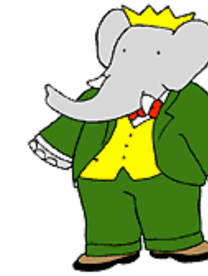


Leptonic decays at BaBar

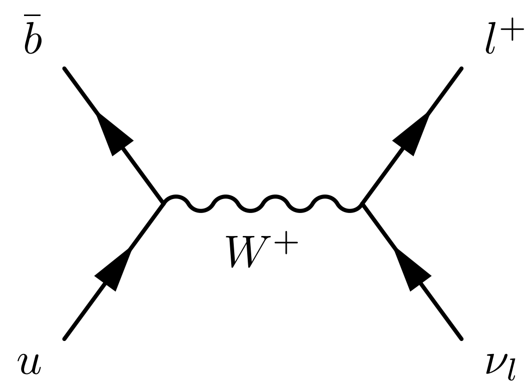
Emmanuele Salvati
University of Massachusetts, Amherst

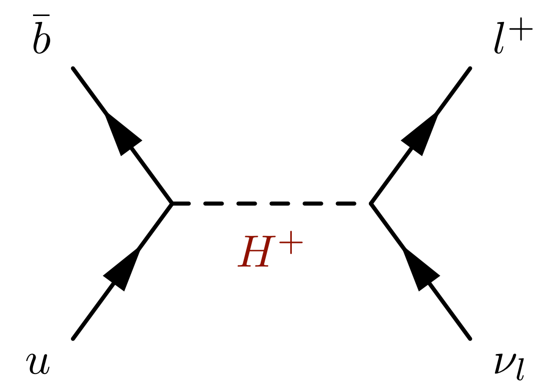
XII International conference on hadron spectroscopy
LNF 8-13 October 2007

outline

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

B →τν





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

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

- The Branching Ratio depends on the choice of V_{ub} and f_B
  - using the values $|V_{ub}| = (4.31 \pm 0.30) \times 10^{-3}$ $f_B = 0.216 \pm 0.022$ GeV

  we get, in the SM $\mathcal{B}(B \to \tau\nu) = (1.6 \pm 0.4) \times 10^{-4}$
- Assuming the SM and using the experimental value of V_{ub}, we can calculate f_B from the BR
- Amplitude mediated by charged Higgs in 2HDM ⇒ shift in the BR (W.Hou, Phys. Rev.D 48,

2342 (1992)
- If we use given values of f_B and V_{ub}, we can constrain the (m_H, tanβ) parameter space
- UTfit collaboration (www.utfit.org) predicts (0.85 ± 0.14) x 10^{-4} using all experimental constraints and determining f_B indirectly

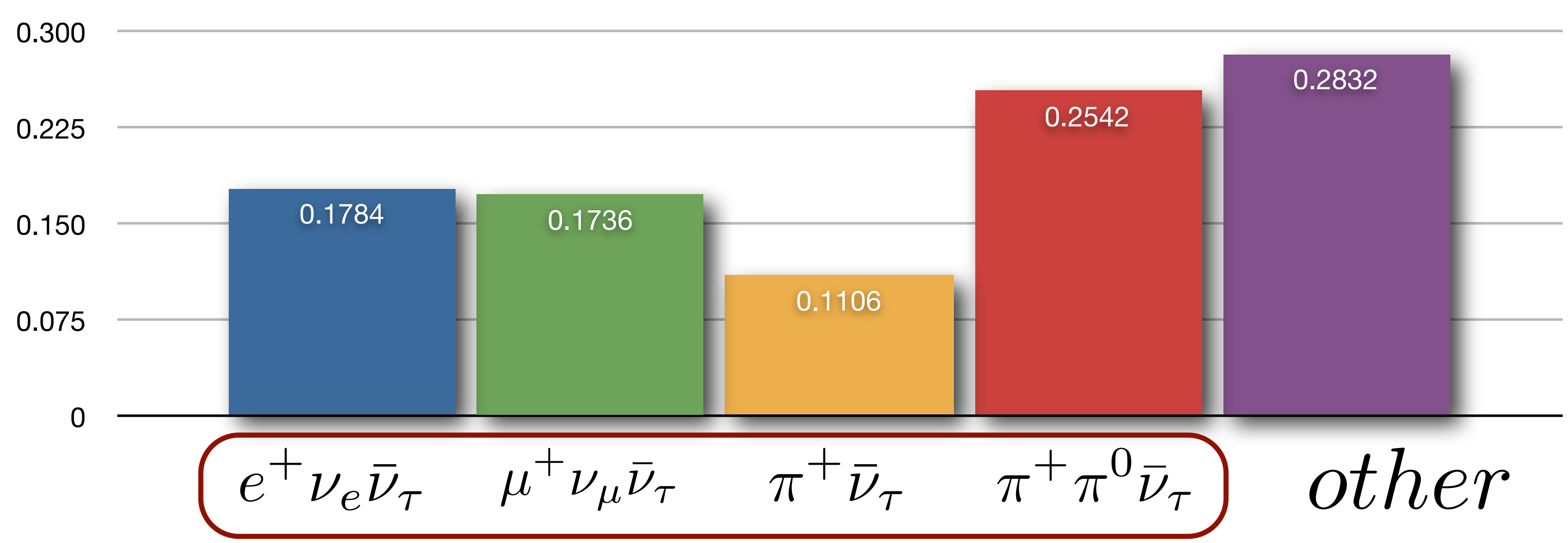
B→τν: experimental

- Largest BF among the pure leptonic B decays
  - B→μν and B→eν are easier but SM rate is very low
- about 71 % of the total τ decays
- many neutrinos in the signal decays
- weak kinematical constraints
  - need a clean environment
  - reconstruct the other B in the event

Standard Model

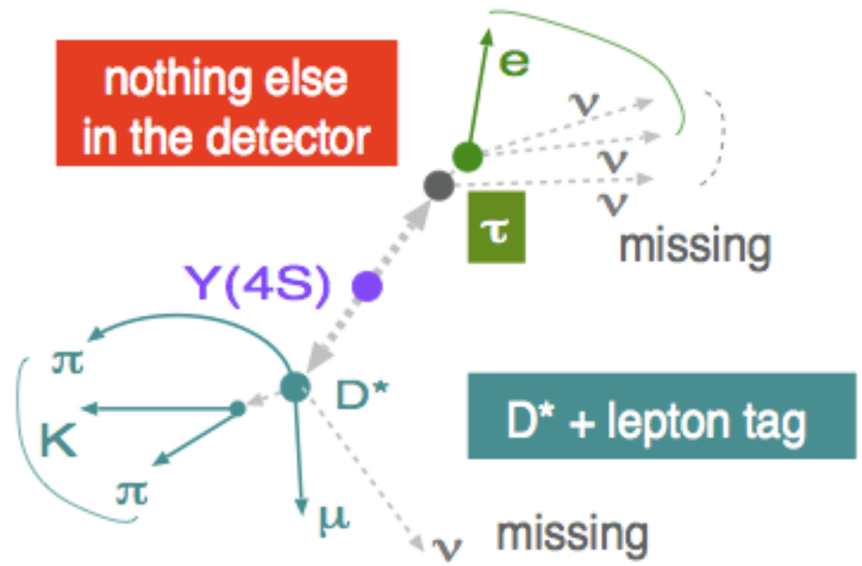
$$\mathcal{B}(B \to \tau\nu) \sim 10^{-4}$$
$$\mathcal{B}(B \to \mu\nu) \sim 10^{-7}$$
$$\mathcal{B}(B \to e\nu) \sim 10^{-10}$$

Branching fractions of the τ decays



B→τν: tag methods

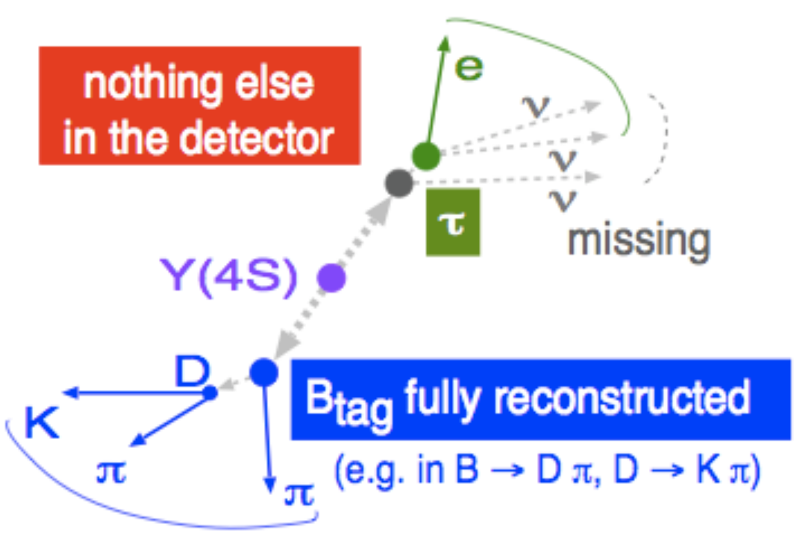
- Semileptonic tag:
  - $B^{\pm} \to D^{(*)0} l \nu$ (l=e,μ)
  - High semileptonic BFs
  - only partial reconstruction because of neutrino
  - higher statistics but lower purity w.r.t. other method



- Hadronic tag:
  - $B^{\pm} \to D^{(*)0}\, n_1\pi^{\pm}, n_2K^{\pm}, n_3K_s, n_4\pi^0$ $(n_1+n_2 \leq 5,\ n_3 \leq 2,\ n_4 \leq 2)$
  - full reconstruction of B decays
  - use beam energy constraints to build discriminating variables

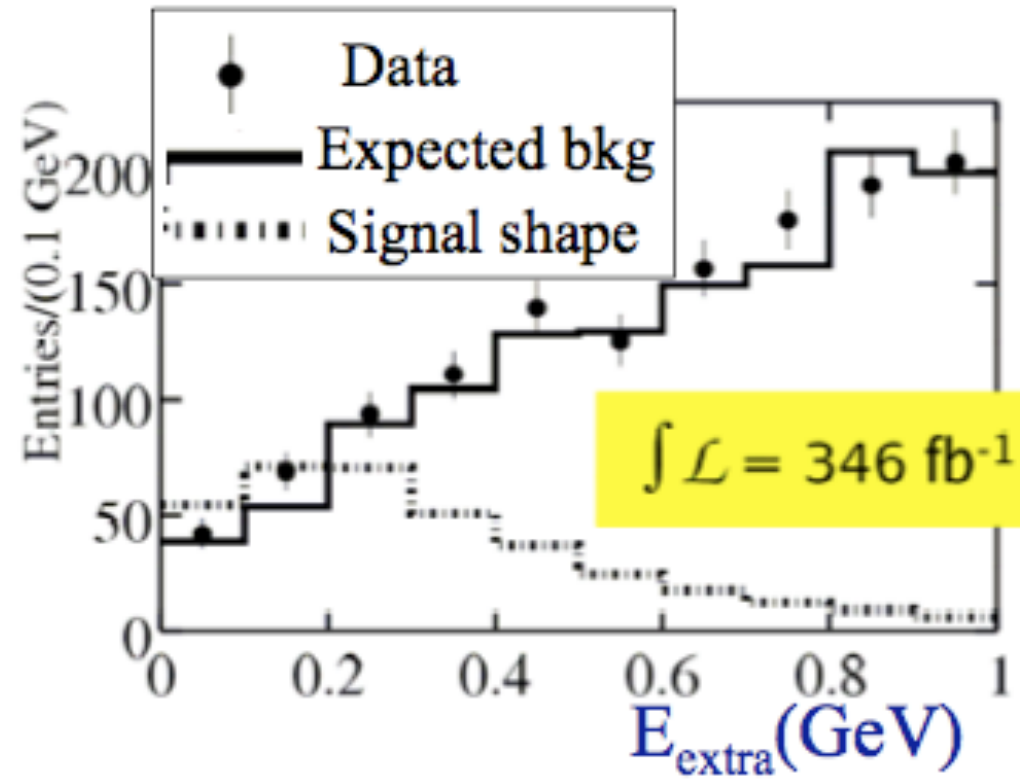
$$m_{\rm ES} \equiv \sqrt{(s/2 + \mathbf{p_0} \cdot \mathbf{p_B})^2 / E_0^2 - p_B^2}$$

$$\Delta E \equiv E_B^* - \sqrt{s}/2$$



B→τν: semileptonic tag

- Search based on 346 fb^{-1}
- Tag efficiency = 0.66 %
- look at $E_{EXTRA}=\sum E_i$ of tracks and clusters not assigned to a particle
- different signal region for E_{EXTRA} depending on the decay mode of τ: E_{EXTRA} < [0.25 ÷ 0.48] GeV
- Tag efficiency and E_{EXTRA} model validated also with double-tag events
- Expected background evaluated from sideband of E_{EXTRA}



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

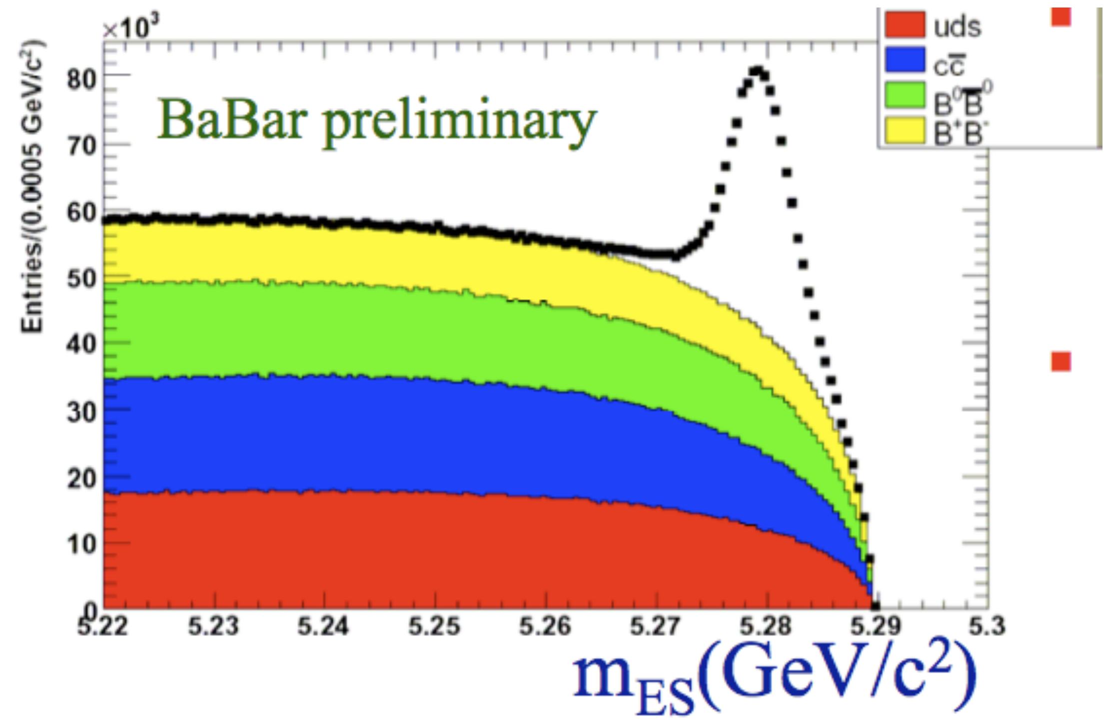
Phys. Rev. D, 76, 052002 (2007)

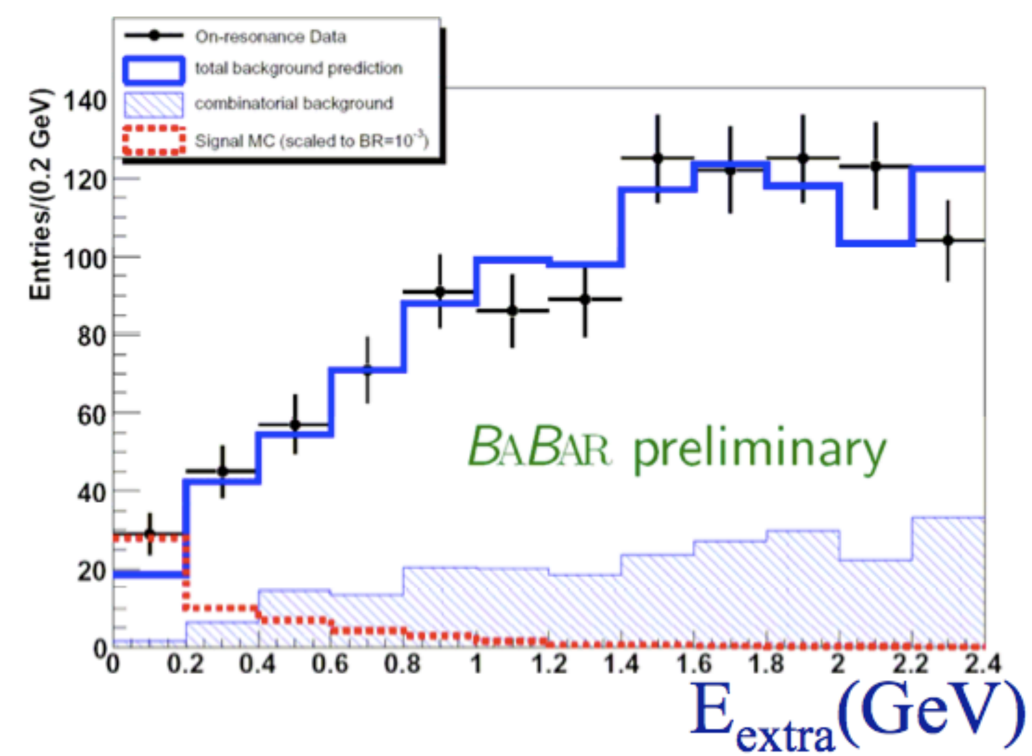
B→τν: hadronic tag

- Search based on 346 fb^{-1}
- Tag efficiency = 0.34 %
- m_{ES} used to discriminate combinatorial background
- Mode dependent selection
- Veto on extra charged tracks
- Particle identification
- $E_{EXTRA}=\sum E_i$ (neutral clusters) in the range $E_{EXTRA}<[0.1 \div 0.29]$ GeV

τ decay mode	Expected background	Observed
$\tau^+ \to e^+\nu\overline{\nu}$	1.47 ± 1.37	4
$\tau^+ \to \mu^+\nu\overline{\nu}$	1.78 ± 0.97	5
$\tau^+ \to \pi^+\overline{\nu}$	6.79 ± 2.11	10
$\tau^+ \to \pi^+\pi^0\overline{\nu}$	4.23 ± 1.39	5
All modes	14.27 ± 3.03	24

- Submitted to PRD - RC *arXiv:0708.2260*





B→τν: Branching Fraction

- Define likelihood and likelihood ratio
- s_i and b_i are the expected signal and background events
- s_i function of BF
- n_i observed events
- $\mathcal{Q}_{min}$ gives the BF
- $\sqrt{-\mathcal{Q}}$ is the significance

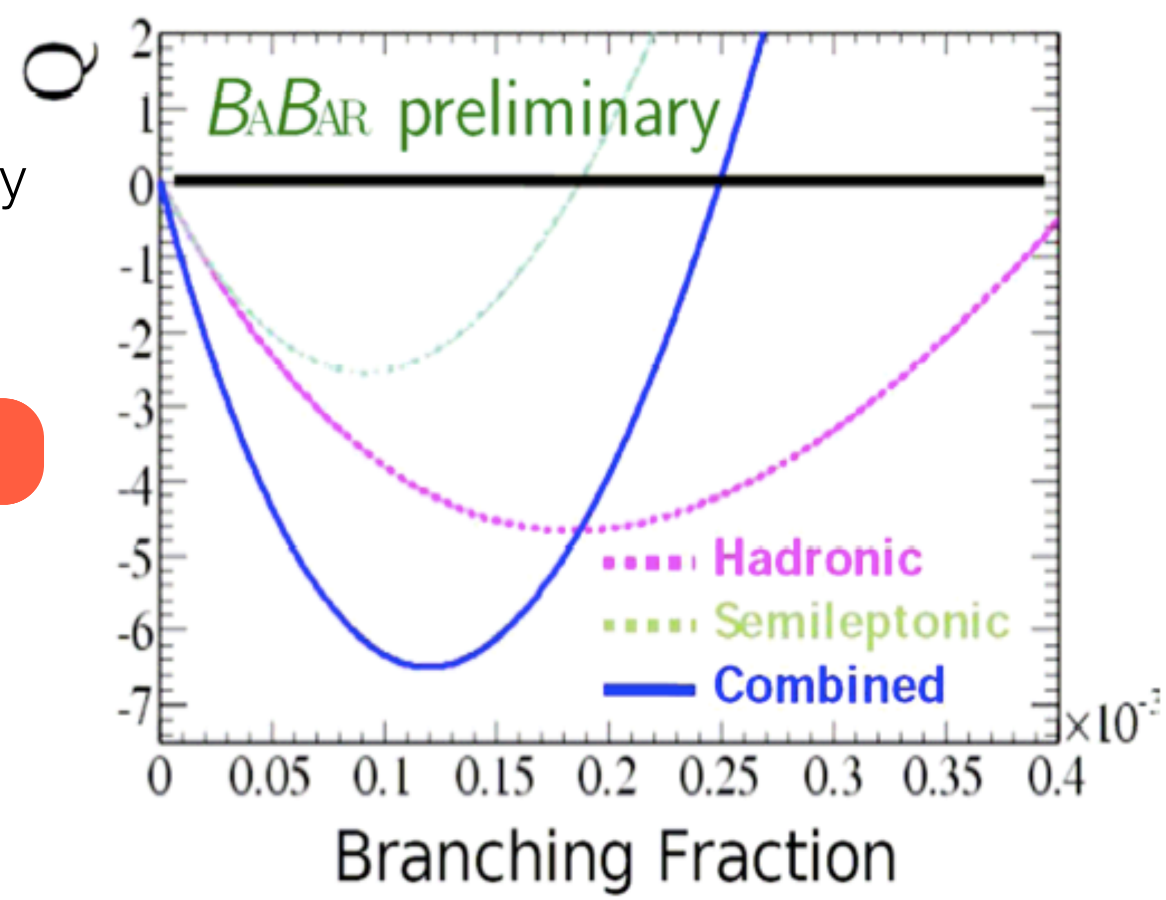
$$\mathcal{L}(s+b) = \prod_{i=1}^{4} \frac{e^{-(s_i+b_i)}(s_i+b_i)^{n_i}}{n_i}$$

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

$$s_i = N_B \times \epsilon_i \times \mathcal{B}$$

$$\mathcal{B}(semilep) = (0.9 \pm 0.6 \pm 0.1) \times 10^{-4}\,[1.3\sigma]$$

$$\mathcal{B}(hadr) = \left(1.8^{+1.0}_{-0.9} \pm 0.3\right) \times 10^{-4}\,[2.2\sigma]$$ Preliminary



Preliminary

$$\mathcal{B}(B \to \tau\nu) = \left(1.2 \pm 0.4^{stat} \pm 0.3^{bkg} \pm 0.2^{eff}\right) \times 10^{-4}\,[2.6\sigma]$$

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

$$f_B \cdot |V_{ub}| = (10.1^{+2.3+1.2}_{-2.5-1.5}) \times 10^{-4}\text{GeV}(\text{hadr})$$

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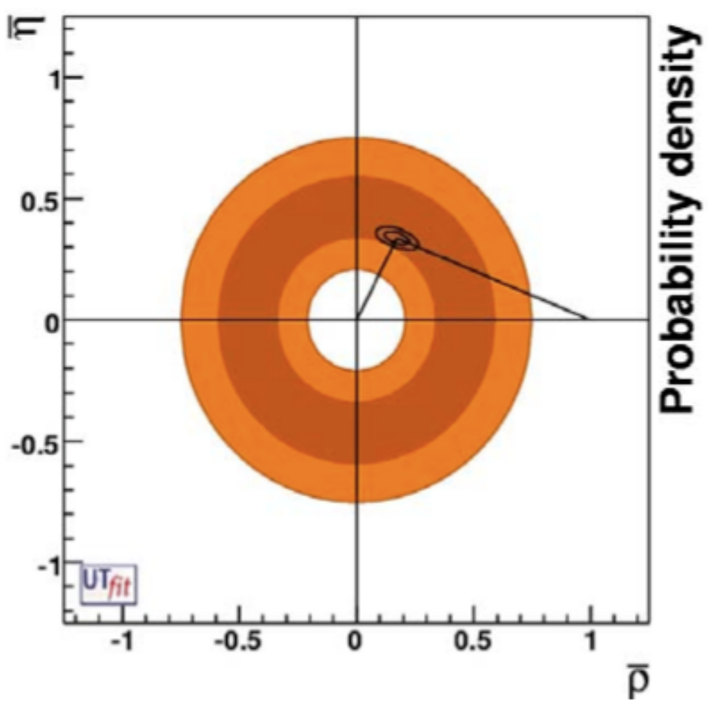
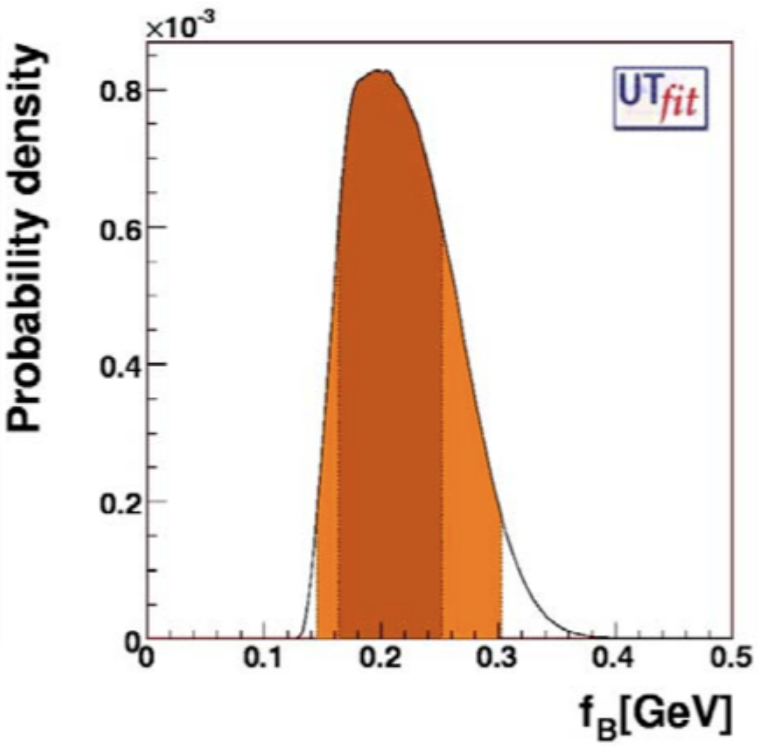
B→τν: Results





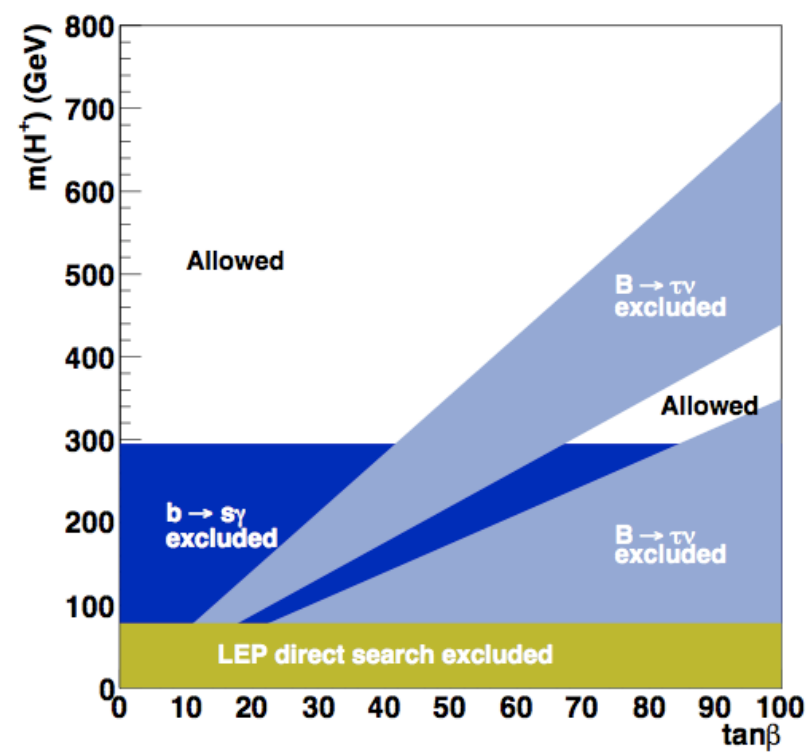
- BaBar-only UTfit constraint on R_B and f_B PDFs

68 % probability
95 % probability

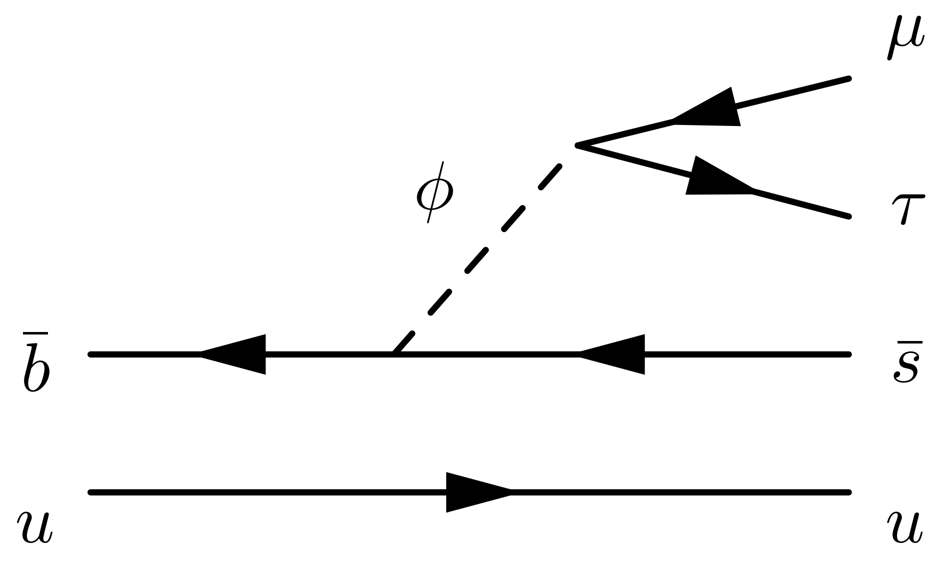
- See www.utfit.org

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

- The ratio $m_H/\tan\beta$ will be measured when B/B_{SM} different from 1
- Constraint on the parameter space shown in the plot
- BaBar + Belle combined
  - Belle: PRL 97, 251802 (2006)



$B \to K\tau\mu$



- Forbidden in the Standard Model
  - Lepton flavor violation
  - b→s flavor changing neutral current
- Permitted in new physics models
  - NP models with extended Higgs sector may introduce tree-level FCNC mediated by new scalar particle
  - See Sher and Yuan, Phys. Rev. D 44, 1461 (1991)
  - Yukawa couplings proportional to

$$\eta_{ij}^{leptons} = \sqrt{m_i m_j}/m_\tau \qquad \eta_{ij}^{quarks} = \sqrt{m_i m_j}/m_b$$

- Transitions involving second and third generations of quarks and leptons are favored in this framework in Grand Unified Theories

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

$B \rightarrow K\tau\mu$ analysis

- First search ever done
- Search based on 346 fb-1
- Look for signal on the recoil of hadronic tag B
- 1-prong τ decay modes (e,μ,π) studied
  - they define three different decay channels
  - signal mode composed of three tracks
- τ four momentum determined using kinematics:

$$\vec{p}_\tau = \vec{p}_{B_{sig}} - \vec{p}_K - \vec{p}_\mu$$

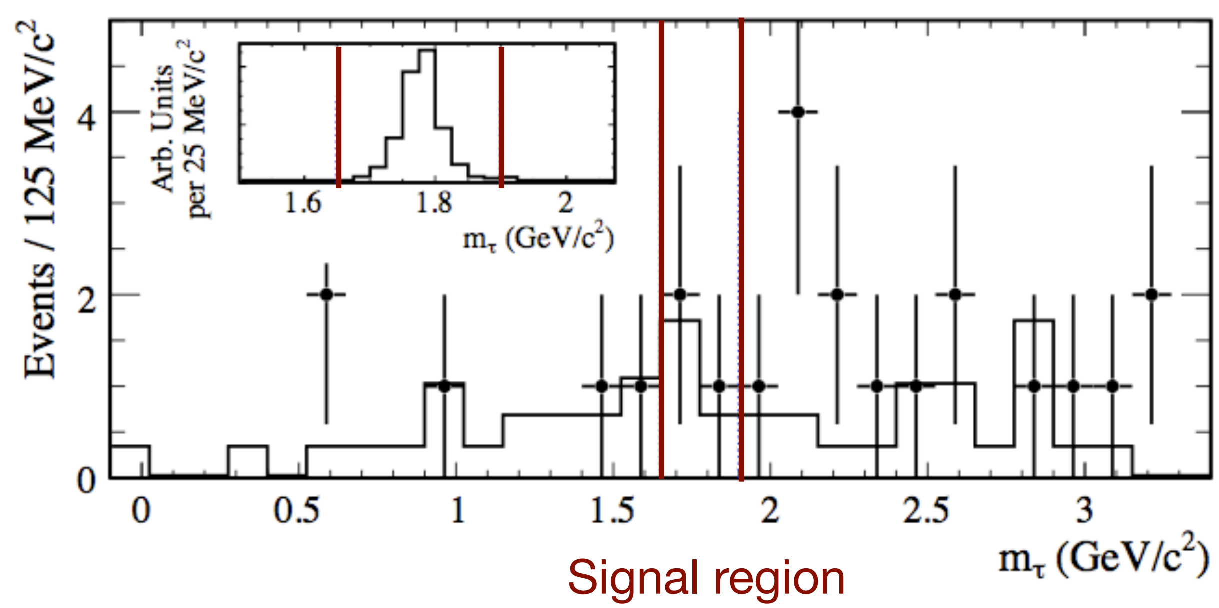
$$E_\tau = E_{\rm beam} - E_K - E_\mu$$

- B→D^0(Kπ)$\mu\nu$ data samples has the same final state
  - removed with cut on invariant mass
- No evidence of signal

$$\mathcal{B}(B \rightarrow K\tau\mu) < 7.7 \times 10^{-5} @ \ 90\% \ \text{C.L.}$$

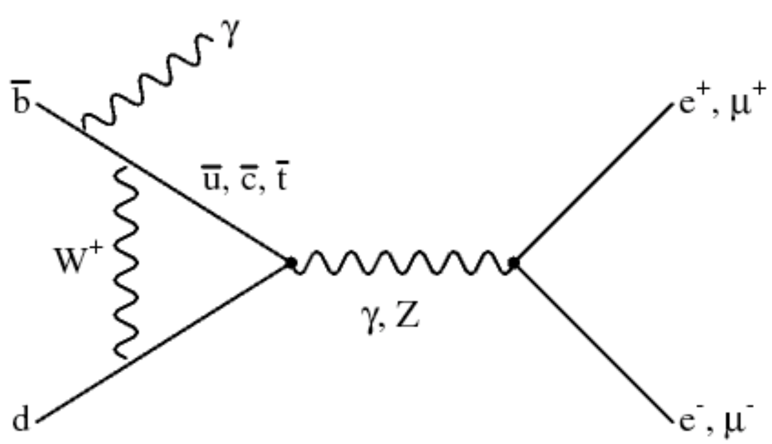
- Accepted by PRL *arXiv:0708.1303*

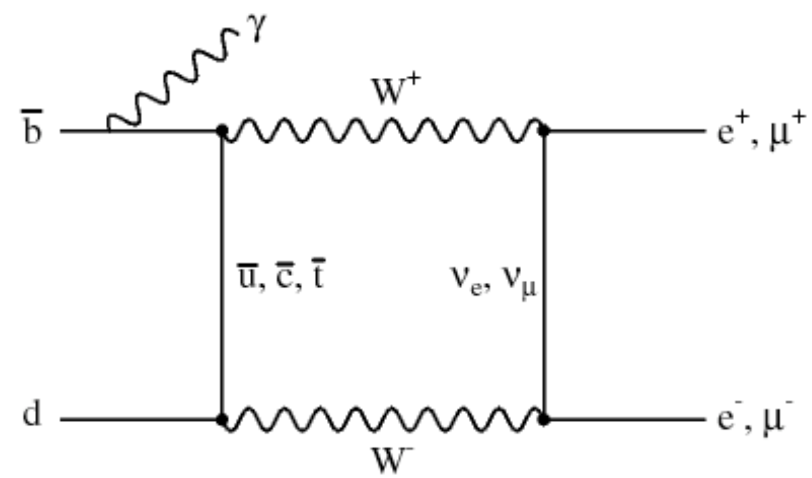
Reconstructed τ mass



Channel	Sig.events	Exp. bkg
electron	1	0.5 ± 0.3
muon	0	0.6 ± 0.3
pion	2	1.8 ± 0.6

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





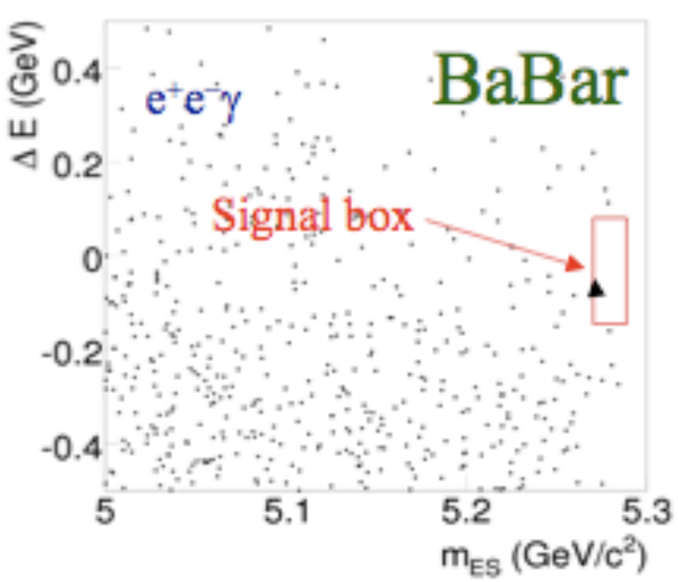
- FCNC processes
  - suppressed in the SM, BR ~ 10^{-10}
  - Can be enhanced by new physics
- First search ever done
- Search done on 292 fb^{-1}
- Construct B^0 candidates from two leptons (electrons or muons) and a photon
- Constrain B^0 candidate to be consistent with the production at the Υ(4S) using m_{ES} and ΔE

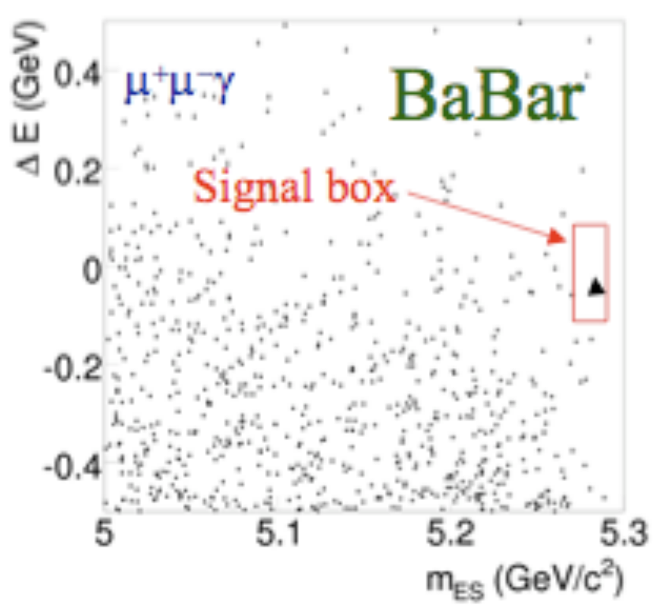
$B \to l^+ l^- \gamma$ analysis

- Main backgrounds:
  - ISR High order QCD
    - Rejected by requiring tracks and photon within fiducial region of the detector and by requiring high tracks and clusters multiplicity
  - Lepton from J/ψ or γ from π^0
    - Rejected by cut on invariant mass
  - Continuum
    - Rejected by cut on topological variables

Mode	n_{obs}	n_{bg}^{exp}	ϵ_{sig} (%)
$e^+e^-\gamma$	1	$1.75 \pm 1.38 \pm 0.36$	7.4 ± 0.3
$\mu^+\mu^-\gamma$	1	$2.66 \pm 1.40 \pm 1.58$	5.2 ± 0.3

- Distributions of ΔE vs m_{ES} shown for the two decays
  - the triangle is the only event in the signal region

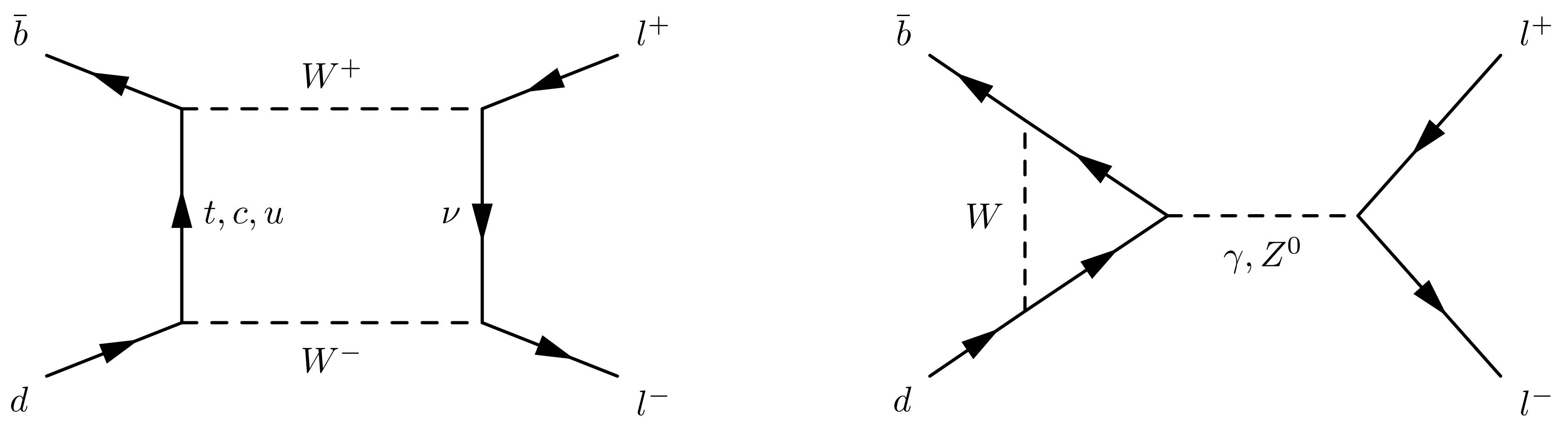




$$\mathcal{B}(B \to e^+e^-\gamma) < 1.2 \times 10^{-7} \text{ 90\% C.L.}$$
$$\mathcal{B}(B \to \mu^+\mu^-\gamma) < 1.6 \times 10^{-7} \text{ 90\% C.L.}$$

- Submitted to PRD-RC *arXiv:0706.2870*

$B \to l^+ l'^-$



$$\mathcal{B}(B \to ll') = \tau(B_d)\frac{G_F^2}{\pi}\left(\frac{\alpha}{4\pi \sin^2\Theta_W}\right)^2 F_{B_d}^2 m_l^2 m_{B_d}^2 \sqrt{1 - 4m_l^2/m_{B_d}^2}\,|V_{tb}^* V_{td}|^2 Y^2(x_t)$$

- $b \to d$ transition
- very suppressed in the SM
- Search done on 347 fb^{-1}

Decay mode	$B^0 \to e^+e^-$	$B^0 \to \mu^+\mu^-$	$B^0 \to e^\pm\mu^\mp$
SM prediction	1.9×10^{-15}	8.0×10^{-11}	0

- ee,$\mu\mu$ and the LFV channel eμ studied
- very sensitive to SM extensions, for example MFV scenarios
  - Buras et al. Nucl. Phys. B 726, 252 (2005)

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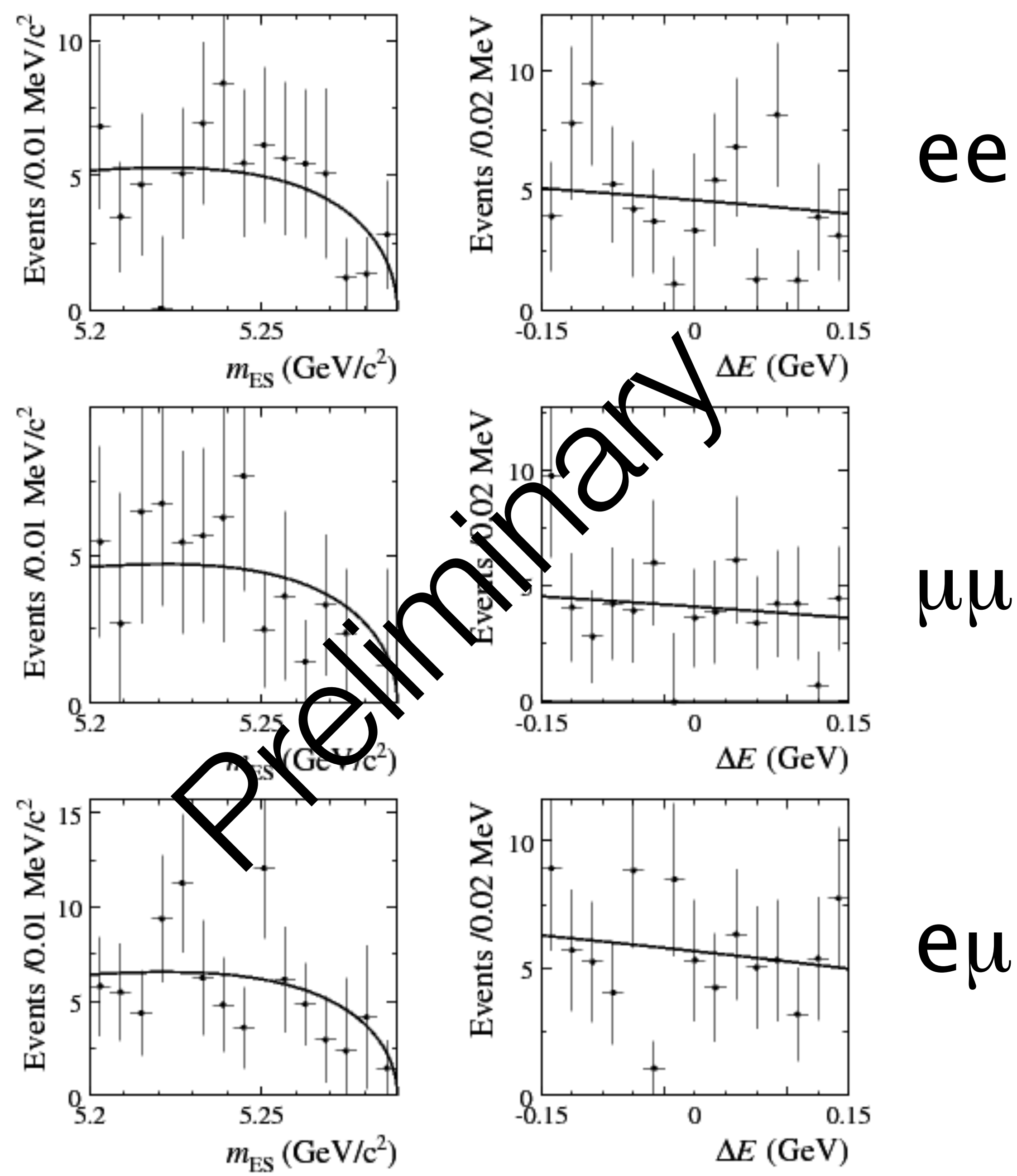
B→l⁺l’⁻ analysis

- Look for two charged tracks
- Main backgrounds: pions, kaons and continuum
- Pions and kaons removed with PID selectors
- Three independent Maximum Likelihood fits to distinguish from continuum events
- Background PDF distributions evaluated from fit to πh ($h=\pi,K$)
  - not enough statistics to see the difference between leptonic and hadronic bkg
  - negligible bias introduced
- background sPlot distributions for m_{ES} and ΔE shown in the picture



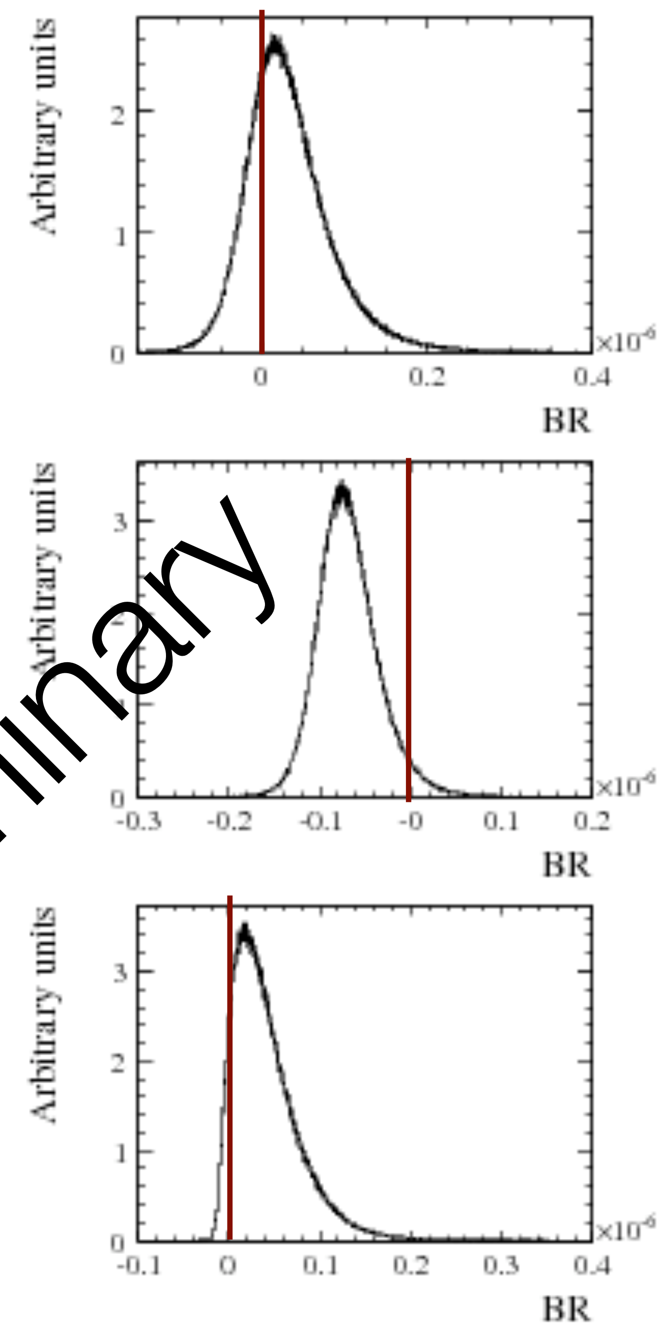
$B \to l^+ l'^-$ results

- UL(BF) estimated with Bayesian approach by integrating the likelihood distribution
- No evidence of signal

$$\int_0^{UL(BR)} dBR_{ll}\mathcal{L}(BR_{ll}) = 0.90 \int_0^{\infty} dBR_{ll}\mathcal{L}(BR_{ll})$$

	$\epsilon_{ll'}(\%)$	$N_{ll'}$	$\mathrm{UL}(\mathcal{BR}) \times 10^{-8}$
$B^0 \to e^+e^-$	16.6 ± 0.3	0.6 ± 2.1	11.3
$B^0 \to \mu^+\mu^-$	15.7 ± 0.2	-4.9 ± 1.4	5.2
$B^0 \to e^\pm\mu^\mp$	17.1 ± 0.2	1.1 ± 1.8	9.2

Preliminary



ee

μμ

eμ

Summary

- BaBar very active in Leptonic decays
- we presented the following results:
  - B→τν
    - $\mathcal{B}(B \to \tau\nu) = \left(1.2 \pm 0.4^{stat} \pm 0.3^{bkg} \pm 0.2^{eff}\right) \times 10^{-4}\ [2.6\sigma]$
    - Set constraint on new physics parameters
  - B→Kτμ
    - First search ever done
    - No evidence of signal
    - $\mathcal{B}(B \to K\tau\mu) < 7.7 \times 10^{-5}$@ 90% C.L.
  - B→llγ
    - First search ever done
    - $\mathcal{B}(B \to e^+e^-\gamma) < 1.2 \times 10^{-7}$ 90% C.L.
    - $\mathcal{B}(B \to \mu^+\mu^-\gamma) < 1.6 \times 10^{-7}$ 90% C.L.
  - B→ll
    - $\mathcal{B}(B \to e^+e^-) < 11.3 \times 10^{-8}$
    - $\mathcal{B}(B \to \mu^+\mu^-) < 5.2 \times 10^{-8}$
    - $\mathcal{B}(B \to e^\pm\mu^\mp) < 9.2 \times 10^{-8}$

Backup slides

Combined BaBar + Belle B→τν

- BaBar combined: (preliminary)
  - $\mathcal{B}(B \to \tau\nu) = \left(1.2 \pm 0.4^{stat} \pm 0.3^{bkg} \pm 0.2^{eff}\right) \times 10^{-4}\,[2.6\sigma]$
- Belle: PRL 97, 251802 (2006)
  - $\mathcal{B}(B \to \tau\nu) = (1.79^{+0.56+0.46}_{-0.49-0.51}) \times 10^{-4}$
- BaBar + Belle:
  - $\mathcal{B}(B \to \tau\nu) = (1.41 \pm 0.43) \times 10^{-4}$

$B \to \tau\nu$

Selection criteria

mode	e^+	μ^+	π^+	$\pi^+\pi^0$
$M_{\rm miss}({\rm GeV}/c^2)$	[4.6, 6.7]	[3.2, 6.1]	≥ 1.6	≤ 4.6
$p^*_{\rm signal}({\rm GeV}/c)$	≤ 1.5	–	≥ 1.6	≥ 1.7
$R_{\rm cont}$	[2.78, 4.0]	> 2.74	> 2.84	> 2.94
$E_{\rm extra}({\rm GeV})$	< 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			
$E_{\rm extra}$	3.4			
signal B	5.5			
tag B	3.6			
$N_{B\overline{B}}$	1.1			
Total	6.6			

Selection criteria

Variable	$\tau^+ \to e^+\nu\overline{\nu}$	$\tau^+ \to \mu^+\nu\overline{\nu}$	$\tau^+ \to \pi^+\overline{\nu}$	$\tau^+ \to \pi^+\pi^0\overline{\nu}$
$E_{\rm extra}$ (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
$p^*_{\rm trk}$ (GeV/c)	< 1.25	< 1.85	> 1.5	n.a.
$cos\theta^*_{\rm miss}$	< 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
$E_{\rm extra}$	15
Total	16.5

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$B \to K\tau\mu$ background

- Example of semileptonic background

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

- Kill almost all of this background by cutting on the invariant mass of K + (opposite charge track) to be greater than D mass

- To normalize signal BF

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

Signal branching fraction ($\mathcal{B}_{K\tau\mu}$); *Signal yield from cut-and-count* ($N_{K\tau\mu}$); *Control sample yield from fit* ($N_{D\mu\nu}$); *Ratio of B_{tag} efficiencies*; *Ratio of signal-side efficiencies*

- Expected background from m_τ sideband (signal/sideband ratio from MC)

$B \rightarrow l^+ l^- \gamma$ background

- background prediction taken from data
- signal to sideband ratio extrapolated from Upper and Lower sidebands