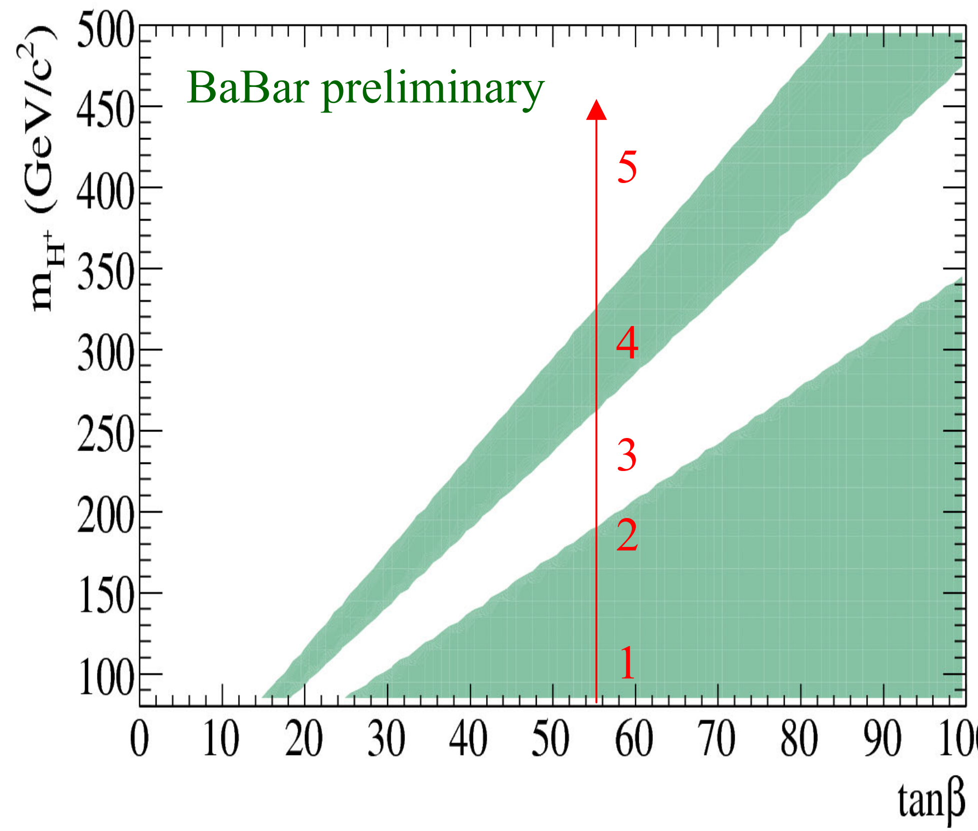
The m_H vs. $\tan\beta$ plot

in two Higgs doublet extensions of the SM:

$$\mathcal{B}(B\to\tau\nu) = \mathcal{B}_{SM}(B\to\tau\nu)\times\left(1-\tan^2\beta\frac{m^2_{B^\pm}}{m^2_{H^\pm}}\right)^2$$

For a fixed value of $\tan\beta$ and increasing values of m_H :

1) Small higgs mass: the BF is enhanced (ruled out by the measurement)
2) The BF approach the SM prediction and can not be resolved over the uncertainty (start the gap).
3) The NP factor become less than 1 and the BF is suppressed but still we are not able to resolve it.
4) The BF is significantly suppressed (ruled out by the measurement)
5) The suppression term approach 1 and we loose exclusion again



B→τν with semileptonic tag

Selection criteria

mode	e^+	μ^+	π^+	$\pi^+\pi^0$
$M_{\text{miss}}(\text{GeV}/c^2)$	[4.6, 6.7]	[3.2, 6.1]	≥ 1.6	≤ 4.6
$p^*_{\text{signal}}(\text{GeV}/c)$	≤ 1.5	–	≥ 1.6	≥ 1.7
R_{cont}	[2.78, 4.0]	> 2.74	> 2.84	> 2.94
$E_{\text{extra}}(\text{GeV})$	< 0.31	< 0.26	< 0.48	< 0.25
Efficiency (%)	4.2 ± 0.1	2.4 ± 0.1	4.9 ± 0.1	1.2 ± 0.1

Systematics

τ decay mode	$e^+\nu\overline{\nu}$	$\mu^+\nu\overline{\nu}$	$\pi^+\overline{\nu}$	$\pi^+\pi^0\overline{\nu}$
Tracking	0.5	0.5	0.5	0.5
Particle Identification	2.5	3.1	0.8	1.5
π^0	–	–	–	2.9
EMC K^0_L	–	–	3.8	–
IFR K^0_L	3.3			
E_{extra}	3.4			
signal B	5.5			
tag B	3.6			
$N_{B\overline{B}}$	1.1			
Total	6.6			

BaBar:semileptonic tag result

$$\mathcal{B}(B^+ \to \tau^+\nu) = (0.9 \pm 0.6(\text{stat.}) \pm 0.1(\text{syst.})) \times 10^{-4}$$

$$\mathcal{B}(B^+ \to \tau^+\nu) < 1.7 \times 10^{-4}$$ 90% CL

$$f_B \cdot |V_{ub}| = (7.2^{+2.0}_{-2.8}(\text{stat.}) \pm 0.2(\text{syst.})) \times 10^{-4}\ \text{GeV}$$

B→τν with hadronic tag

Selection criteria

Variable	$\tau^+ \to e^+\nu\overline{\nu}$	$\tau^+ \to \mu^+\nu\overline{\nu}$	$\tau^+ \to \pi^+\overline{\nu}$	$\tau^+ \to \pi^+\pi^0\overline{\nu}$
E_{extra} (GeV)	< 0.160	< 0.100	< 0.230	< 0.290
π^0 multiplicity	0	0	≤ 2	n.a.
Track multiplicity	1	1	≤ 2	1
$\lvert cos\theta^*_{TB}\rvert$	≤ 0.9	≤ 0.9	≤ 0.7	≤ 0.7
p^*_{trk} (GeV/c)	< 1.25	< 1.85	> 1.5	n.a.
$cos\theta^*_{\text{miss}}$	< 0.9	n.a	< 0.5	< 0.55
$p^*_{\pi^+\pi^0}$ (GeV/c)	n.a.	n.a.	n.a.	> 1.5
ρ quality	n.a.	n.a.	n.a.	< 2.0
E_{π^0} (GeV)	n.a.	n.a.	n.a.	> 0.250
Efficiency(%)	3.1±0.2	1.7±0.1	2.9±0.2	2.2±0.2

% Contributions to the systematic uncertainty on the BF due to signal selection efficiency

MC statistics	3.6
Particle Identification	2.0
π^0	0.6
Tracking	5.5
E_{extra}	15
Total	16.5

BaBar : hadronic tag results

$$\mathcal{B}(B^+ \to \tau^+\nu) = 1.8^{+1.0}_{-0.9}(\text{stat.+bkg}) \pm 0.3(\text{syst.})) \times 10^{-4}$$

$$f_B \cdot |V_{ub}| = (10.1^{+2.8}_{-2.5}(\text{stat.}) \pm 0.8(\text{syst.})) \times 10^{-4}\ \text{GeV}$$

Significance: 2.2σ (2.7σ without bkg. uncertitude)

$B \rightarrow \tau\nu$ confidence intervals

$$\mathcal{L}(s+b) = \Pi_{i=1}^{4} \frac{e^{-(s_i + b_i)}(s_i + b_i)^{n_i}}{n_i} \qquad s_i = N_B \varepsilon_i \mathcal{B}$$

$$Q(\mathcal{B}) = -2\ln(\mathcal{L}(s+b) / \mathcal{L}(b))$$

systematic uncertainties on the background predictions included in the confidence interval determination by convoluting the likelihood functions with Gaussian probabilities.

Branching fraction computation:

Scan over branching fraction hypothesis and find the one that minimize $2\ln(L_{s+b}/L_b)$

Upper limit computation:

generate thousands of "toy" MC experiments for each signal branching fraction hypothesis, and determine the confidence level of the hypothesis as follows:

$$C.L._s = \frac{C.L._{s+b}}{C.L._b} = \frac{N_{Q_{s+b} \leq Q}}{N_{Q_b \leq Q}}$$

B→Kτμ

- Particularly attractive since it involves couplings of the new field with 3rd and 2nd generations both for the quarks (b,s) and the leptons (τ,μ).

- If quark and lepton couplings are equal at GUT scale, the branching fraction is sensitive to $\eta_{\mu\tau}^4$ since

$$\eta_{ij}^{\text{quark}} = \eta_{ij}^{\text{lepton}} \quad \Rightarrow \quad \eta_{sb} = \eta_{\mu\tau}$$

- "Most natural" values for lepton couplings are proportional to

$$\eta_{ij} = \sqrt{m_i m_j}/m_\tau$$

$\eta_{ee} = 0.0003$ $\eta_{e\mu} = 0.004$ $\eta_{e\tau} = 0.02$ $\eta_{\mu\mu} = 0.06$ $\boxed{\eta_{\mu\tau} = 0.24}$

See Sher and Yuan, Phys. Rev. D44, 1461 (1991) for the full story.

$B \to K\tau\mu$

- The main backgrounds are from $B^- \to \mu^- \nu D^{(*)0} X$ followed by $D^{(*)0} \to K^- X'$. Here are two examples with exactly the same final states.

$$B^- \to D^0 \mu^- \bar{\nu} \qquad\qquad B^- \to K^- \tau^+ \mu^-$$
$$D^0 \to K^- \pi^+ \qquad\qquad \tau^+ \to \pi^+ \bar{\nu}$$
$$D^0 \to K^- l^+ \nu \qquad\qquad \tau^+ \to l^+ \nu \bar{\nu}$$

- Can kill almost all of the B^+ background (~99%) simply by requiring that the invariant mass of the kaon with the opposite-charge track be *greater* than the D mass.
- Events used to normalize the signal BF

Signal yield from cut-and-count

Ratio of B_{tag} efficiencies

Ratio of signal-side efficiencies

Signal branching fraction

$$\mathcal{B}_{K\tau\mu} = \left(\frac{N_{K\tau\mu}}{N_{D\mu\nu}}\right) \left(\frac{\epsilon_{\text{tag}}^{D\mu\nu}}{\epsilon_{\text{tag}}^{K\tau\mu}}\right) \left(\frac{\epsilon_{D\mu\nu}}{\epsilon_{K\tau\mu}}\right) \mathcal{B}_{D\mu\nu}$$

Control sample yield from fit

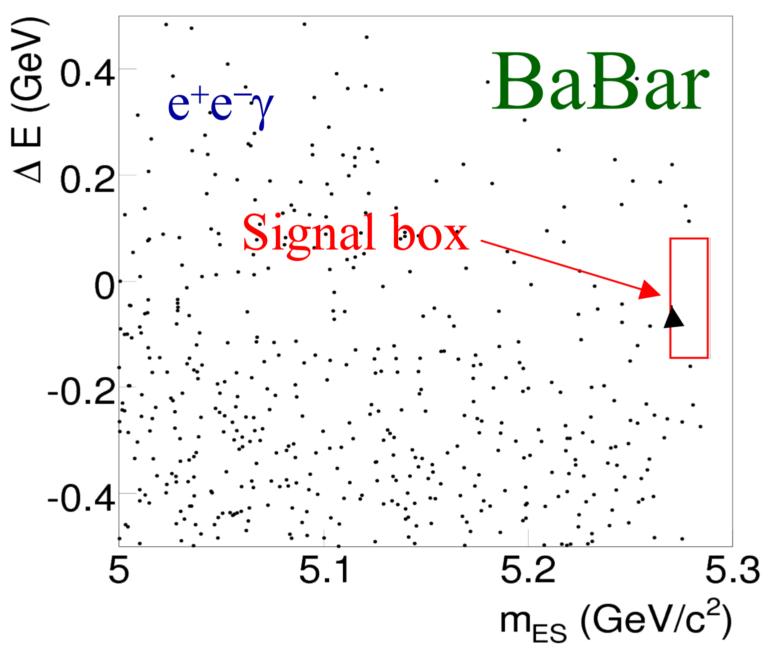
$B \to K\tau\mu$

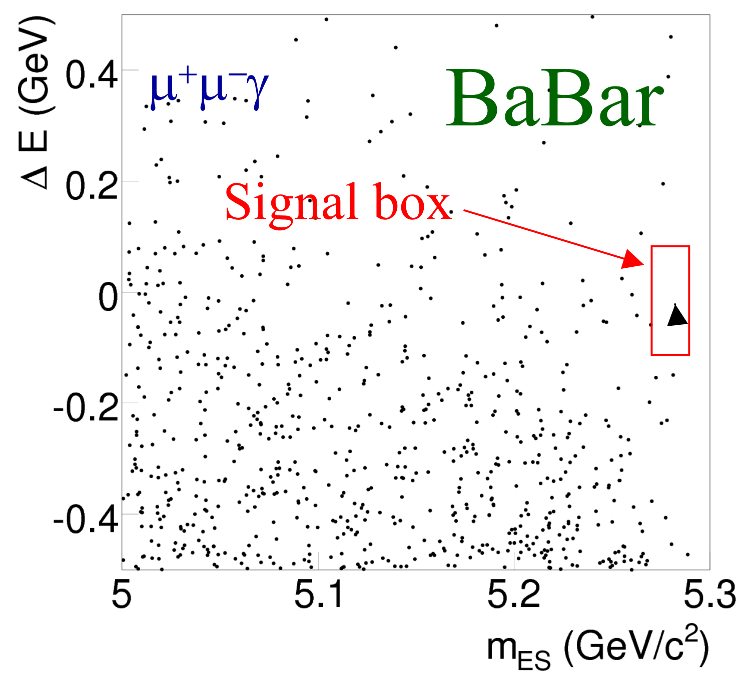
- Expected backgrounds estimated from m_τ sideband
- Signal-to-sideband ratio taken from MC

Channel	N_{sb} (MC)	N_{sb} (data)	BG ratio	b_i	n_i	ϵ_i (%)
electron	5.2 ± 1.3	5	0.10 ± 0.05	0.5 ± 0.3	1	$3.28 \pm 0.13 \pm 0.22$
muon	0.7 ± 0.5	2	0.30 ± 0.15	0.6 ± 0.3	0	$2.09 \pm 0.10 \pm 0.19$
pion	6.9 ± 1.6	14	0.13 ± 0.04	1.8 ± 0.6	2	$2.18 \pm 0.11 \pm 0.24$

$B \to \ell^+\ell^-\gamma$

Mode	n_{obs}	n_{bg}^{exp}	ϵ_{sig} (%)	N_{UL}	$\mathcal{B}_{UL}$
$e^+e^-\gamma$	1	$1.75 \pm 1.38 \pm 0.36$	7.4 ± 0.3	2.82	1.2×10^{-7}
$\mu^+\mu^-\gamma$	1	$2.66 \pm 1.40 \pm 1.58$	5.2 ± 0.2	2.55	1.5×10^{-7}

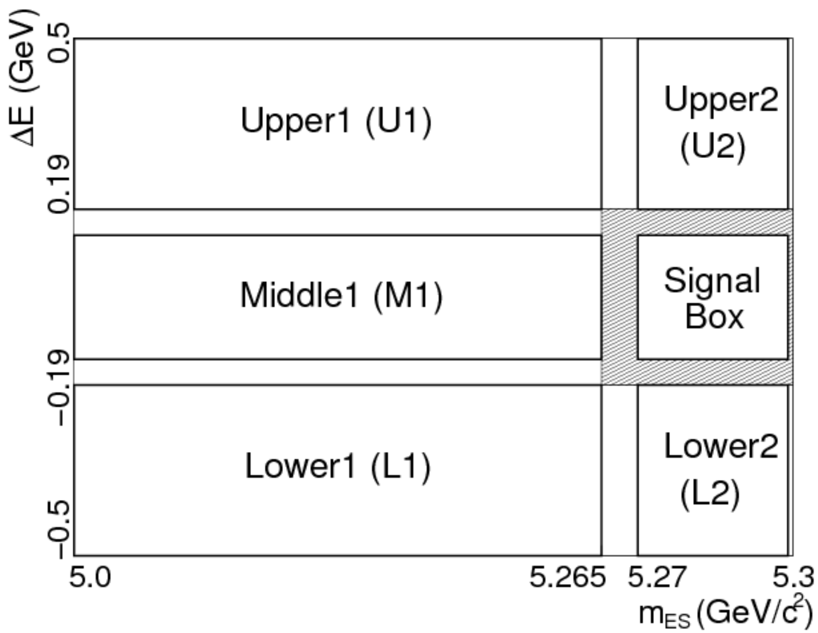




$B \rightarrow \ell^+ \ell^- \gamma$

- Main backgrounds from:
  - ISR-High order QED
    - Rejected by requirng Tracks and photon in well within the fiducial region of the detector and high tracks and clusters multiplicity
  - Lepton from J/ψ or γ from π^0
    - Rejected by vetoing on invariant masses
  - Continuum
    - Rejected by cut on topological variables

$B \rightarrow \ell^+\ell^-\gamma$



- Backgound predictions obtained from data sideband
- Signal-to-sideband ratio extrapolated from Upper and Lower sidebands