Leptonic B Decays at BaBar

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On the behalf of the BaBar collaboration

15th International Conference on Supersymmetry and the Unification of Fundamental Interactions

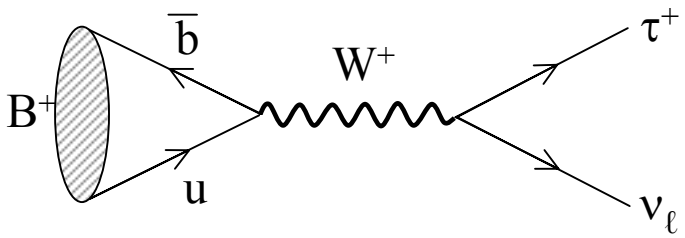
Outline

Recent results from the BaBar collaboration

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

B→ℓν decays

In the Standard Model



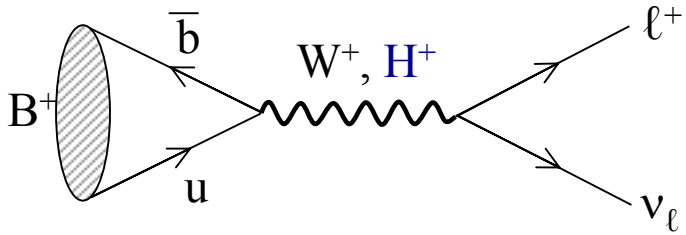
$$\mathcal{B}_{SM}(B\to\tau\nu) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1-\frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

helicity suppression

We can extract $f_B \times |Vub|$ from BF measurement

$\mathcal{B}_{SM}(B\to\tau\nu)$ in the range [0.7,1.6]x10^{-4} depending f_B and |Vub| used.
UTFit collaboration predicts (0.85 ± 0.11) x10^{-4} using all experimental constraints available and indirectly determining f_B (i.e. not from lattice QCD)

Beyond the Standard Model



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

ratio of vacuum expectation values for two Higgs doublets.

Charged Higgs mass

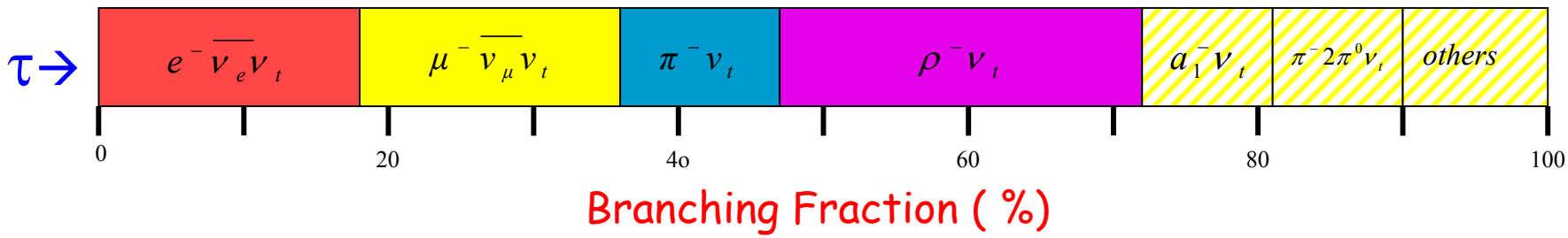
- Charged Higgs mediated amplitude in 2HDM
  - See for example: W.Hou, Phys. Rev. D. 48, 2342
- Branching Fraction enhanced or suppressed
- constrain the (m_{H+},tanβ) parameter space

B→τν 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→τν helicity favored but experimentally more difficult

Main τ decay modes:



- ~ 71% of the total τ decays
- Final state contains:
  - 1 track (+ 1 π^0 in the ρ channel)
  - 2-3 neutrinos
- Not many kinematical constraints
- Cleaning the experimental environment helps
  - Reconstructing the other B (tag B) of the event
  - Look for the signal in the rest of the event

Tag technique

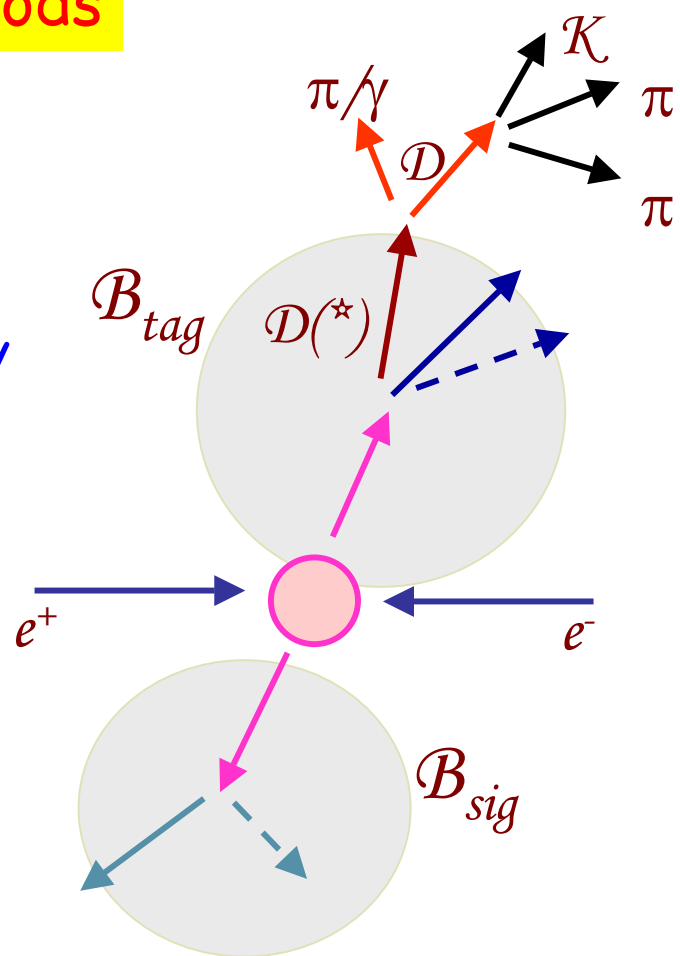
Two tag methods

- Hadronic:
  - Tag $B^- \to D^{(*)0}\, n_1\pi^\pm\,,\ n_2K^\pm\,,\ n_3K^0_s\,,n_4\pi^0$ $(n_1 + n_2 <= 5;\ n_3<=2;\ n_4<=2)$
  - Full reconstruction of B decays
  - Use of beam energy constraints to check the tag B candidate consistency

    $m_{ES} = \sqrt{(E^*_{beam})^2 - (p^*_B)^2}$

    $\Delta E = E_B - E^*_{beam}$
  - Higher purity but lower statistics

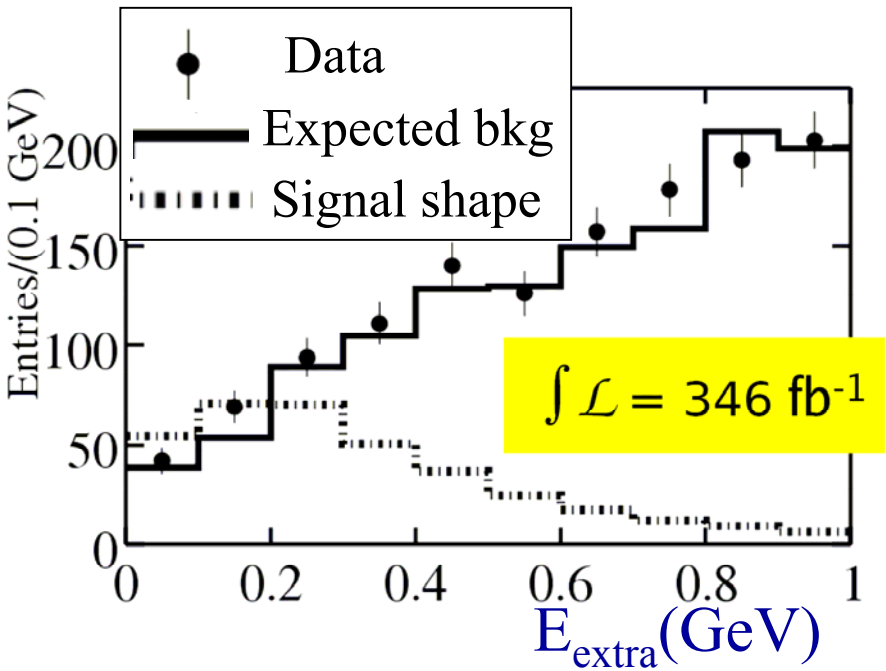
- Semileptonic:
  - Tag $B^- \to D^{(*)0}\ell\nu(\ell = e, \mu)$
  - High semileptonic BFs
  - Partial reconstruction (additional neutrino)
  - Higher statistics but lower purity



Look for signal in the rest of the event

B→τν with semileptonic tag

- Tagged 2.5 x10^6 B mesons (ε^{tag} = 0.66%)
- Most discriminating variable E_{extra}= Σ E (energy of neutral clusters and tracks not assigned to the tag B or the signal candidates)
- Mode dependent selection E_{extra} < 0.25-0.48 GeV
- Tag efficiency and E_{extra} model validated using double tagged events
- Expected background evaluated by extrapolating data in E_{extra} sidebands with same ratio as in MC

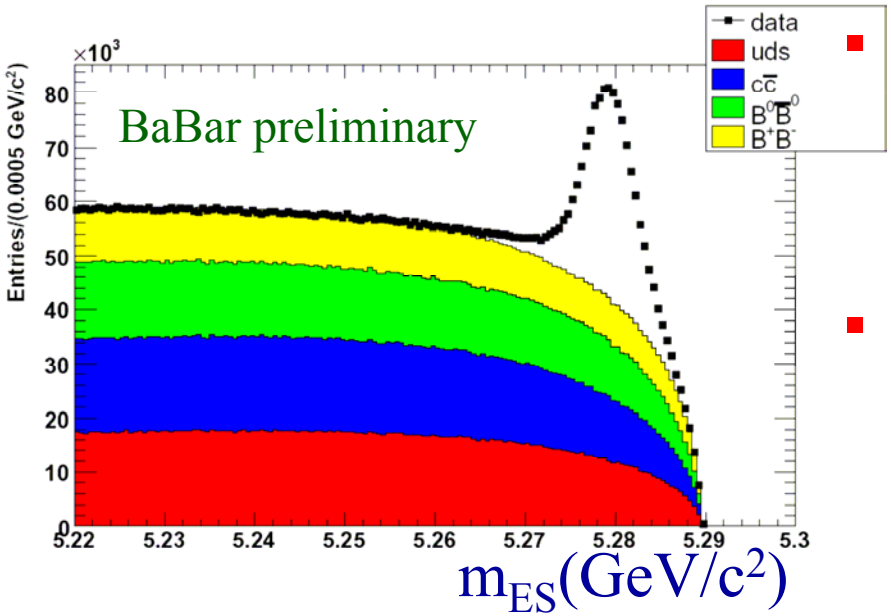


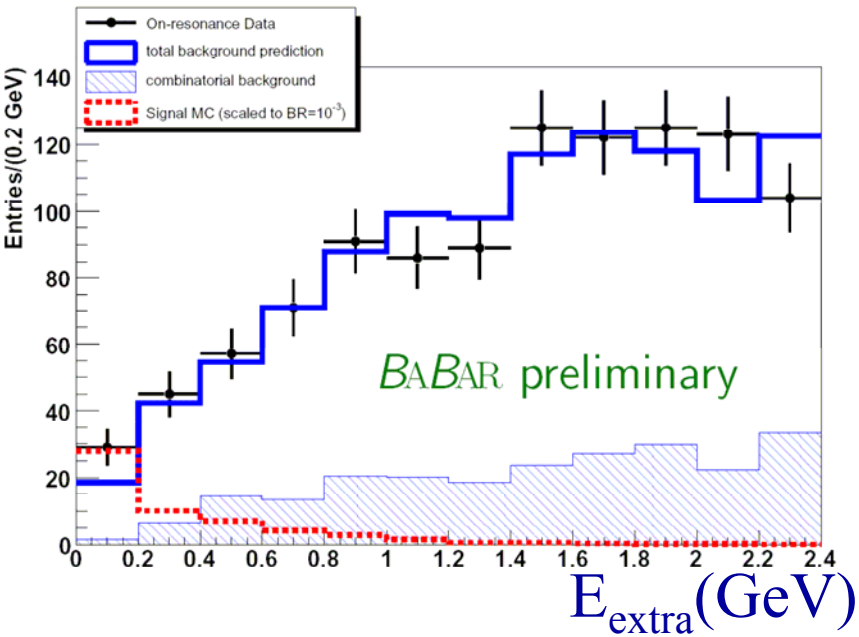
τ decay mode	Expected background	observed
τ→evν	44.3 ± 5.2	59
τ→μνν	39.8 ± 4.4	43
τ→πν	120.3 ± 10.2	125
τ→ππ^{0}ν	17.3 ± 3.3	18
All modes	221.7 ± 12.7	245

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→τν Branching Fraction

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

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

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

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

BaBar semileptonic tag analysis:

$\mathcal{B}(B\to\tau\nu) = (0.9 \pm 0.6 \pm 0.1)\times10^{-4}$ [1.3σ]

BaBar hadronic tag analysis: preliminary

$\mathcal{B}(B\to\tau\nu) = (1.8\ ^{+1.0}_{-0.9} \pm 0.3)\times10^{-4}$ [2.2σ]

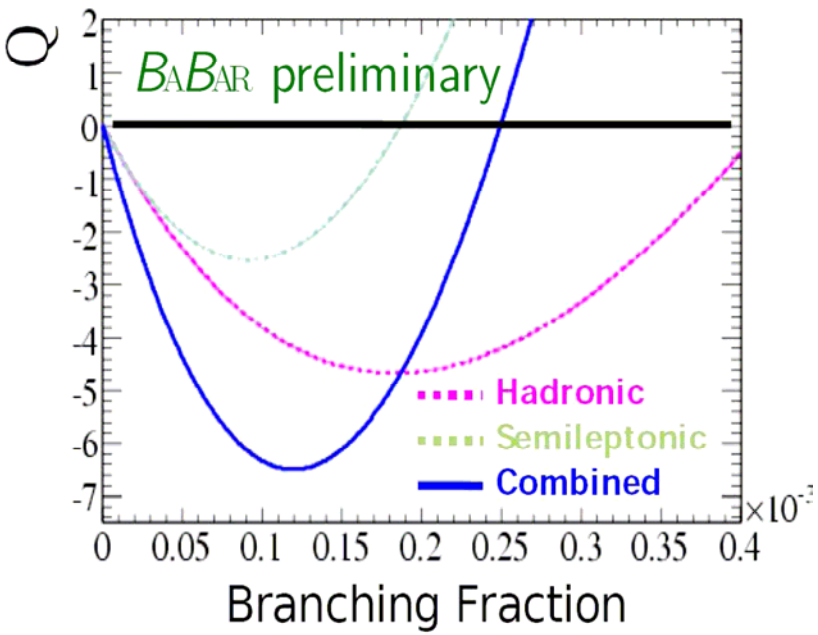
Combined Result: BaBar preliminary [2.6σ]

$\mathcal{B}(B\to\tau\nu) = (1.2 \pm 0.4^{stat} \pm 0.3^{bkg} \pm 0.2^{eff})\times10^{-4}$

SM prediction: $\mathcal{B} = (1.6 \pm 0.4)\times10^{-4}$

Belle result: $\mathcal{B} = (1.79^{+0.56\ +0.46}_{-0.49\ -0.51})\times10^{-4}$ [3.5σ]

with 414 fb^{-1} PRL 97, 251802 (2006) 414 fb^{-1}



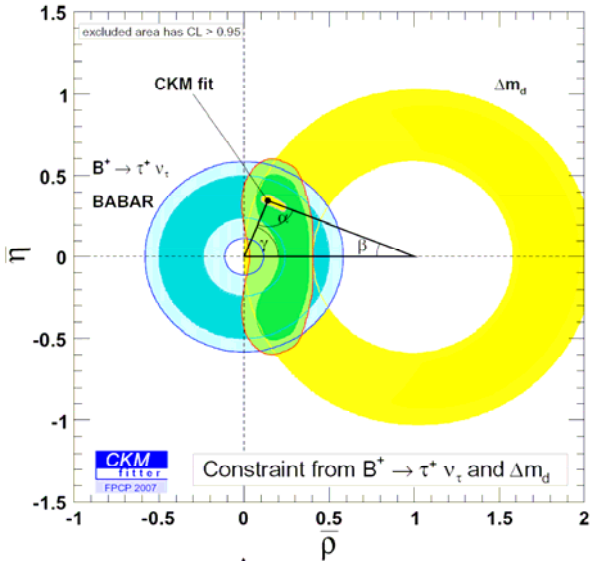
Interpreting the result (SM)

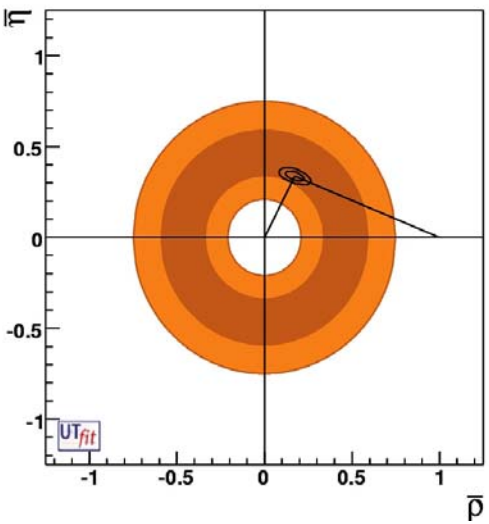
$$\mathcal{B}_{SM}(B\to\tau\nu) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1-\frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

CKM-fitter collaboration showed at FPCP 07 the constraint on the $\rho-\eta$ plane using
$f_B = (223 \pm 15 \pm 26)$ MeV (lattice QCD)

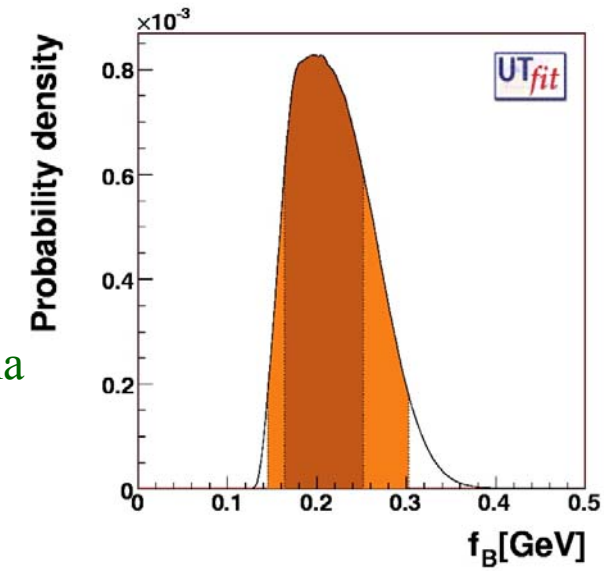
UT-Fit collaboration updated their results with the lastest BaBar measurement
See http://www.utfit.org (rare decays)

CKM-Fitter @ FPCP 07

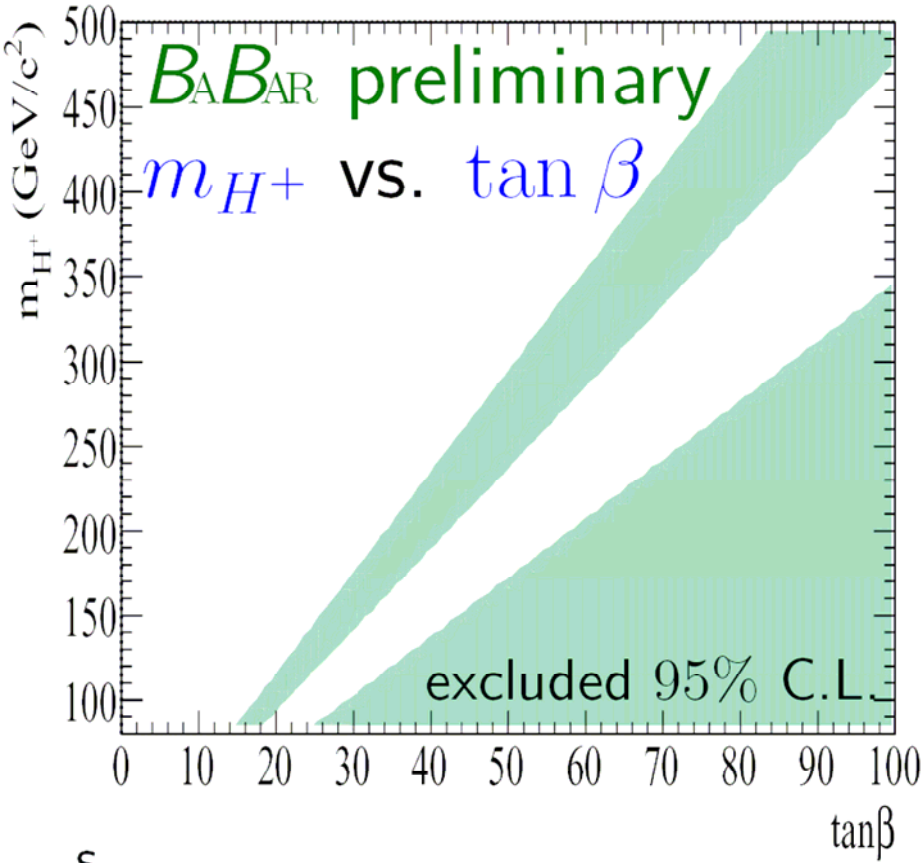




BaBar only UT-fit constraint on
R_b and f_B PDF
Courtesy from M.Bona



Interpreting the result (2HDM)

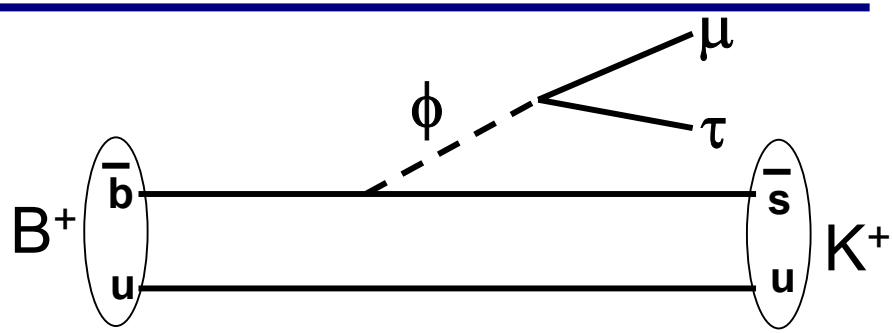


Shown above the limit set by direct search at LEP: m_{H+}>78.5 GeV @95% CL

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

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

B→Kτμ



New scalar from adding a Higgs doublet.

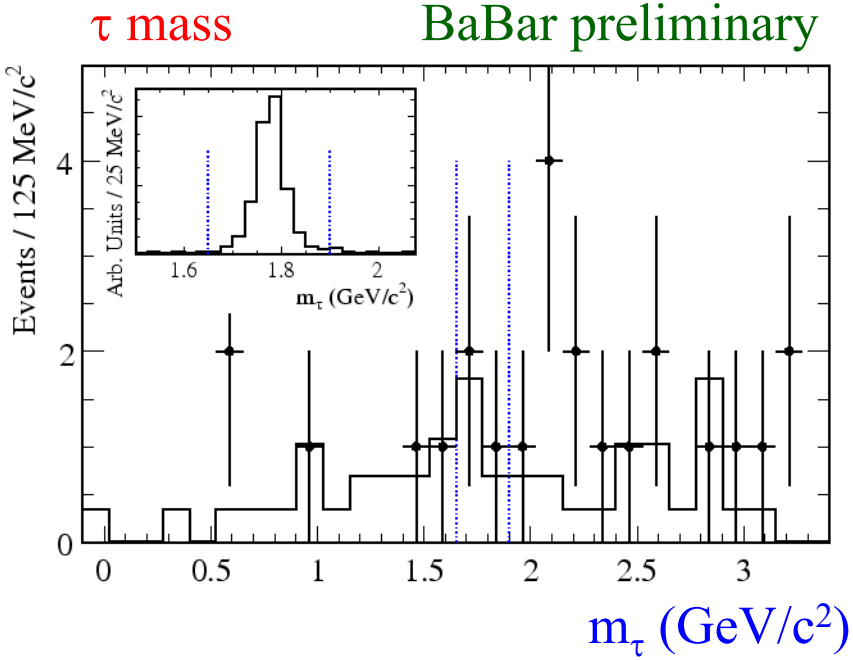
- Forbidden in the SM
  - Lepton flavor violation
  - b→s flavor changing neutral current
- Permitted in Grand Unified Theories (GUTs)
  - See for example Sher and Yuan, Phys. Rev. D44, 1461 (1991)
  - Lepton couplings tend to be proportional to $\eta_{ij} = \sqrt{m_i m_j}/m_\tau$
  - Transitions involving third generations of both quark and leptons are favored in this framework

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

$B \to K\tau\mu$

- Search based on 346 fb^{-1}
- Look for signal on the recoil of hadronic tag Bs
- $B \to D^0(K\pi)\mu\nu$ data control sample to normalize the signal BF
- 1-prong τ decay modes (e,μ,π) studied.
- τ four momentum determined using kinematics:
  - $p_\tau = p_{Btag} - p_K - p_\mu$

τ decay mode	Expected background	observed
$\tau \to e\nu\nu$	0.5 ± 0.3	1
$\tau \to \mu\nu\nu$	0.6 ± 0.3	0
$\tau \to \pi\nu$	1.8 ± 0.6	2

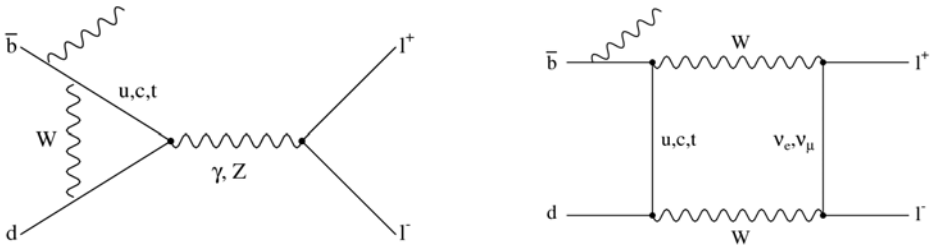


First search ever done for this channel
No evidence of signal

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

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

Submitted to PRL: **arXiv:0706.2870**

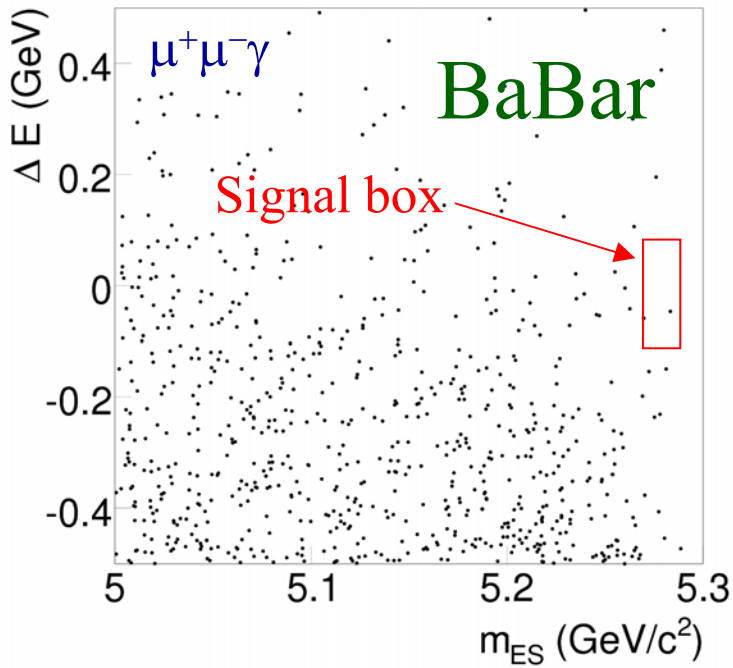


- FCNC processes
  - Suppressed in the SM
  - BF is $O(10^{-10})$
  - Can be enhanced by new physics

First search ever done for these channels

- Search based on 320×10^6 BB pairs
- Look for B^0 candidates combining 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

τ decay mode	Expected background	Observed
$B \to e^+e^-\gamma$	1.75 ± 1.38	1
$B \to \mu^+\mu^-\gamma$	2.66 ± 1.40	1



$\mathcal{B}(B \to e^+e^-\gamma) < 1.2 \times 10^{-7}$, $\mathcal{B}(B \to \mu^+\mu^-\gamma) < 1.5 \times 10^{-7}$ @90% CL

Summary

- $B \to \tau\nu$
  - $\mathcal{B} = (1.2 \pm 0.4^{stat} \pm 0.3^{bkg} \pm 0.2^{eff}) \times 10^{-4}$
  - 2.6s significance (3.2s stat.)
  - Set constraints on New Physics parameters

- $B \to K\tau\mu$
  - First search ever done
  - No evidence of signal
  - $\mathcal{B} < 7.7 \times 10^{-5}$ @90% CL

- $B \to \ell^+\ell^-\gamma$
  - First search ever done
  - $\mathcal{B}(B \to e^+e^-\gamma) < 1.2 \times 10^{-7}$ @90% CL
  - $\mathcal{B}(B \to \mu^+\mu^-\gamma) < 1.5 \times 10^{-7}$ @90% CL

Recent BaBar results

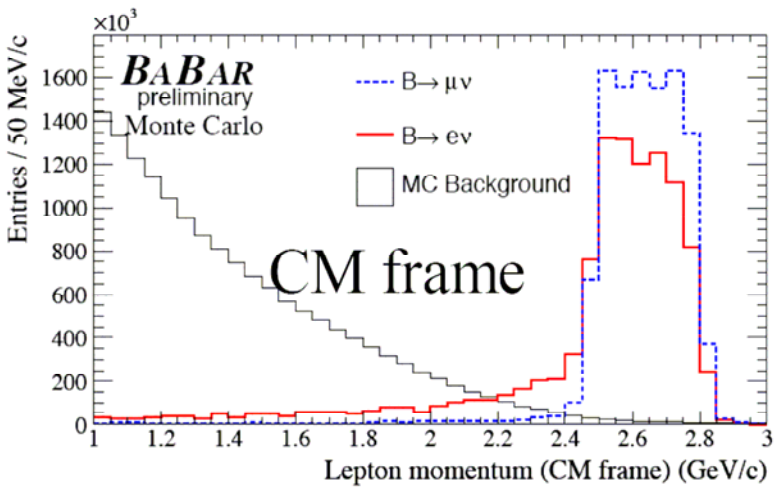
Backup slides

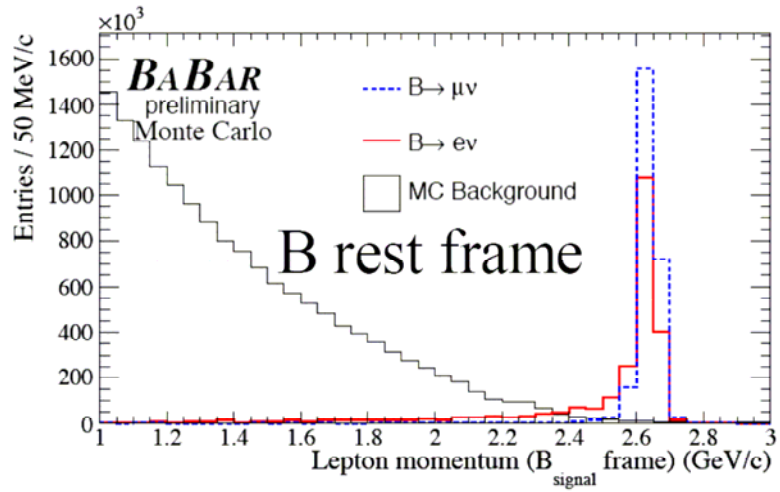
B→e/μν

BF helicity suppressed

- $BF_{SM}(\mu\nu)=(4.7 \pm 0.7)x10^{-7}$
- $BF_{SM}(e\nu)=(11.1 \pm 0.1)x10^{-11}$

- 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.

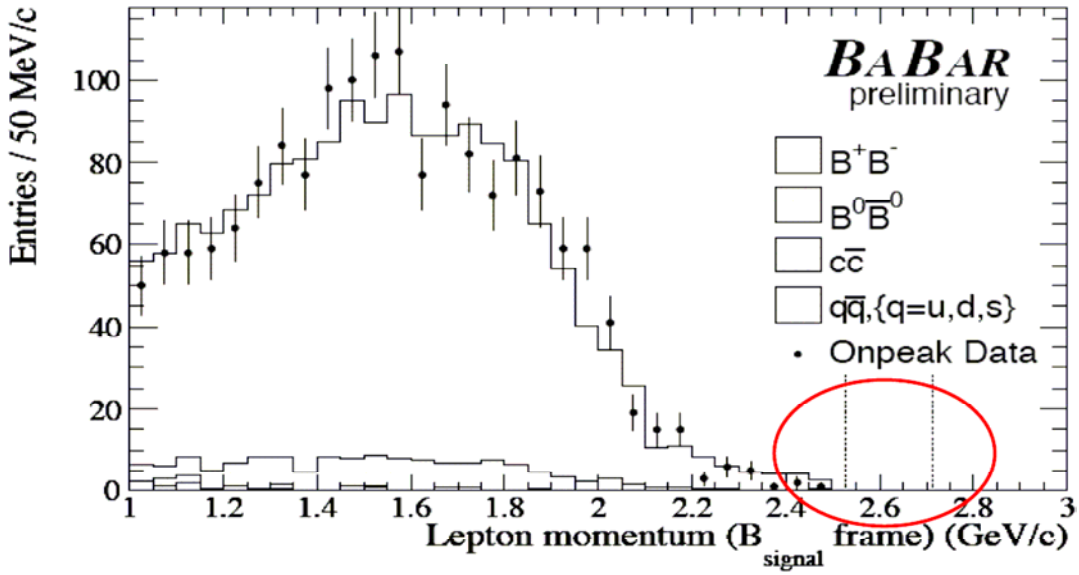




B→e/μν

- 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

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



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

B→ℓνγ

- 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 l_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 branching fraction

B(B→lνγ) ~(1-5)x10^{-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:

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

- 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

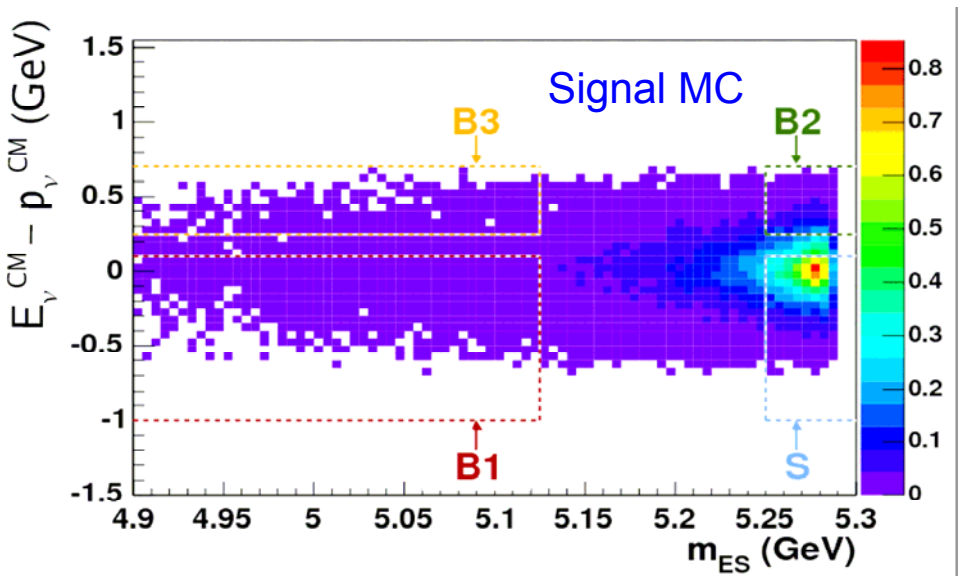
No evidence of signal set UL at 90% CL

$$\Delta B(B \to \gamma \mu \nu_\mu) < 2.1 \times 10^{-6}$$
$$\Delta B(B \to \gamma e \nu_e) < 2.8 \times 10^{-6}$$
$$\Delta B(B \to \gamma \ell \nu_\ell) < 2.3 \times 10^{-6}$$

(Bayesian limits with flat prior in BF)

With some input from theory, joint fit translates to:

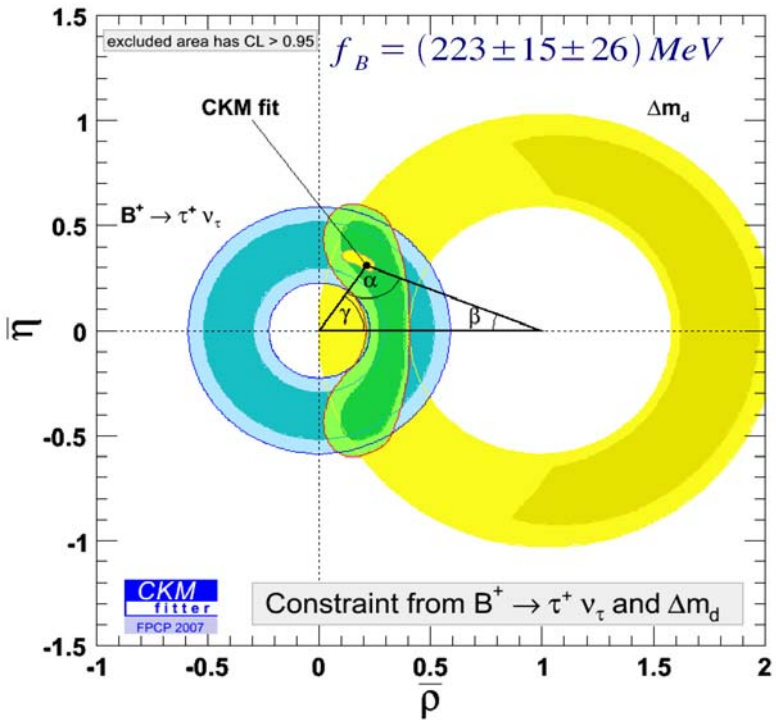
$$BF(B \to \gamma \ell \nu_\ell) < 5.0 \times 10^{-6} \quad (90\%\ CL)$$



Approaching the SM prediction

Combined BaBar+Belle B→τν

- BaBar combined (346 fb^{-1}): Preliminary
  - $\mathcal{B}(B\to\tau\nu) = (1.2 \pm 0.4^{stat} \pm 0.3^{bkg} \pm 0.2^{eff})\ x10^{-4}$
- Belle had tag (414 fb^{-1}): PRL 97,251802 (2006)
  - $\mathcal{B}(B\to\tau\nu) = (1.79^{+0.56\ +0.46}_{-0.49\ -0.51})\ x10^{-4}$
- BaBar+Belle (Gaussian weighted average)
  - $\mathcal{B}(B\to\tau\nu) = (1.41 \pm 0.43)\ x10^{-4}$



The m_H vs. tanβ 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 tanb 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