Leptonic B Decays

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On behalf of the BaBar Collaboration

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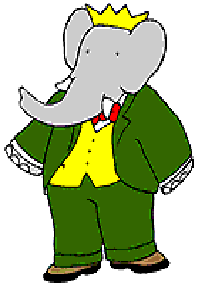
Outline



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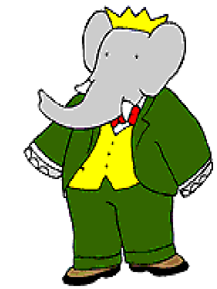
- Motivation and experimental method
- New results on the Leptonic B meson decays from BaBar:

Part A:
- $B^+ \to l^+ \nu \ (l = e, \mu, \tau)$,

Part B:
- $B^0 \to l^+ l'^- \ (l, l' = e, \mu, \tau)$

Including lepton flavor violating (LFV) modes!!

- Summary



Motivation

- Clean SM prediction, highly suppressed

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

Scenario 1: If SM contribution dominates, extract f_B more precisely through experiment.

Dependence on the lepton mass.

Scenario 2: Using |Vub| from semileptonic experiments, and f_B from LQCD. Test new physics “corrections” to the SM prediction.

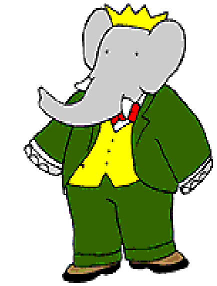
- Potentially sensitive to new physics
  - SUSY, leptoquarks, Higgs
  - lepton universality?

No dependence on the lepton flavor here!

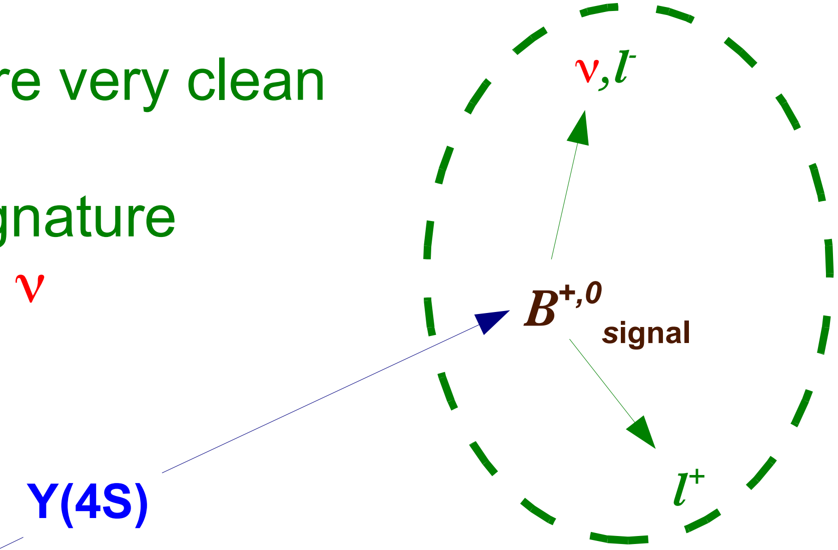
Correction factor due to MSSM Higgs at tree level.

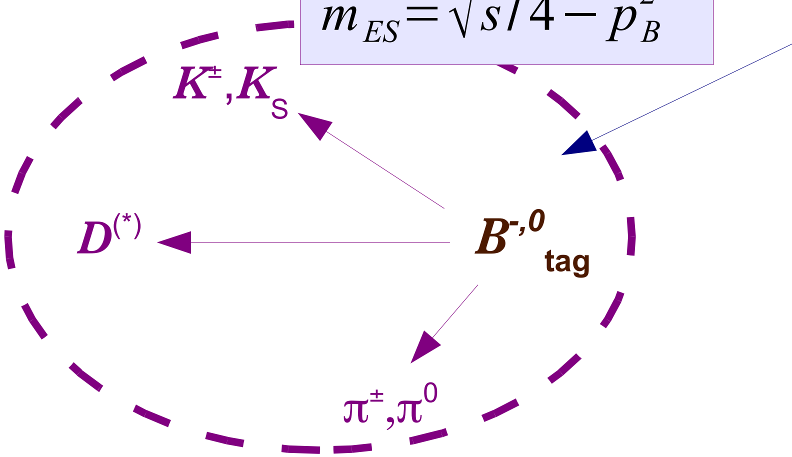
$$R_{B^+\to\ell^+\nu} = \frac{\mathcal{B}(B^+ \to \ell^+ \nu)}{\mathcal{B}_{\rm SM}(B^+ \to \ell^+ \nu_\ell)} = \left[1 - \frac{\tan^2\beta}{(1+\epsilon_0 \tan\beta)} \frac{m_B^2}{m_H^2}\right]^2,$$

Experimental Method



- Leptonic B decays without τ are very clean
  - No final state hadrons
  - High momentum lepton signature
- missing momentum carried by ν





$$\Delta E = E_B - \sqrt{s}/2$$

$$m_{ES} = \sqrt{s/4 - p_B^2}$$

For many analyses presented today, one of the B mesons is reconstructed hadronically:

- greatly suppresses qq (q=u,d,s,c) and $\tau^+\tau^-$ events,
- allows the determination of the signal B rest frame → an even better handle on signal kinematics,
- smaller signal selection efficiency

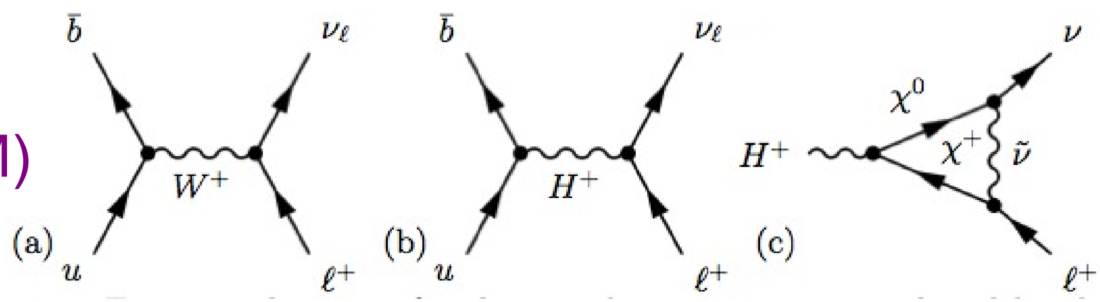
Although not discussed today, BaBar also considers semileptonic B tags!

$B^+ \to l^+ \nu$

- $l = \tau$
- $l = e, \mu$

(using hadronic B tag)

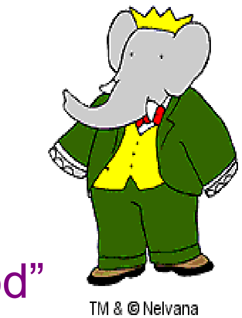
a) SM process
b) H^+ mediation (e.g. MSSM)
c) LFV susy loop



Previous BR Upper Limits

	$B^+ \to \tau^+ \nu$	$B^+ \to \mu^+ \nu$	$B^+ \to e^+ \nu$
SM BR	$1.5 \pm 0.4 \times 10^{-4}$	5.2×10^{-7}	1.2×10^{-11}
BaBar	$< 1.8 \times 10^{-4}$	$< 6.2 \times 10^{-6}$	$< 7.9 \times 10^{-6}$
Belle	$\sim (1.8 \pm 0.5 \pm 0.5) \times 10^{-4}$	$< 9.8 \times 10^{-7}$	$< 1.7 \times 10^{-6}$

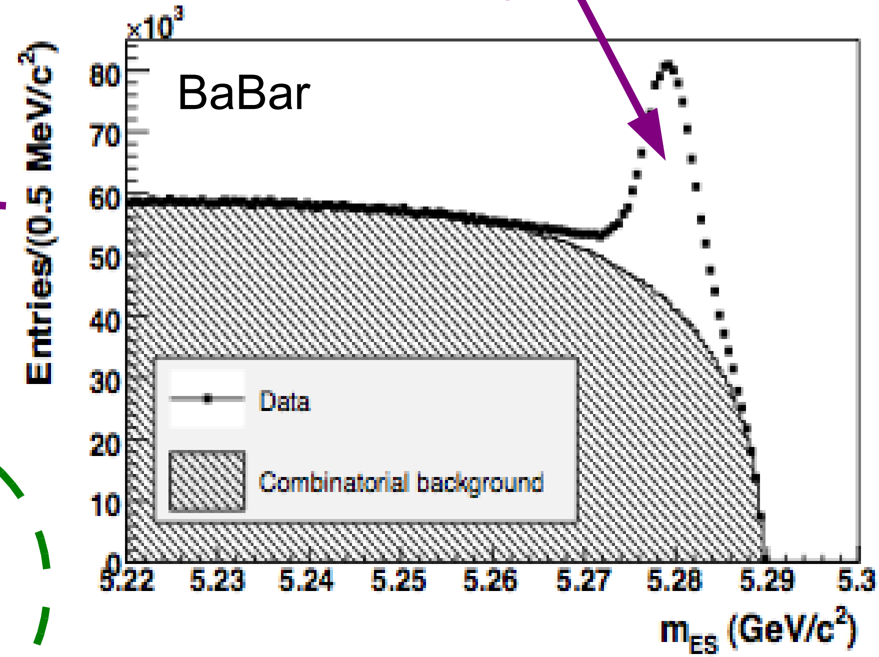
$B^+ \to \tau^+ \nu$

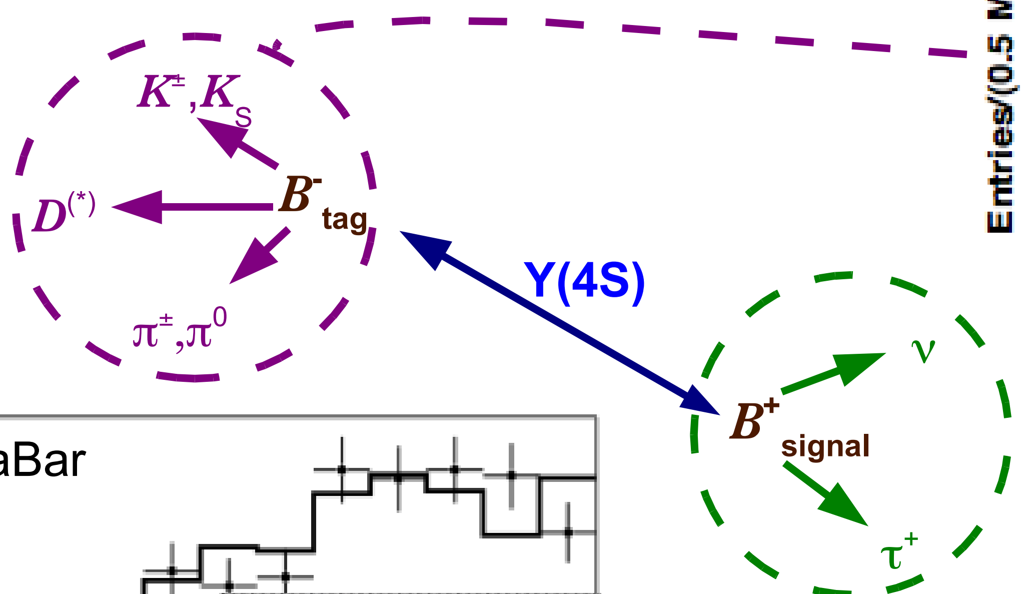


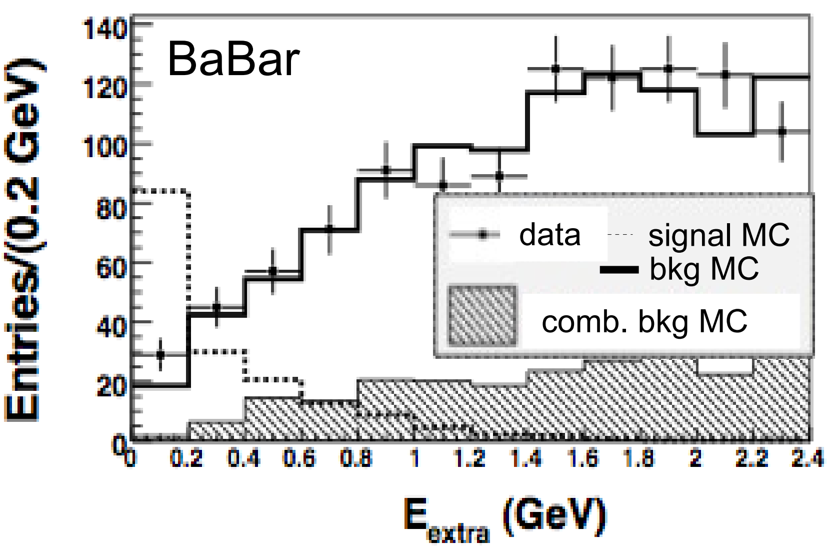
Various approaches used by BaBar

- reconstruct one B meson in hadronic modes

The "good" B tags

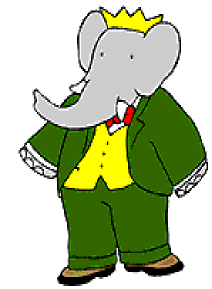






- consider 71% of τ decay modes,
- signal selection: extra energy in the calorimeter, missing mass, event shape variables.

$B^+ \rightarrow \tau^+ \nu$



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Systematic uncertainties:

- total ~12 %

Source of systematics	e^+	μ^+	π^+	$\pi^+\pi^0$	Total
MC statistics	3.1	0.6	1.5	2.6	4.3
Particle Identification	1.5	1.3	0.2	0.2	2.0
π^0	–	–	–	1.4	1.4
Tracking	3.7	0.4	0.1	1.6	5.8
E_{extra}	4.7	0.6	0.9	2.6	8.8
Signal B					11.6
Tag B					3
Total					12

Total signal selection efficiency: (9.8±0.3)%

Background estimated by fitting m_{ES} on E_{extra} sideband and signal regions

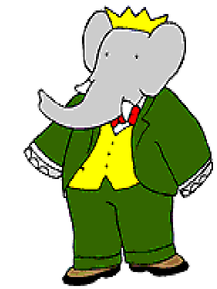
considerable statistical uncertainty on the bkg.

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

with hadronic tags: $B(B^+ \rightarrow \tau^+ \nu) = (1.8^{+0.9}_{-0.8}(stat.) \pm 0.4(bkg.) \pm 0.2(syst.)) \times 10^{-4}$

with semileptonic tags: $B(B^+ \rightarrow \tau^+ \nu) = (0.88^{+0.68}_{-0.67}(stat.) \pm 0.11(syst.)) \times 10^{-4}$

$B^+ \rightarrow l^+\nu \ (l=e,\mu)$



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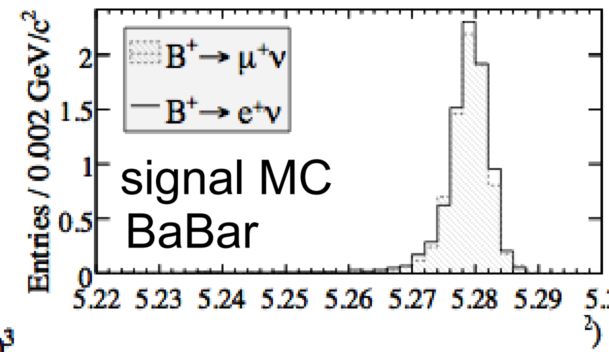
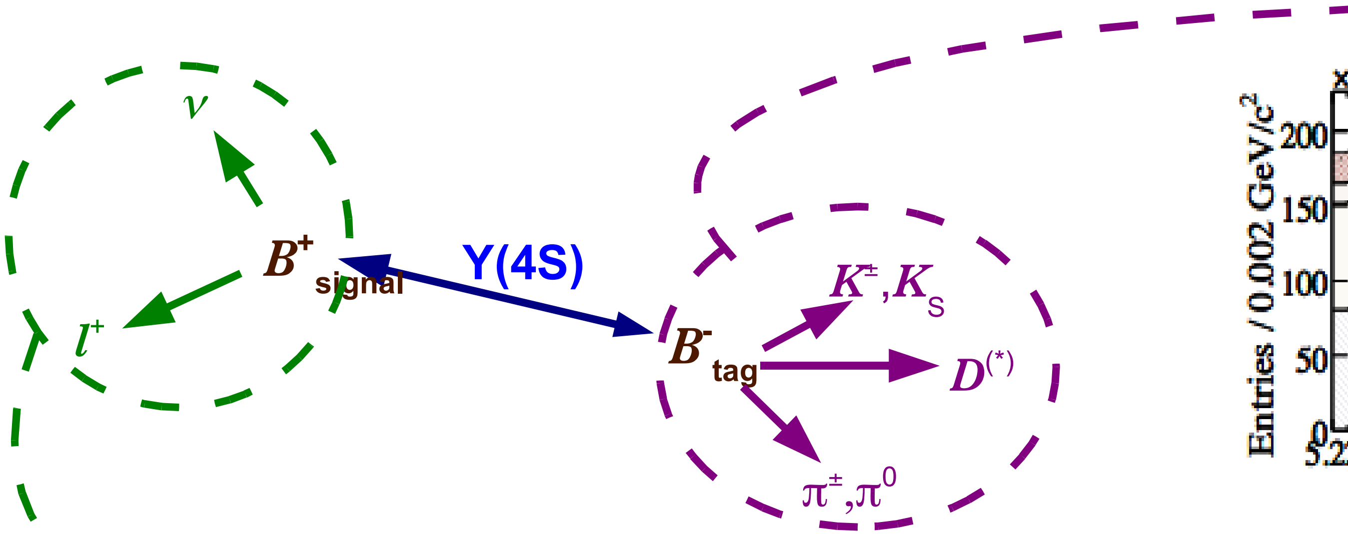
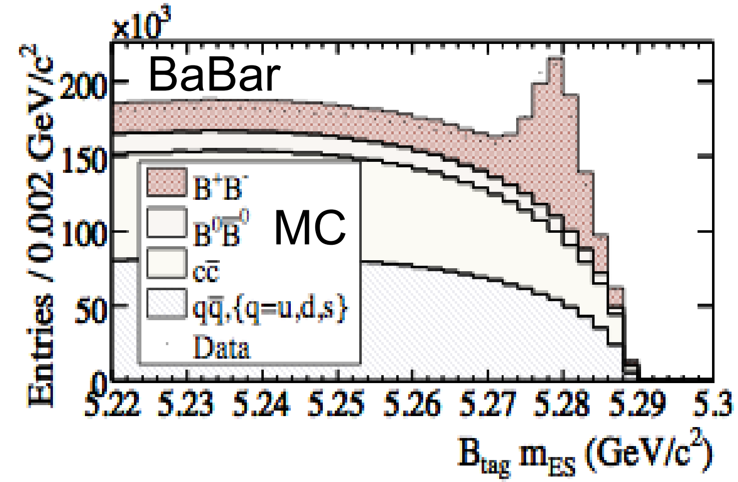
- Reconstruct one B meson in hadronic modes
  - less sensitive to signal than inclusive approach,
  - much lower background (<<1),
  - excellent method for the future precision studies in high luminosity B factories

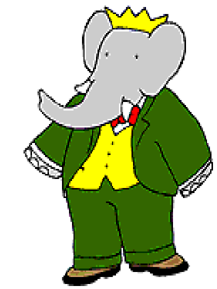






Signal side selection criteria:

- monoenergetic lepton in signal B frame.
- missing momentum (carried by the neutrino),
- extra energy in the calorimeter (should be close to zero)



$B^+ \to l^+\nu$ ($l=e,\mu$)

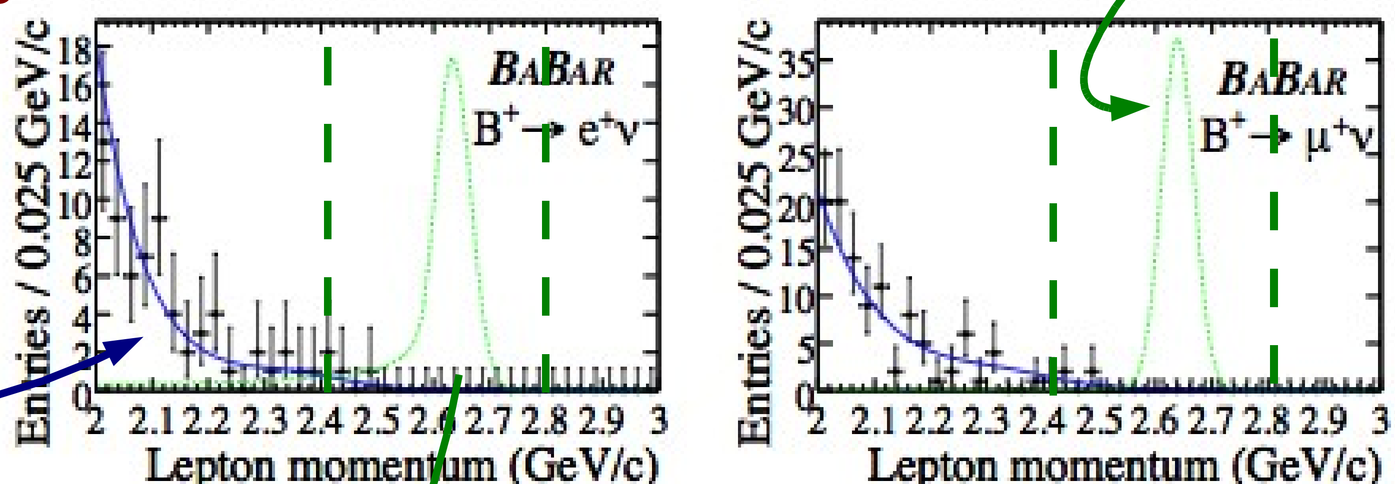
- Unbinned maximum likelihood (ML) fit on lepton momentum in the signal B rest frame

$$\mathcal{L}(n_s, n_b) = \frac{e^{-(n_s+n_b)}}{N!}\prod_{i=1}^{N}[n_s f_s(i) + n_b f_b(i)],$$

Signal PDF (arbitrary scaling)

data points

Background and signal ML fit



(number of events "under the peak")

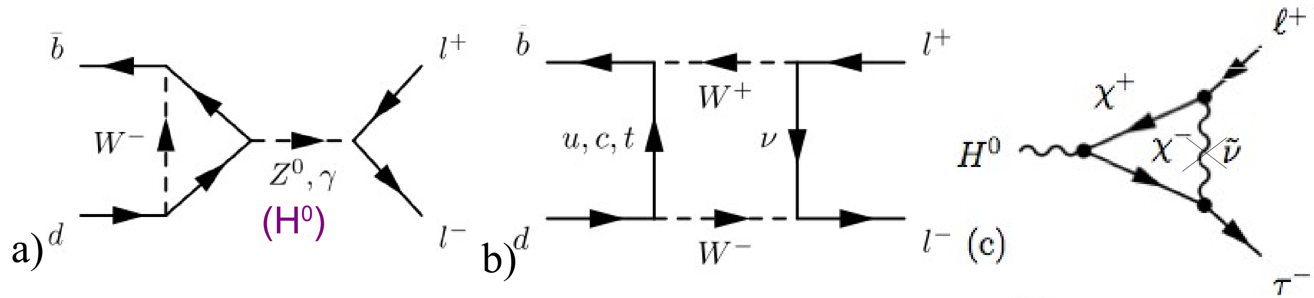
	$e^+\nu$	$\mu^+\nu$
$\epsilon_{tot} \times 10^5$	135 ± 4	120 ± 4
n_b^* MC	2.66 ± 0.13	5.74 ± 0.25
n_b^*	2.67 ± 0.19	5.67 ± 0.34
n_s^*	-0.07 ± 0.03	-0.11 ± 0.05
$\mathcal{B} \times 10^{-6}$	$-0.1^{+2.6}_{-1.7}$	$-0.2^{+2.7}_{-1.8}$
$\mathcal{B}^{90\%\ C.L.}$	5.2×10^{-6}	5.6×10^{-6}

- Main uncertainties
  - PDF shape, B tagging, **statistics.**

$B^0 \to l^+l^-$

- $B^0 \to ee,\ \mu\mu,\ e\mu$
- $B^0 \to e\tau,\ \mu\tau$

a) SM penguin
b) SM box*
c) LFV susy loop



*LFV modes also possible with neutrino oscillation

Previous BR Upper Limits

	$B^0 \to e^+e^-$	$B^0 \to \mu^+\mu^-$	$B^0 \to e^+\mu^-$	$B^0 \to e^+\tau^-$	$B^0 \to \mu^+\tau^-$
SM	1.9×10^{-15}	8.0×10^{-11}	0	0	0
BaBar	$<6.1 \times 10^{-8}$	$<8.3 \times 10^{-8}$	$<18 \times 10^{-8}$	-	-
CLEO/CDF	$<8.3 \times 10^{-7}$	$<1.8 \times 10^{-8}$	$<15 \times 10^{-7}$	$<1.3 \times 10^{-4}$	$<3.8 \times 10^{-5}$

$B^0 \rightarrow e^+e^-, \mu^+\mu^-, e^+\mu^-$

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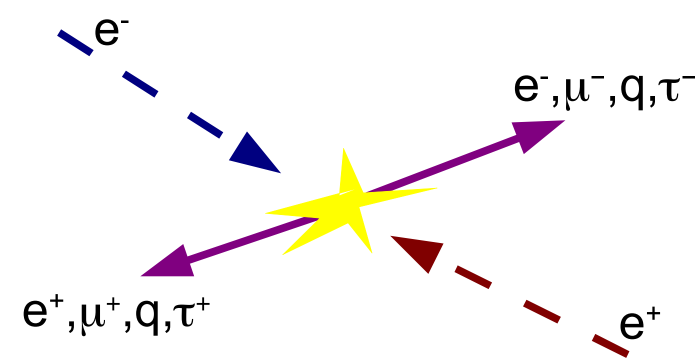
- B^0 candidate formed from two oppositely charged tracks with a common vertex
- Dominant background from $B^0 \rightarrow \pi^+\pi^-$ and $B^0 \rightarrow K^+\pi^-$
  - other BB backgrounds are negligible thanks to stringent Particle ID (PID) requirements



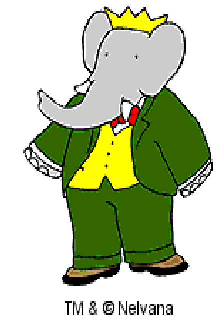
Other backgrounds:
- QED events: require at least 4 charged tracks per event
- non-resonant qq or $\tau^+\tau^-$ events: event shape cuts (sphericity, R_2, Fisher discr.)

normalized 2nd Fox-Wolfram moment

momentum weighted by 0th and 2nd Legendre moments $L_{0,2}(\cos\theta)$

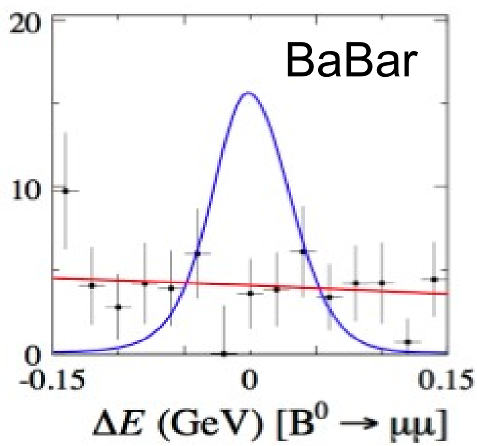
PID efficiencies:
- ~93% electrons (fakes ~0.1%)
- ~73% muons (fakes ~3%)

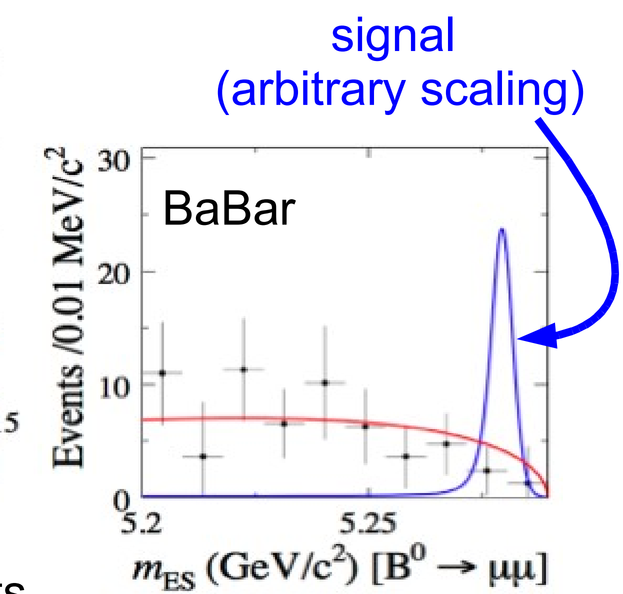
$B^0 \to e^+e^-, \mu^+\mu^-, e^+\mu^-$



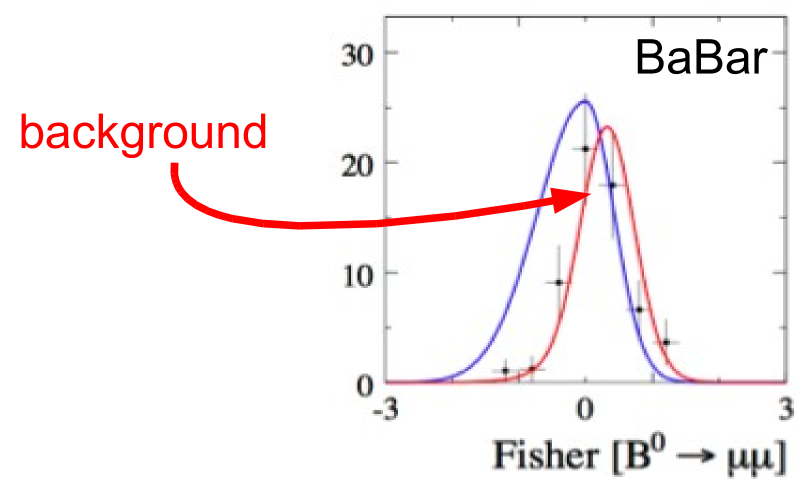
- ML fit on ΔE, m_{ES}, and Fisher discr.
  - background shapes derived from h^+h^- MC
  - float only the number of signal and background events

- Dominant uncertainty from Particle ID (~4%)

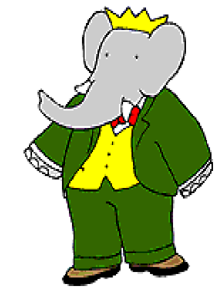




	$\epsilon_{ll'}$ (%)	$N_{ll'}$	UL(BF) $\times 10^{-8}$
$B^0 \to e^+e^-$	16.6 ± 0.3	0.6 ± 2.1	11.3
$B^0 \to \mu^+\mu^-$	15.7 ± 0.2	-4.9 ± 1.4	5.2
$B^0 \to e^\pm\mu^\mp$	17.1 ± 0.2	1.1 ± 1.8	9.2



$B^0 \rightarrow e^+\tau^-, \mu^+\tau^-$



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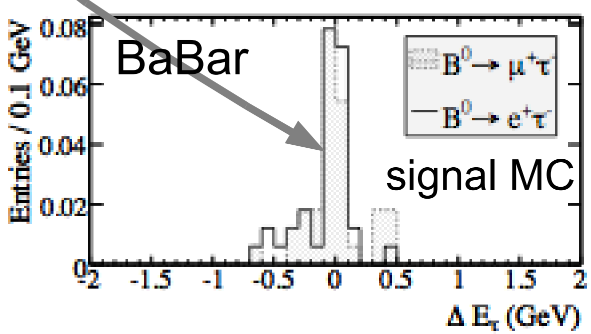
- Use hadronic B reconstruction
- Analysis very similar to $B^+ \rightarrow l^+\nu$, with additional tau reconstruction
  - if no second lepton ID, τ decay mode assigned by finding the smallest $|\Delta E_\tau|$

$$\Delta E_\tau = \sum_i E_{\pi_i} + p_\nu - 1.777\,\mathrm{GeV},$$

m_τ

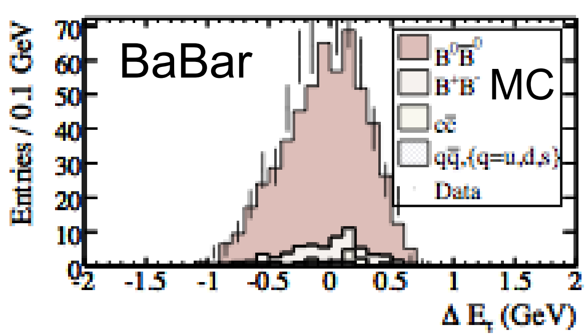
τ decay mode	Branching Fraction
$e^- \overline{\nu}_e \nu_\tau$	17.84±0.05
$\mu^- \overline{\nu}_\mu \nu_\tau$	17.36±0.05
$\pi^- \nu_\tau$	10.90±0.07
$\pi^- \pi^0 \nu_\tau$	25.50±0.10
$\pi^- \pi^0 \pi^0 \nu_\tau$	9.25±0.12
$\pi^- \pi^- \pi^+ \nu_\tau$	9.33±0.08

$\sum$ ~90%

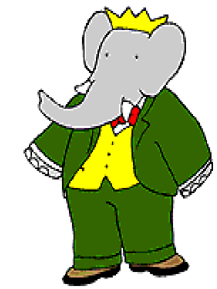


Other signal selection:

- m_{ES}, missing momentum, extra energy in the calorimeter, event shape variables.



$B^0 \to e^+\tau^-, \mu^+\tau^-$



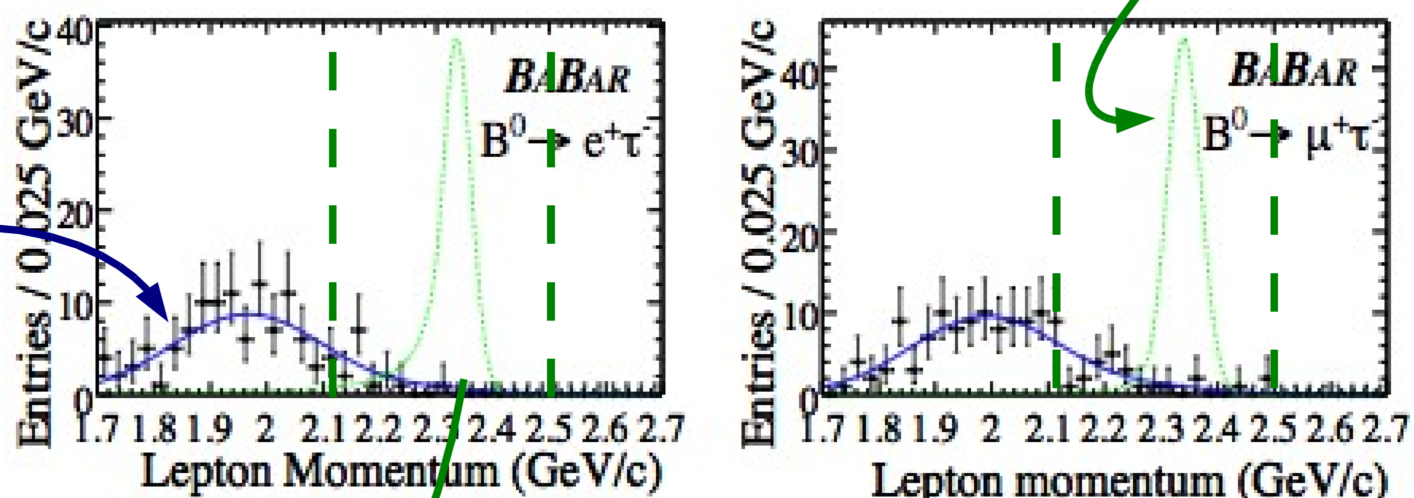
- Unbinned ML fit on lepton momentum in the signal B rest frame

$$\mathcal{L}(n_s, n_b) = \frac{e^{-(n_s+n_b)}}{N!} \prod_{i=1}^{N} [n_s f_s(i) + n_b f_b(i)],$$

Signal PDF (arbitrary scaling)

data points

Background and signal ML fit



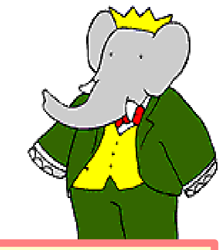
(number of events "under the peak")

higher background than for $B^+ \to l^+ \nu$

	$e^+\tau^-$	$\mu^+\tau^-$
$\epsilon_{tot} \times 10^5$	32 ± 2	27 ± 2
n_b^* MC	8.69 ± 0.27	12.14 ± 0.45
n_b^*	9.35 ± 0.35	13.03 ± 0.31
n_s^*	0.02 ± 0.01	0.01 ± 0.01
$\mathcal{B} \times 10^{-6}$	0^{+15}_{-10}	0^{+11}_{-7}
$\mathcal{B}^{90\%\ C.L.}$	2.8×10^{-5}	2.2×10^{-5}

- Main uncertainties
  - PDF shape, B tagging, **statistics.**

Summary



Hadronic and semileptonic B tags:

$$B(B^+ \to \tau^+ \nu) = (1.2 \pm 0.4(stat.) \pm 0.3(bkg.) \pm 0.2(syst.)) \times 10^{-4}$$

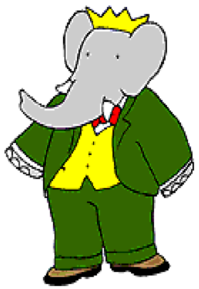
Leptonic B decays

	# of BB pairs	BaBar BR UL	Status
$B^+ \to \tau^+ \nu$	383 M		Published in PRD
$B^+ \to \mu^+ \nu$		5.6×10^{-6}	
$B^+ \to e^+ \nu$	378 M	5.2×10^{-6}	Accepted by PRD-RC
$B^0 \to \mu^+ \tau^-$		2.2×10^{-5}	
$B^0 \to e^+ \tau^-$		2.8×10^{-5}	
$B^0 \to \mu^+ \mu^-$		5.2×10^{-8}	
$B^0 \to e^+ e^-$	384 M	11.3×10^{-8}	Published in PRD
$B^0 \to e^+ \mu^-$		9.2×10^{-8}	

- No evidence of physics beyond the Standard Model.
- All of these analyses will be updated with the full BaBar data set, which is now available.

Extra Slides

Summary 2



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$$B(B^+\to\tau^+\nu)=(1.2\pm0.4(stat.)\pm0.3(bkg.)\pm0.2(syst.))\times10^{-4}$$

$$B(B^+\to\tau^+\nu)=(1.79^{+0.59}_{-0.49}(stat.)^{+0.46}_{-0.51}(syst.))\times10^{-4}$$

Leptonic B decays

	# of BB pairs	Prev. Best UL	BaBar BR UL	Status
$B^+\to\tau^+\nu$	383 M			Published in PRD
$B^+\to\mu^+\nu$		1.7×10^{-6}	5.6×10^{-6}	
$B^+\to e^+\nu$	378 M	9.8×10^{-7}	5.2×10^{-6}	Accepted by PRD-RC
$B^0\to\mu^+\tau^-$		3.8×10^{-5}	2.2×10^{-5}	
$B^0\to e^+\tau^-$		1.4×10^{-4}	2.8×10^{-5}	
$B^0\to\mu^+\mu^-$		1.8×10^{-8}	5.2×10^{-8}	
$B^0\to e^+e^-$	384 M	6.1×10^{-8}	11.3×10^{-8}	Published in PRD
$B^0\to e^+\mu^-$		18×10^{-8}	9.2×10^{-8}	

BaBar, Belle, CLEO, CDF

BaBar Detector

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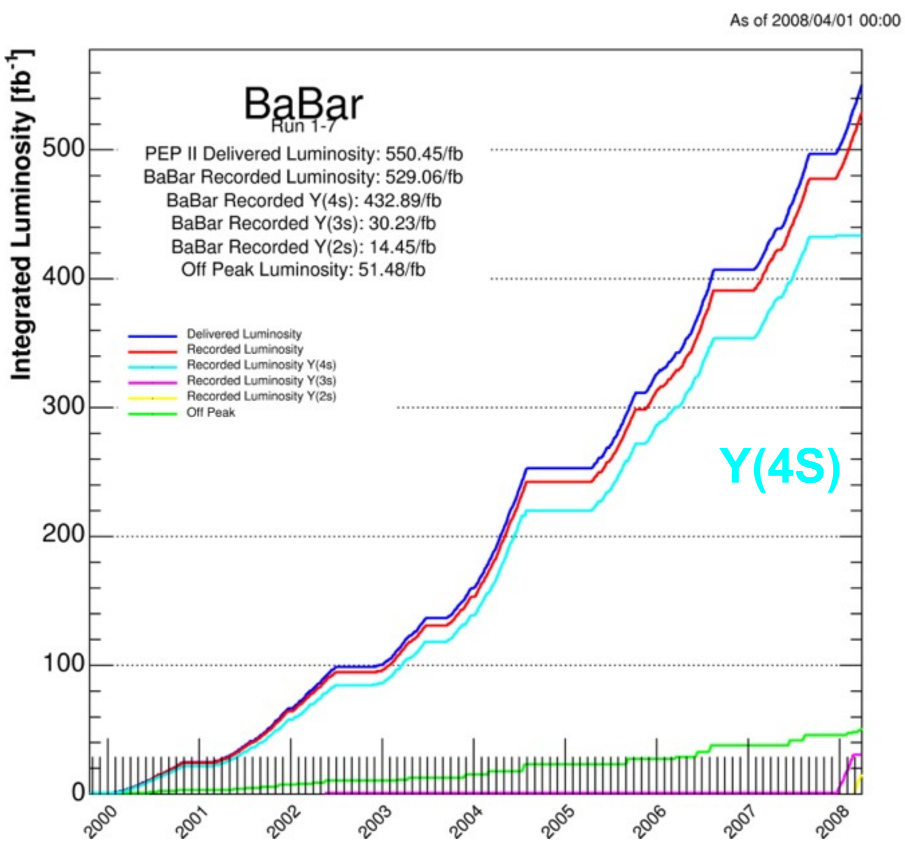
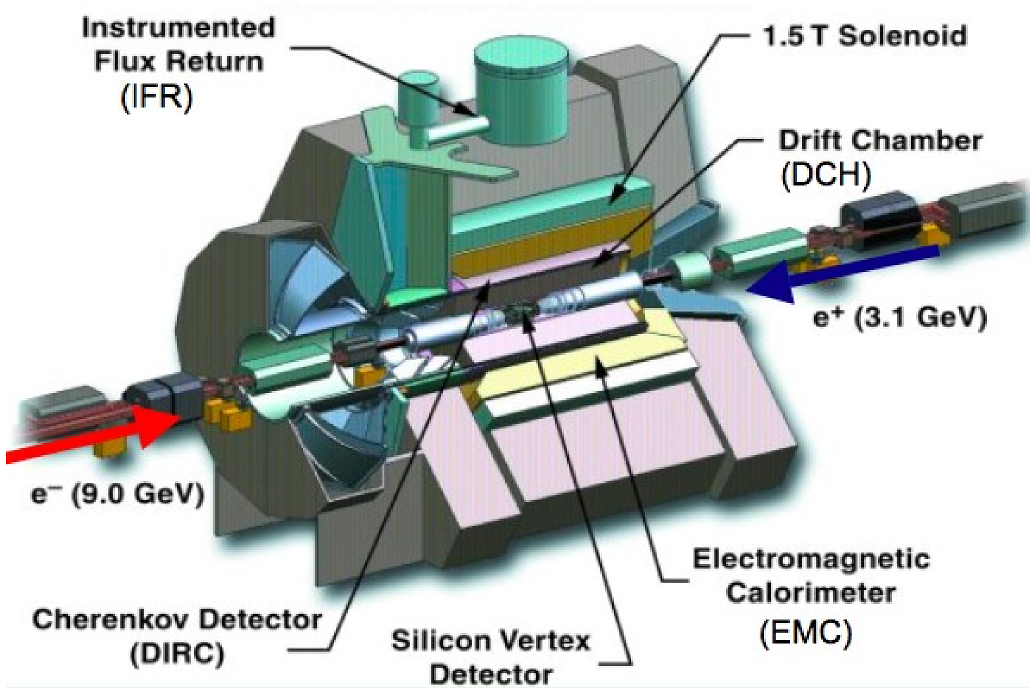
Asymmetric e$^-$ to e$^+$ collisions at PEP-II at the Y(4S) resonance

$$\sqrt{s} = 10.58\,GeV$$





The results presented today are based on data from runs 1-5, ~350M BB pairs.

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