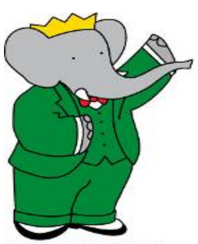
Rare or forbidden B decays with *BABAR*

Steven Robertson
Institute of Particle Physics
&
McGill University



Presented at
ICHEP 2012
*on behalf of the **BABAR** Collaboration*
July 6, 2012
Melbourne, Australia

INSTITUTE OF PARTICLE PHYSICS

McGill

Outline

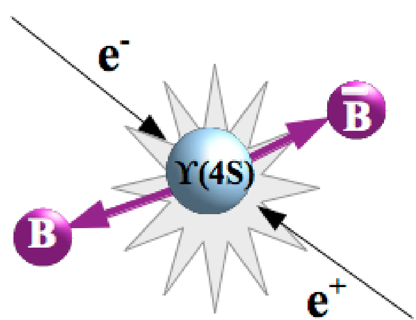
Recent ***BABAR*** results of searches for the rare or forbidden decays:

- $B^+ \to h^- \ell^+ \ell^+$
- $B^+ \to h^+ \tau^+ \ell^-$

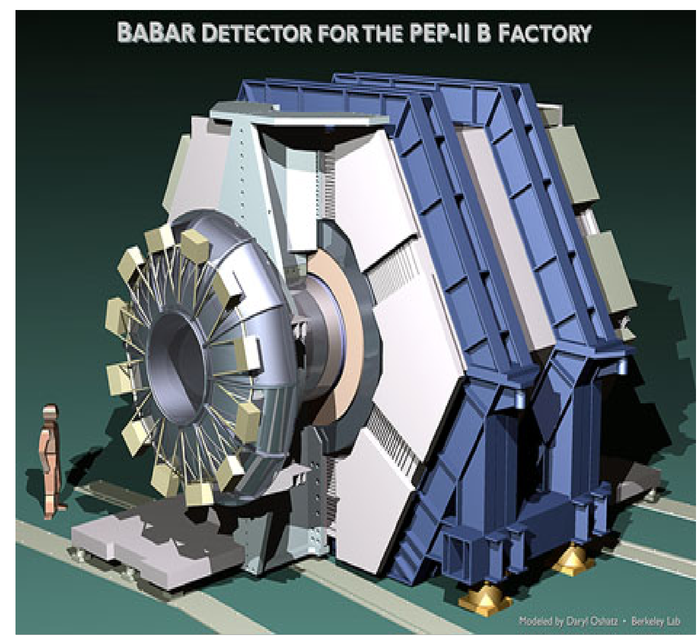
$\left.\right\}$ $h = K, \pi$; $\ell = e, \mu$

- $B^0 \to \nu \bar{\nu} (\gamma)$ (i.e. invisible final states)

BABAR
data sample of ~470 million $\Upsilon(4S) \to B\bar{B}$ events



e^+e^- collisions at CM energy of ~10.58 GeV

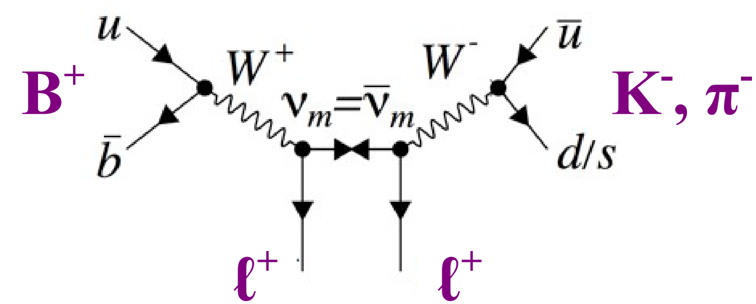


$B^+ \to h^- \ell^+ \ell^+$ ($h=K,\pi$)

BABAR
PRD, 85, 071103(R) (2012)

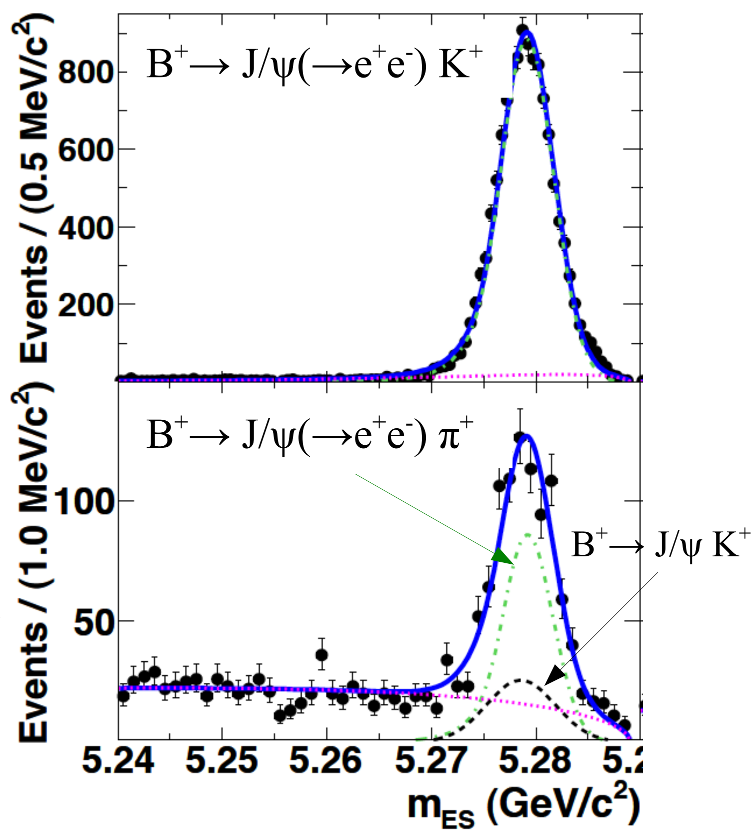
Lepton number not explicitly conserved in many SM extensions

- LNV in $B^+ \to h^- \ell^+\ell^+$ is $\Delta L = 2$ process which can occur via Majorana neutrinos
  - complementary to $0\nu\beta\beta$ searches



BABAR **search for** $B^+ \to h^- \ell^+\ell^+$ ($h=K,\pi$)

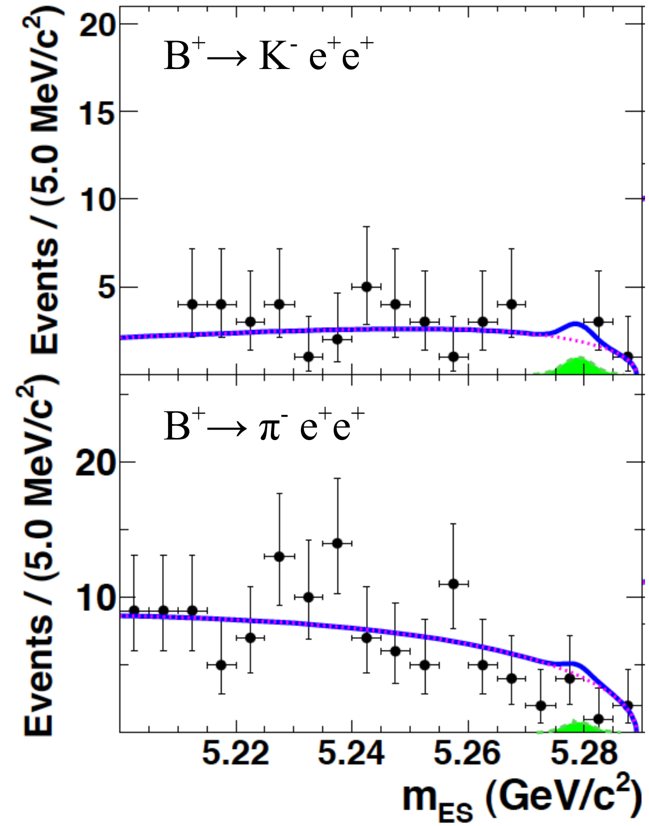
- 3-charged-particle final states, with "wrong-sign" charge combinations compared with SM $B^+ \to K^+\ell^+\ell^-$ modes
  - Event selection similar to $B \to K^{(*)}\ell^+\ell^-$ analysis (see talk by G. Eigen, Weds 2:15)
- Use $B^+ \to h^+ J/\psi\ (\to \ell^+\ell^-)$ control samples to validate signal efficiencies

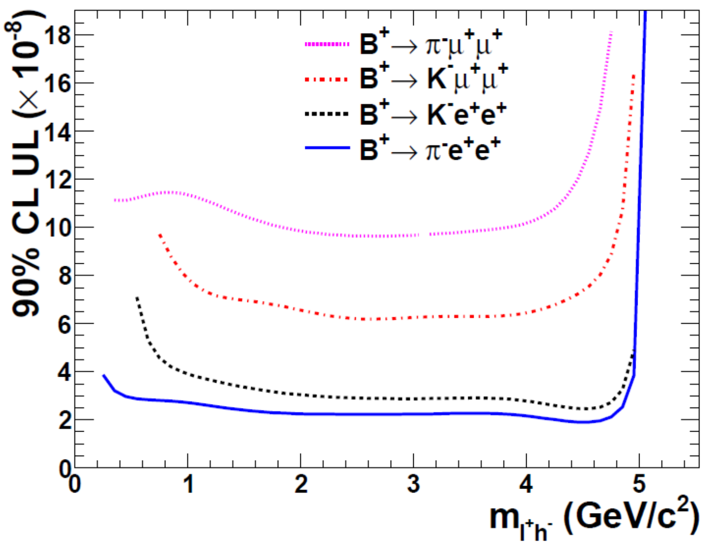


$B^+ \rightarrow h^- \ell^+ \ell^+$ (h=K,π)

BABAR
PRD, 85, 071103(R) (2012)

- Background suppression using 18-input Boosted Decision Tree (BDT) based on event shape variables
- Signal extracted from 2-d fit to m_{ES} and BDT output





Mode	$\mathcal{B}$ $(\times 10^{-8})$	$\mathcal{B}_{UL}$ $(\times 10^{-8})$
$B^+ \rightarrow \pi^- e^+ e^+$	$0.27^{+1.1}_{-1.2} \pm 0.1$	2.3
$B^+ \rightarrow K^- e^+ e^+$	$0.49^{+1.3}_{-0.8} \pm 0.1$	3.0
$B^+ \rightarrow \pi^- \mu^+ \mu^+$	$0.03^{+5.1}_{-3.2} \pm 0.6$	10.7
$B^+ \rightarrow K^- \mu^+ \mu^+$	$0.45^{+3.2}_{-2.7} \pm 0.4$	6.7

- Substantial improvement in electron channel results
- $\mu^+\mu^+$ mode sensitivity comparable to LHCb:

LHCb: $\mathcal{B}(B^+ \rightarrow X^- \mu^+ \mu^+) < 1.3 \times 10^{-8} - 2.6 \times 10^{-6}$ (41 pb⁻¹)
PRL 108, 101601 (2012); arXiv:1201.5600

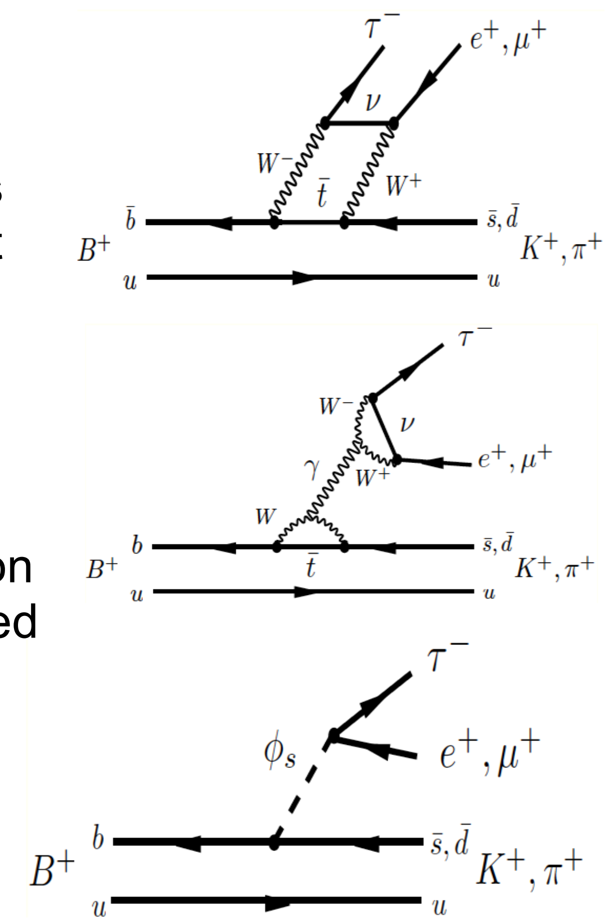
$B^{\pm} \rightarrow h^{\pm}\tau^{+}\ell^{-}$ (h=K,π)

Lepton flavour is not conserved in standard model

- Charged LFV from neutrino mixing expected, but at levels far below current experimental sensitivity, hence excellent probes of beyond-SM physics

New sources of explicit non-conservation arise in many new physics scenarios

- Most interesting decays are those containing 3rd generation charged lepton (τ) due to large mass (e.g. Higgs mediated LFV) and less stringent experimental constraints



M. Sher, Y. Yuan, Phys.Rev. D44 1461 (1991)

BABAR (383M $B\bar{B}$)

$\mathcal{B}(B^{\pm} \rightarrow K^{\pm}\tau^{+}\mu^{-}) < 7.7 \times 10^{-5}$

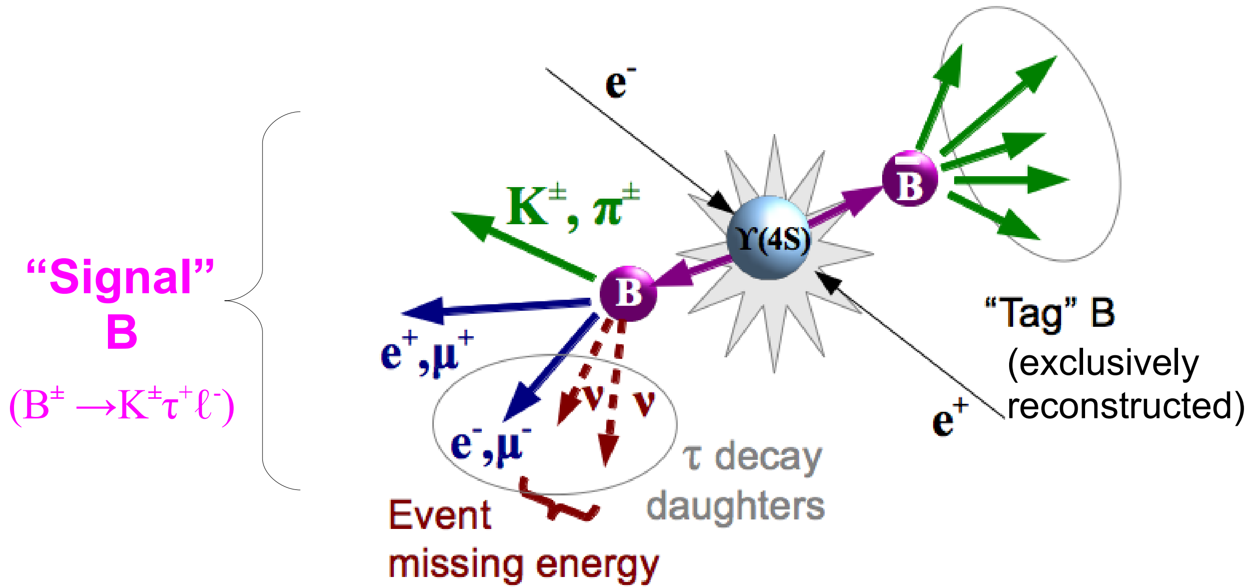
PRL 99, 201801 (2007)

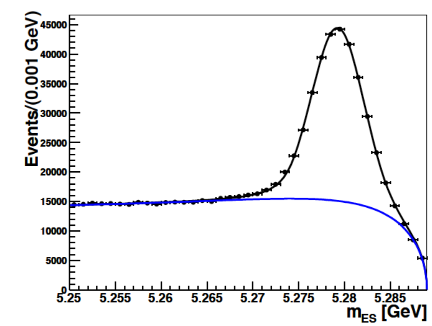
- New search reports first experimental results for $B \rightarrow K\tau e$, $\pi\tau\mu$, and $\pi\tau e$

Methodology

B decays with neutrinos (or other missing energy) have limited kinematic information available to uniquely identify the signal decay

- Instead, exclusively reconstruct one of the B meson decays (“tag B”) in one of several thousand hadronic (or semileptonic) decay modes:





$$m_{\mathrm{ES}} \equiv \sqrt{E^{*2}_{\mathrm{beam}} - \mathrm{p}^{*2}_{B}}$$
$$\Delta E^{*} \equiv E^{*}_{B} - E^{*}_{\mathrm{beam}}$$

- Improves knowledge of signal kinematics and missing energy, and strongly suppresses combinatorial backgrounds
- Disadvantage: low reconstruction efficiency

- Analogous method based on semileptonic $B^0 \rightarrow D^{(*)-}\ell^+\nu$ decays

$B^{\pm} \to h^{\pm}\tau^{+}\ell^{-}$ (h=K,π)

BABAR
Accepted by PRD
arXiv:1204.2852

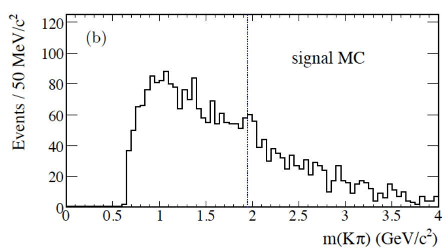
Search for evidence of signal decay in remaining detector activity after “hadronic tag B” reconstruction

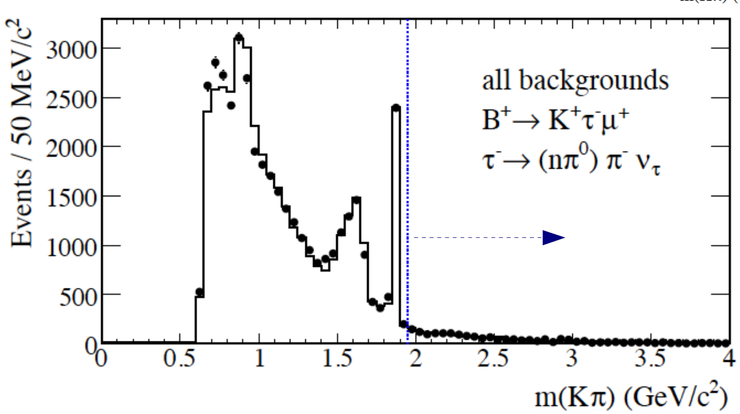
- 1-prong τ decay modes ($e/\mu/\pi$) i.e. 3-track final state signature

Suppress backgrounds from b→c decay by requiring “K-π” invariant mass to be above D mass ($m_{K\pi}$> 1.95 GeV)

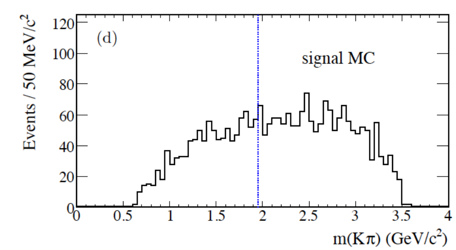
- combine primary hadron (h) with oppositely charged track (either the primary lepton or tau daughter e, μ or π)

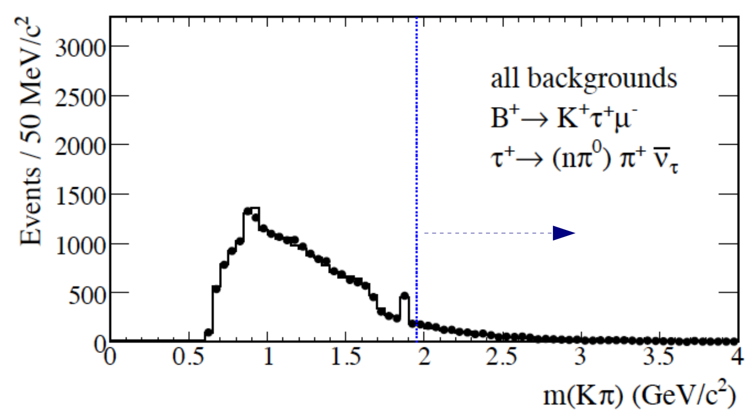
$B^{+} \to K^{+}\tau^{-}\ell^{+}$
background:
$B^{+} \to D^{(*)0}\ell^{+}\nu$
with $D^{0} \to K^{+}\pi^{-}$





$B^{+} \to K^{+}\ell^{-}\tau^{+}$
background:
$B^{+} \to D^{(*)0}\pi^{+}$
with $D^{0} \to K^{+}\ell^{-}\nu$





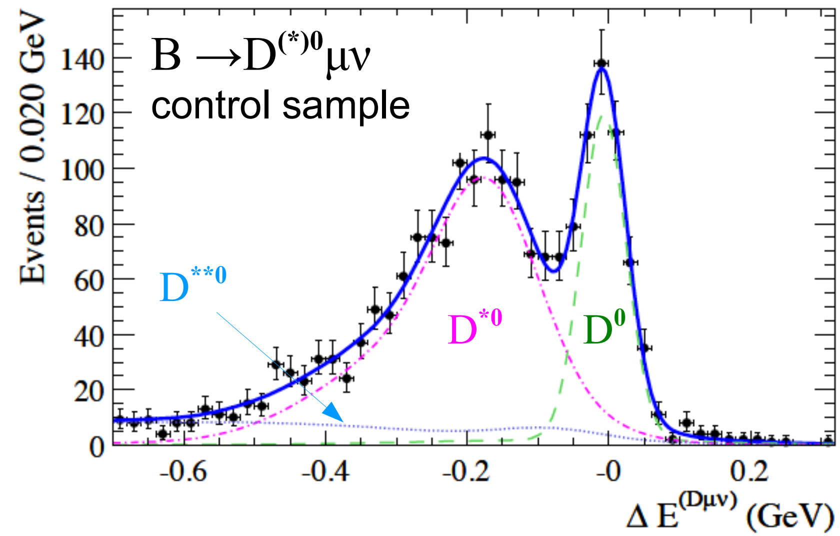
$B^{\pm} \to h^{\pm}\tau^{+}\ell^{-}$ ($h=K,\pi$)

BABAR
Accepted by PRD
arXiv:1204.2852

Define $B^{+} \to D^{(*)0}\,\ell^{+}\nu$ ($D^{0} \to K^{+}\pi^{-}$) control samples by requiring $m(K\pi)$ consistent with D^{0} mass:

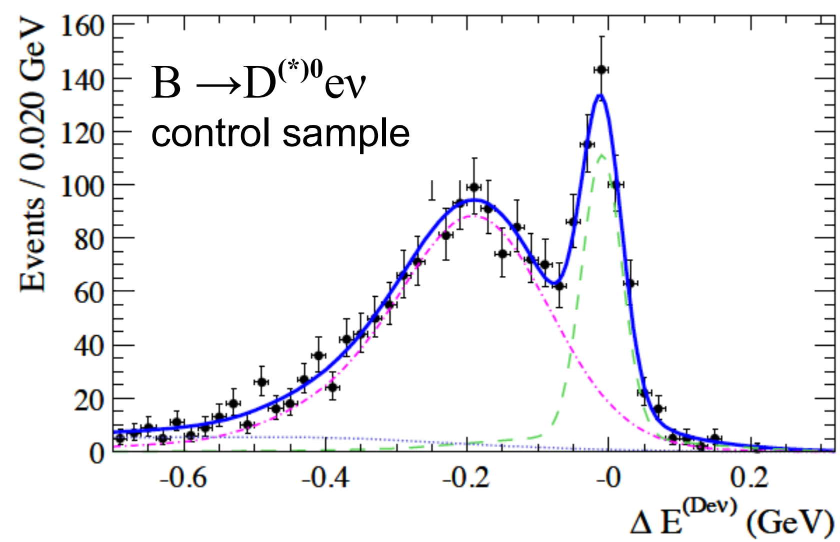
$$1.845 < m(K\pi) < 1.885\ \mathrm{GeV}/c^{2}$$

- use to normalize signal modes to measured $B^{+} \to D^{(*)0}\,\ell^{+}\nu$ branching fractions



Continuum background suppressed with multivariate likelihood based on event shape, calorimeter energy deposition and PID quality

- veto $J/\psi \to \ell^{+}\ell^{-}$ and photon conversions based on $m(\ell^{+}\ell^{-})$



$B^{\pm} \to h^{\pm}\tau^{+}\ell^{-}$ (h=K,π)

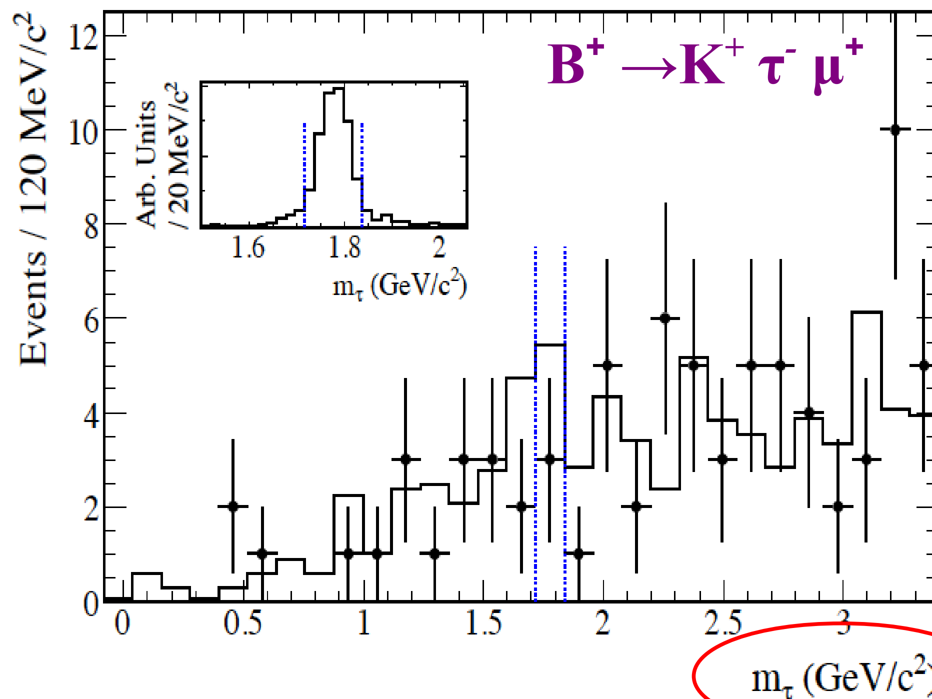
BABAR
Accepted by PRD
arXiv:1204.2852

Extract signal from data yield in reconstructed τ invariant mass (m_τ)

- 4-vector of τ determined from h-ℓ-B combination

$$\vec{p}_\tau = -\vec{p}_{\mathrm{tag}} - \vec{p}_h - \vec{p}_\ell,$$
$$E_\tau = E_{\mathrm{beam}} - E_h - E_\ell,$$
$$m_\tau = \sqrt{E_\tau^2 - |\vec{p}_\tau|^2},$$

- m_τ sideband regions used to estimat background in signal region



Model independent limits on NP scale in τ-μ flavour changing operators*:

Λ_{bd}>11 TeV
Λ_{bs}>15 TeV

* PRD 66, 053002 (2002)

	$\mathcal{B}(B \to h\tau\ell)$ $(\times 10^{-5})$	
Mode	central value	90% C.L. UL
$B^+ \to K^+\tau\mu$	$0.0\ ^{+2.7}_{-1.4}$	< 4.8
$B^+ \to K^+\tau e$	$-0.6\ ^{+1.7}_{-1.4}$	< 3.0
$B^+ \to \pi^+\tau\mu$	$0.5\ ^{+3.8}_{-3.2}$	< 7.2
$B^+ \to \pi^+\tau e$	$2.3\ ^{+2.8}_{-1.7}$	< 7.5

$B^0 \to \nu\bar{\nu}(\gamma)$ ("invisible")

BABAR
Submitted to PRD
arXiv:1206.2543

$B^0 \to \nu\bar{\nu}$ strongly helicity suppressed FCNC in SM

- Presence of energetic photon removes suppression:

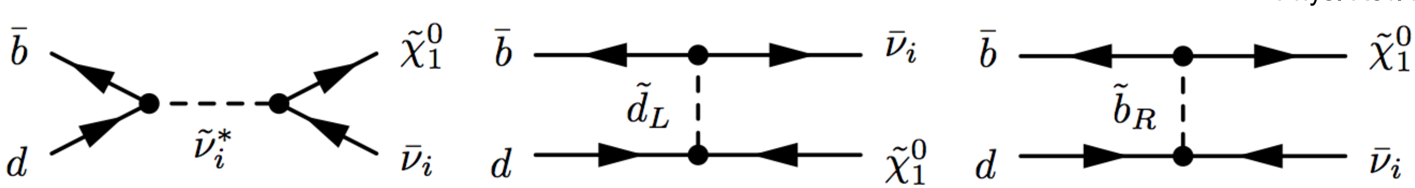
$$B(B^0 \to \nu\bar{\nu}\gamma)_{SM} \sim 10^{-9}$$

- Experimental signature (missing energy) does not distinguish between final state neutrinos or other undetected particles

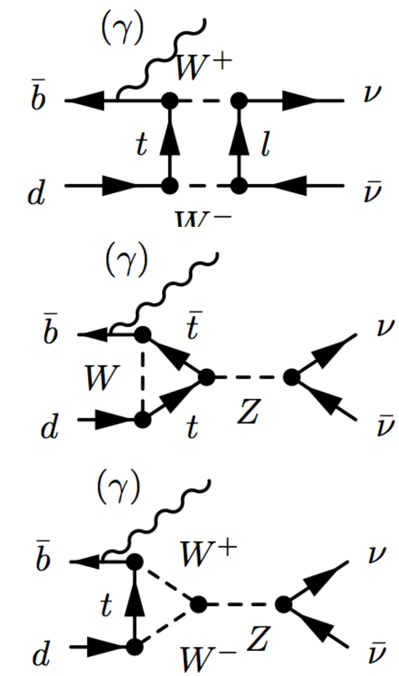
Possibility of enhancement to $\sim 10^{-7}$-10^{-6} in some new physics models (RPV SUSY, LED models)

- Light neutralino contributions to $B^0 \to$ invisible:

$$B_d^0 \to \bar{\nu}_i \tilde{\chi}_1^0$$



SM contributions:

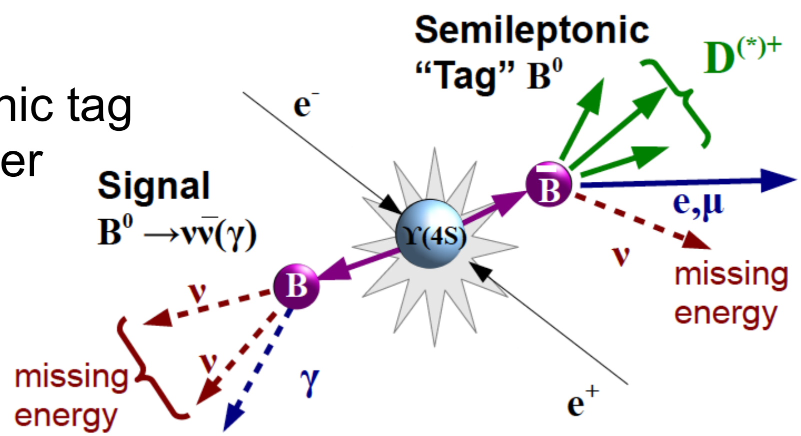


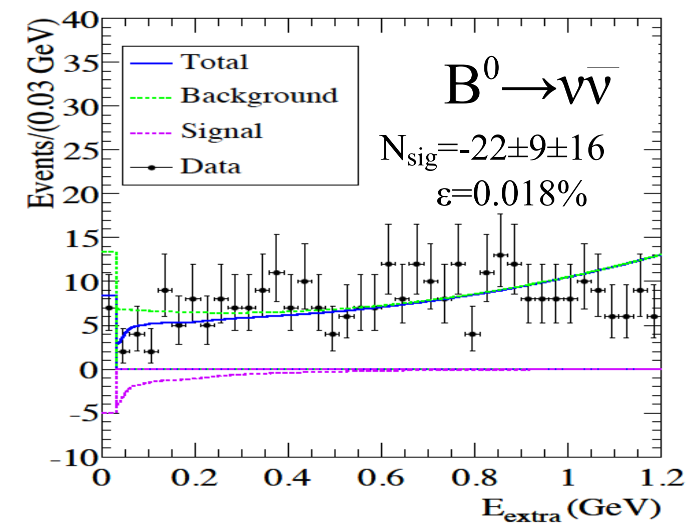
A. Dedes, H. Dreiner, and P. Richardson, Phys. Rev. D65, 015001 (2002).

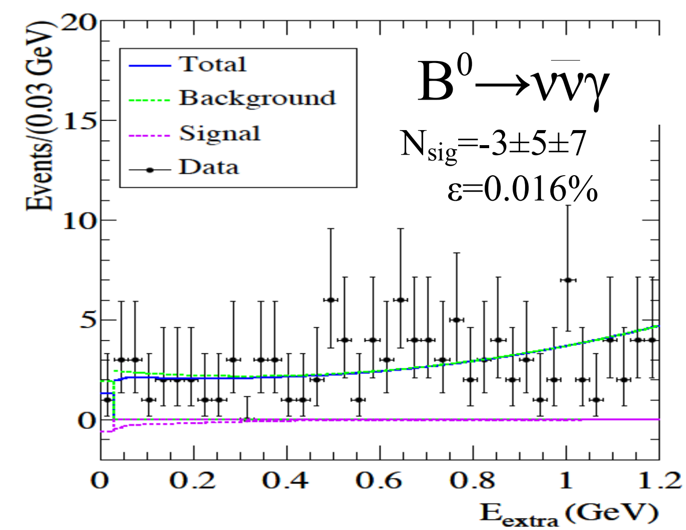
$B^0 \to \nu\bar{\nu}(\gamma)$ ("invisible")

Use semileptonic tag reconstruction method to identify B decays associated with little or no detector activity

- Similar to hadronic tag method but higher yield:







- Require no additional charged tracks
- Further background suppression using neural net combining event shape and tag-B kinematic variables
- Signal yield obtained from fit to E_{extra}

  (≡ total calorimeter energy excluding B_{tag} and signal γ)

$$\mathcal{B}(B^0 \to \text{invisible}) < 2.4 \times 10^{-5}$$
$$\mathcal{B}(B^0 \to \text{invisible} + \gamma) < 1.7 \times 10^{-5} \quad (E_\gamma > 1.2\ \text{GeV})$$

~order of magnitude improvement over previous ***BABAR*** limits

Summary

Recent results from ***BABAR*** on very rare or forbidden processes:

- Search for lepton number violation in $B^+ \to h^- \ell^+ \ell^+$

  PRD, 85, 071103(R) (2012)

- Search for lepton flavour violation in $B^+ \to h^+ \tau^+ \ell^-$

  Accepted by PRD; arXiv:1204.2852

- Search for "invisible" final states in $B^0 \to \nu \bar{\nu} (\gamma)$

  Submitted to PRD; arXiv:1206.2543

⇒ No evidence of signal in any mode, consistent with standard model expectation

Backup slides

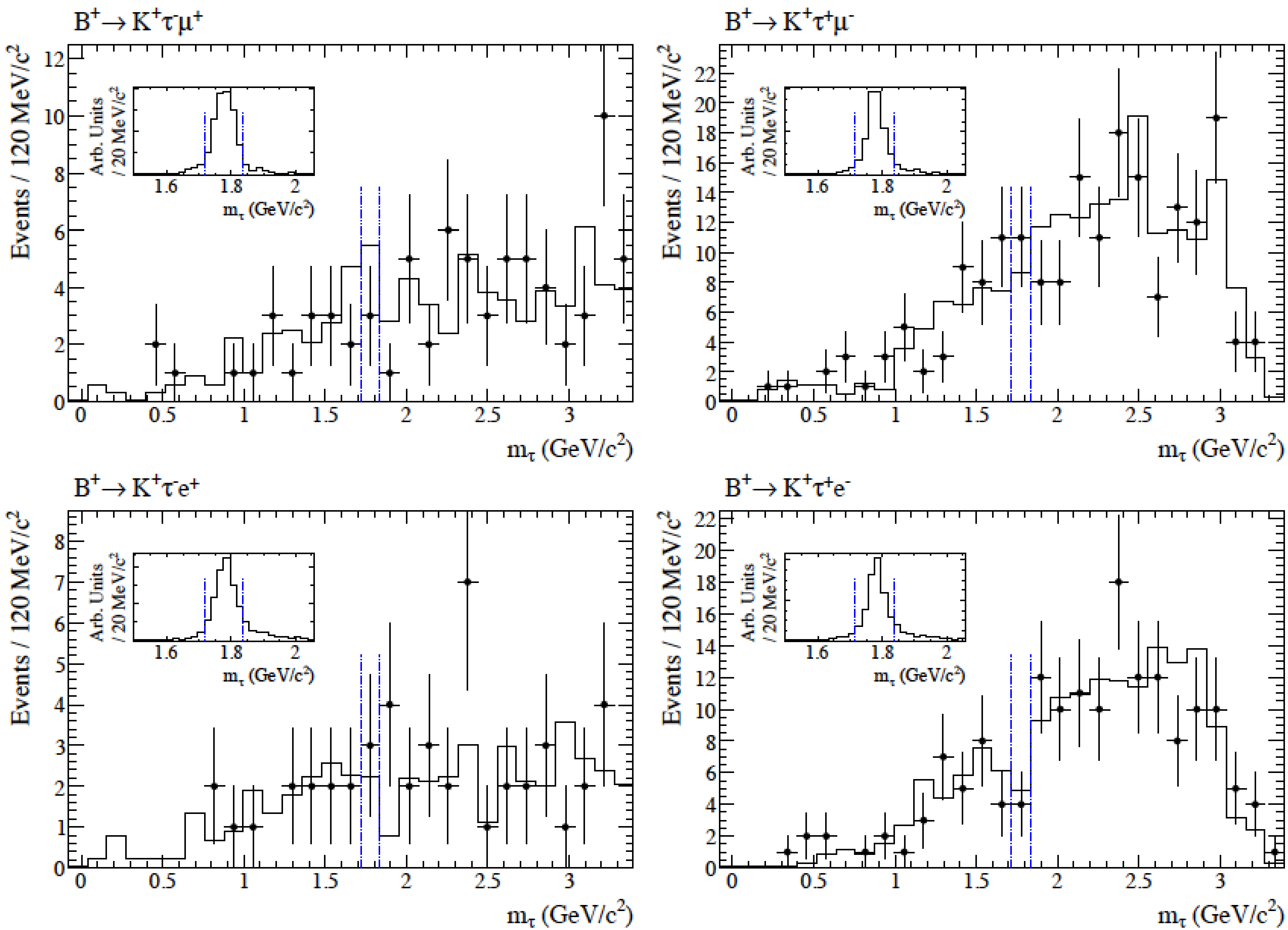
$B^{\pm} \rightarrow h^{\pm}\tau^{+}l^{-}$

BABAR
Accepted by PRD
arXiv:1204.2852

Mode	τ channel	b_i	n_i	$\epsilon_{h\tau\ell,i}$	$\mathcal{B}(B \to h\tau\ell)$ $(\times 10^{-5})$ central value	$\mathcal{B}(B \to h\tau\ell)$ $(\times 10^{-5})$ 90% C.L. UL
	e	0.4 ± 0.2	2	$(2.6 \pm 0.2)\%$		
$B^+ \to K^+\tau^-\mu^+$	μ	0.3 ± 0.2	0	$(3.2 \pm 0.4)\%$	$0.8\ ^{+1.9}_{-1.4}$	< 4.5
	π	1.8 ± 0.8	1	$(4.1 \pm 0.4)\%$		
	e	0.2 ± 0.1	0	$(3.7 \pm 0.3)\%$		
$B^+ \to K^+\tau^+\mu^-$	μ	0.2 ± 0.1	0	$(3.6 \pm 0.7)\%$	$-0.4\ ^{+1.4}_{-0.9}$	< 2.8
	π	6.9 ± 1.5	11	$(9.1 \pm 0.5)\%$		
	e	0.6 ± 0.1	2	$(2.2 \pm 0.2)\%$		
$B^+ \to K^+\tau^-e^+$	μ	0.1 ± 0.1	0	$(2.7 \pm 0.6)\%$	$0.2\ ^{+2.1}_{-1.0}$	< 4.3
	π	1.5 ± 0.5	1	$(4.8 \pm 0.6)\%$		
	e	0.8 ± 0.5	0	$(2.8 \pm 1.1)\%$		
$B^+ \to K^+\tau^+e^-$	μ	0.1 ± 0.1	0	$(3.2 \pm 0.7)\%$	$-1.3\ ^{+1.5}_{-1.8}$	< 1.5
	π	4.6 ± 1.3	4	$(8.7 \pm 1.2)\%$		
	e	0.9 ± 0.6	0	$(2.3 \pm 0.2)\%$		
$B^+ \to \pi^+\tau^-\mu^+$	μ	1.1 ± 0.4	2	$(2.9 \pm 0.4)\%$	$0.4\ ^{+3.1}_{-2.2}$	< 6.2
	π	3.3 ± 0.9	4	$(2.8 \pm 0.2)\%$		
	e	2.1 ± 0.5	2	$(3.8 \pm 0.3)\%$		
$B^+ \to \pi^+\tau^+\mu^-$	μ	3.6 ± 0.9	4	$(4.8 \pm 0.3)\%$	$0.0\ ^{+2.6}_{-2.0}$	< 4.5
	π	25 ± 3	23	$(9.1 \pm 0.6)\%$		
	e	0.1 ± 0.1	1	$(2.0 \pm 0.8)\%$		
$B^+ \to \pi^+\tau^-e^+$	μ	0.4 ± 0.2	1	$(2.8 \pm 0.3)\%$	$2.8\ ^{+2.4}_{-1.9}$	< 7.4
	π	6.0 ± 1.4	7	$(5.8 \pm 0.3)\%$		
	e	1.0 ± 0.4	0	$(2.9 \pm 0.3)\%$		
$B^+ \to \pi^+\tau^+e^-$	μ	3.0 ± 1.2	2	$(4.6 \pm 0.4)\%$	$-3.1\ ^{+2.4}_{-2.1}$	< 2.0
	π	5.7 ± 2.5	3	$(3.7 \pm 1.0)\%$		

$B^{\pm} \rightarrow h^{\pm} \tau^{+} l^{-}$

BABAR
Accepted by PRD
arXiv:1204.2852



The *BABAR* experiment

Large data samples corresponding to

- **432 fb^{-1}** $\Upsilon(4S)$ “onpeak”
- **53 fb^{-1}** “offpeak”
  - collected ~40MeV below $\Upsilon(4S)$ peak
- Also samples of “narrow Υ” events:
  - 122 x 10^{6} $\Upsilon(3S)$ decays
  - 99 x 10^{6} $\Upsilon(2S)$ decays