Rare Leptonic B and $b \to s l^+ l^-$ Decays at B-factories

Jack L. Ritchie
University of Texas at Austin
(representing BaBar)

Recent results from BaBar and Belle

Topics

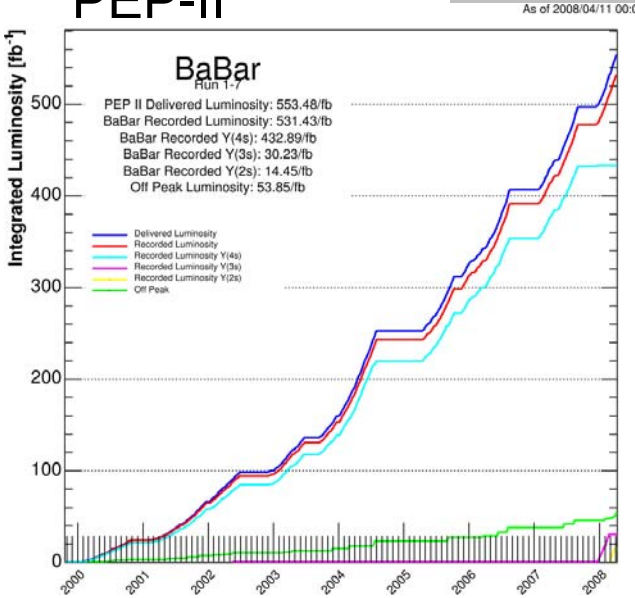
Flavor changing neutral currents

- $B \to K^{(*)} l^+ l^-$ - recent *BABAR*
- $B \to \pi l^+ l^-$ - recent Belle
- $B \to K^{(*)} \nu\bar{\nu}$ - recent *BABAR*
- $B^0 \to l^+ l^-$
- $B^{\pm} \to l^{\pm} \nu$

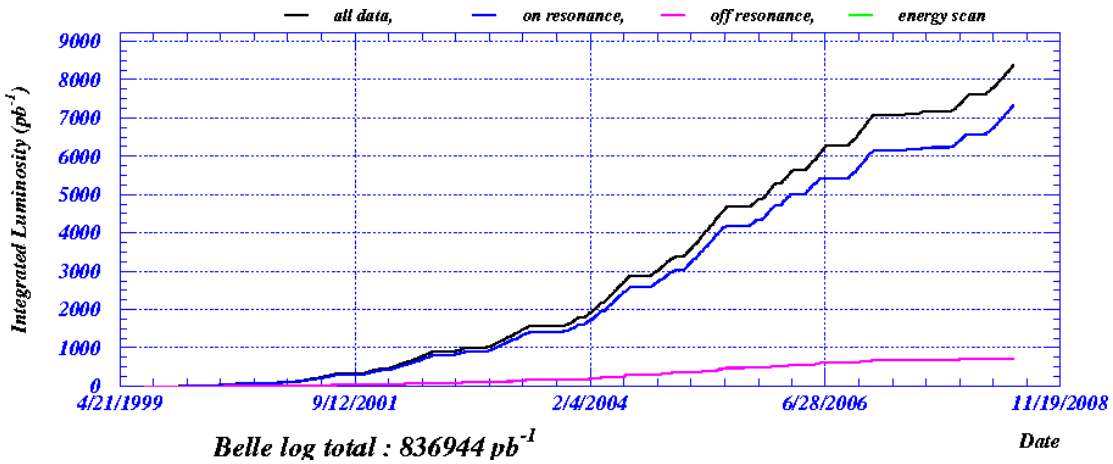
(where $l = \mu$ or e)

The B-factories

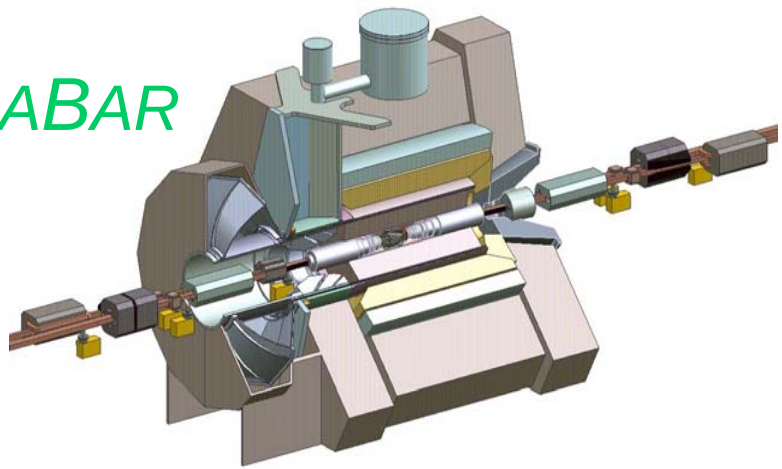
PEP-II



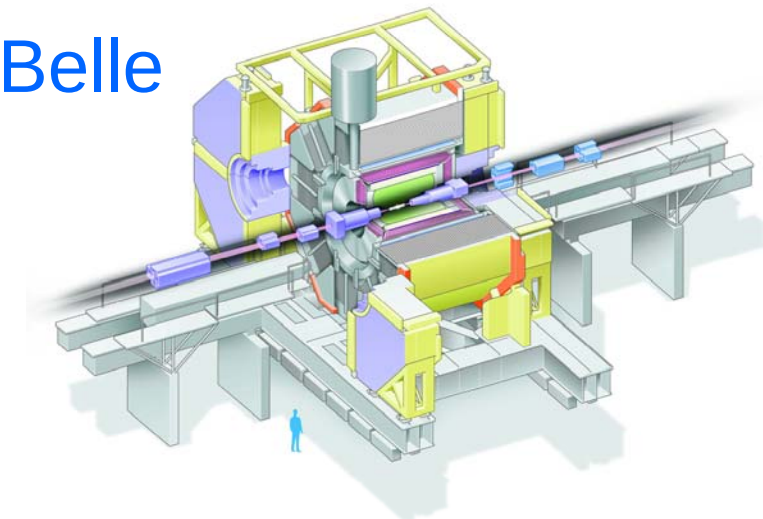
KEKB



BABAR

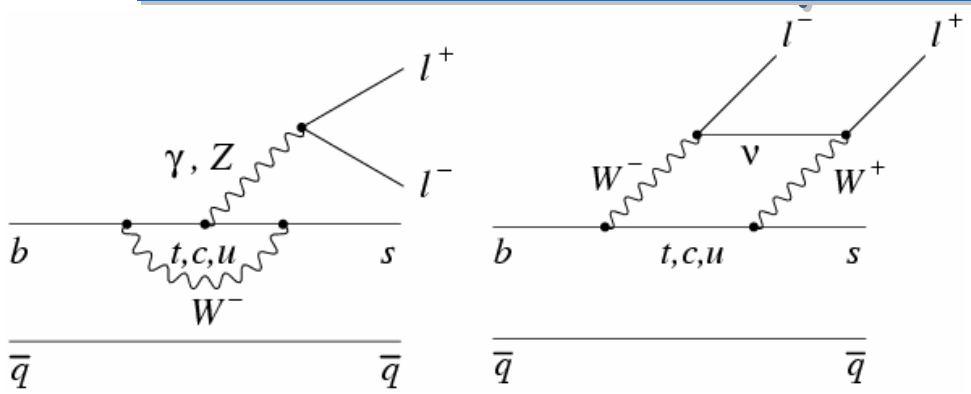


Belle



Enormous luminosities have led to major advances in the study of rare B decays.

$b \to s\, l^+ l^-$ Theory Framework



Short-distance physics appears in the Wilson coefficients.
C_7, C_9, C_{10} important for $b \to s\, l^+ l^-$

$$H_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} (V_{tb}V_{ts}^*) \sum_{i=1}^{10} C_i\, O_i$$

CKM factors

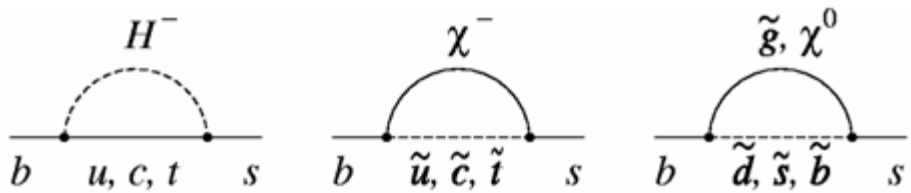
Wilson coefficients

operators

Magnitude of $|C_7| \approx 0.33$ known from $B \to X_S\gamma$, but sign not constrained.

$|C_9|^2 + |C_{10}|^2$ constrained by $b \to s\, l^+ l^-$ branching fraction, but not relative sign.

New physics may modify the C's or introduce additional terms (e.g., scalar, pseudoscalar)



$b \to s\, l^+ l^-$ Experimental Issues

- Fully inclusive measurements not possible
  - → Semi-inclusive analysis via sum of exclusive states ($K\, l^+ l^- + n\pi$)
  - → Exclusive $B \to K\, l^+ l^-$ and $B \to K^*\, l^+ l^-$ for most studies
  - → Ten sub-modes: $\left\{K^\pm, K^0_S, K^\pm\pi^\mp, K^\pm\pi^0, K^0_S\pi^\pm\right\} \times [e^\pm e^\mp, \mu^\pm \mu^\mp]$

- Interference from $B \to K^{(*)}\, J/\psi$ and $B \to K^{(*)}\, \psi(2S)$
  - → Remove with cuts on $l^+ l^-$ mass
  - → Provide important control samples (same topology, known BFs)

- Main backgrounds from B and D semileptonic decays
  - → Suppress using event shape, vertex info, missing energy (combined in neural nets, or other method)

- Background from $B \to D\pi\, (D \to K^{(*)}\pi)$ with $\pi \to \mu$ mis-ID
  - → Veto based on $K^{(*)}\pi$ mass close to D mass

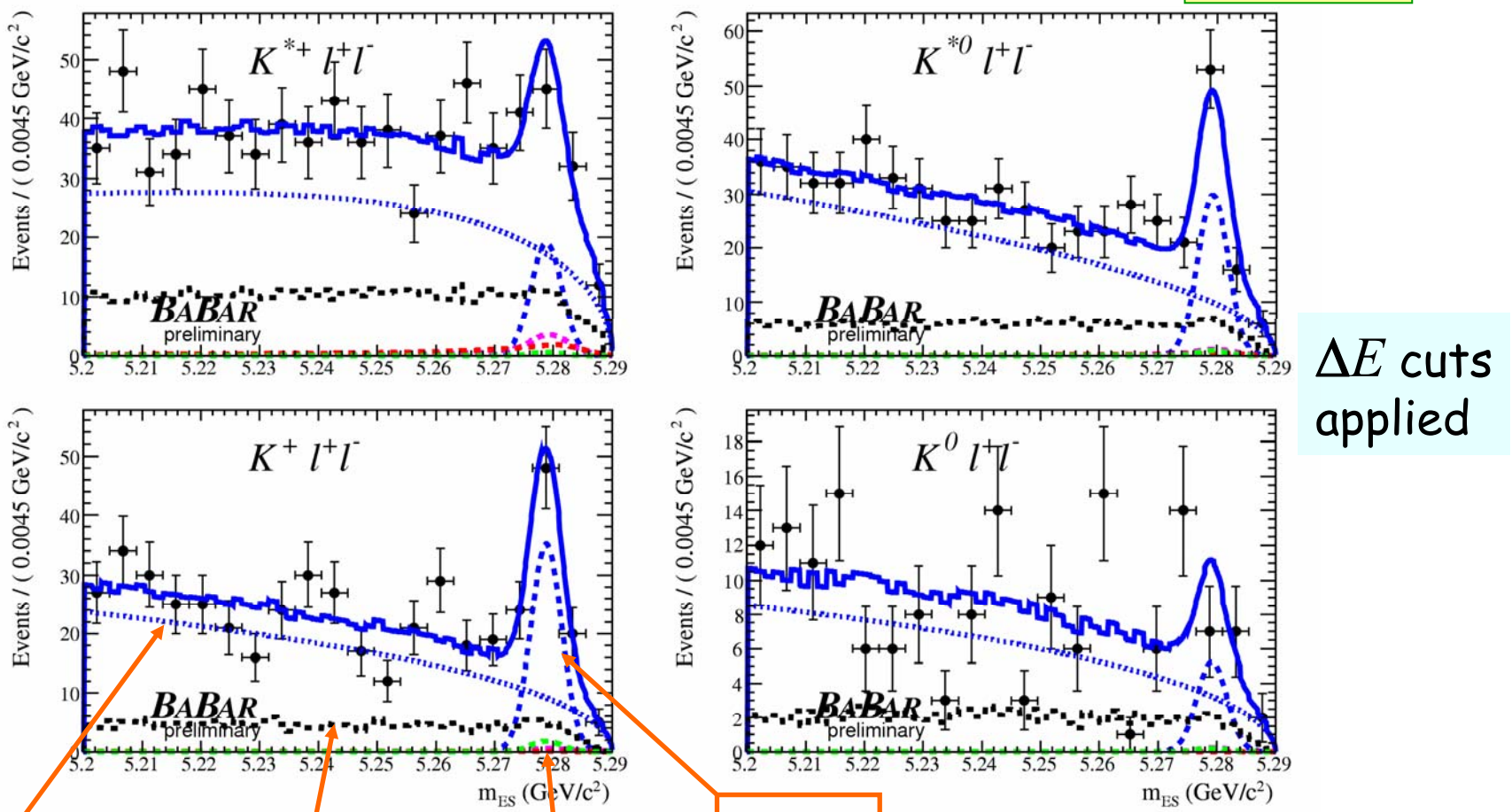
- Extract signal with maximum likelihood fit
  - → Fit versus M_{ES}, with mode-dependent ΔE cut

$$\Delta E = E^*_B - E^*_{\text{beam}}$$

$$M_{\text{ES}} = M_{\text{bc}} = \sqrt{E^{*2}_{\text{beam}} - p^{*2}_B}$$

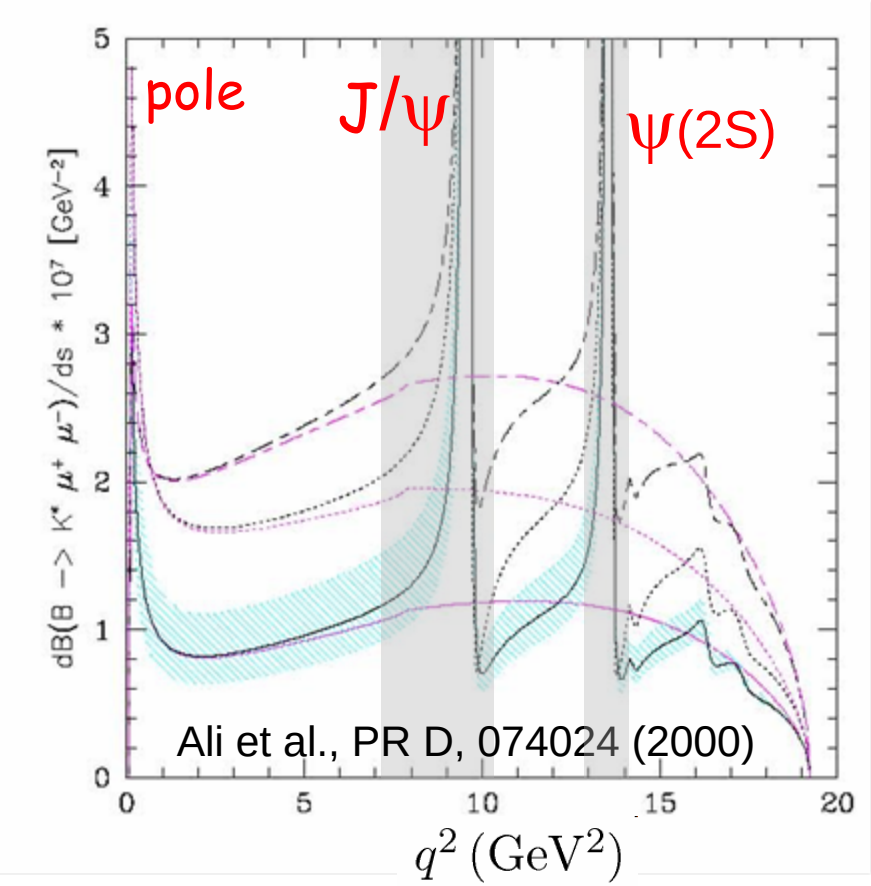
$B \to K^{(*)}\, l^+ l^-$ Signals

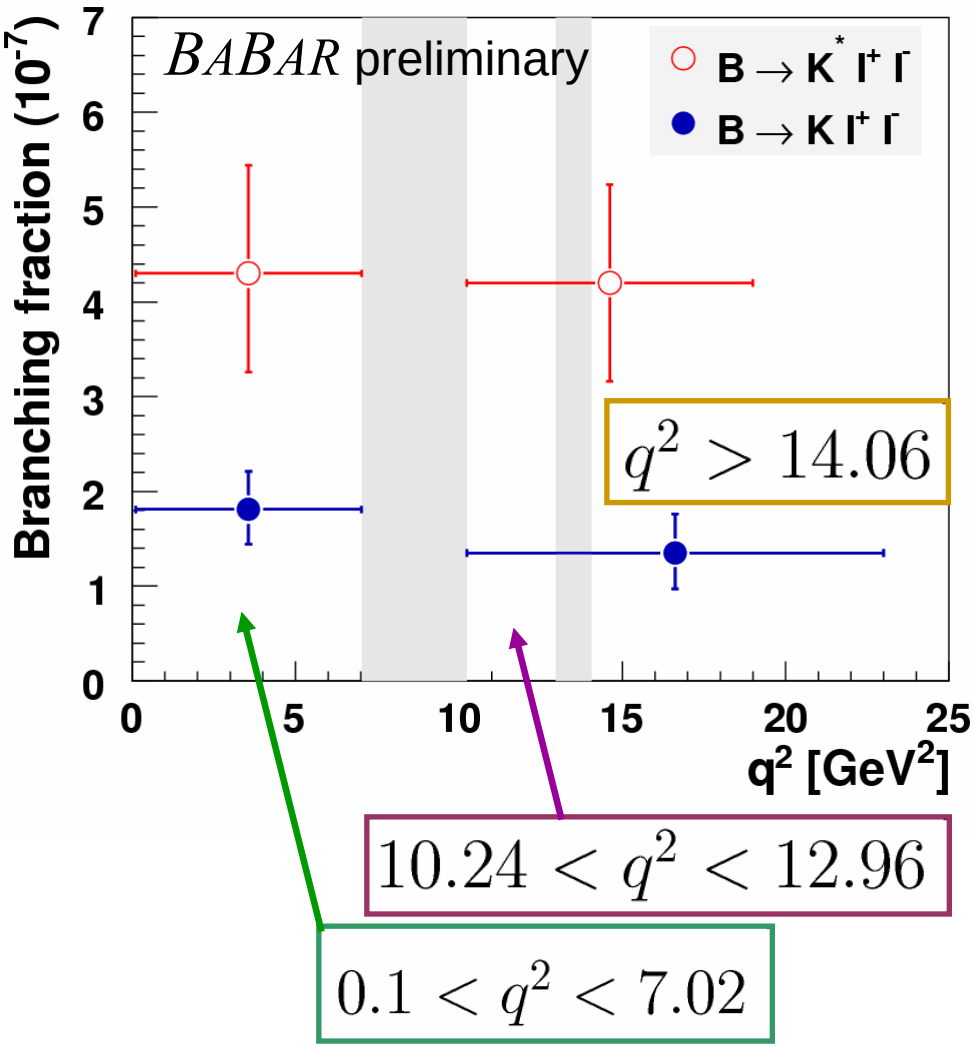
349 fb^{-1}



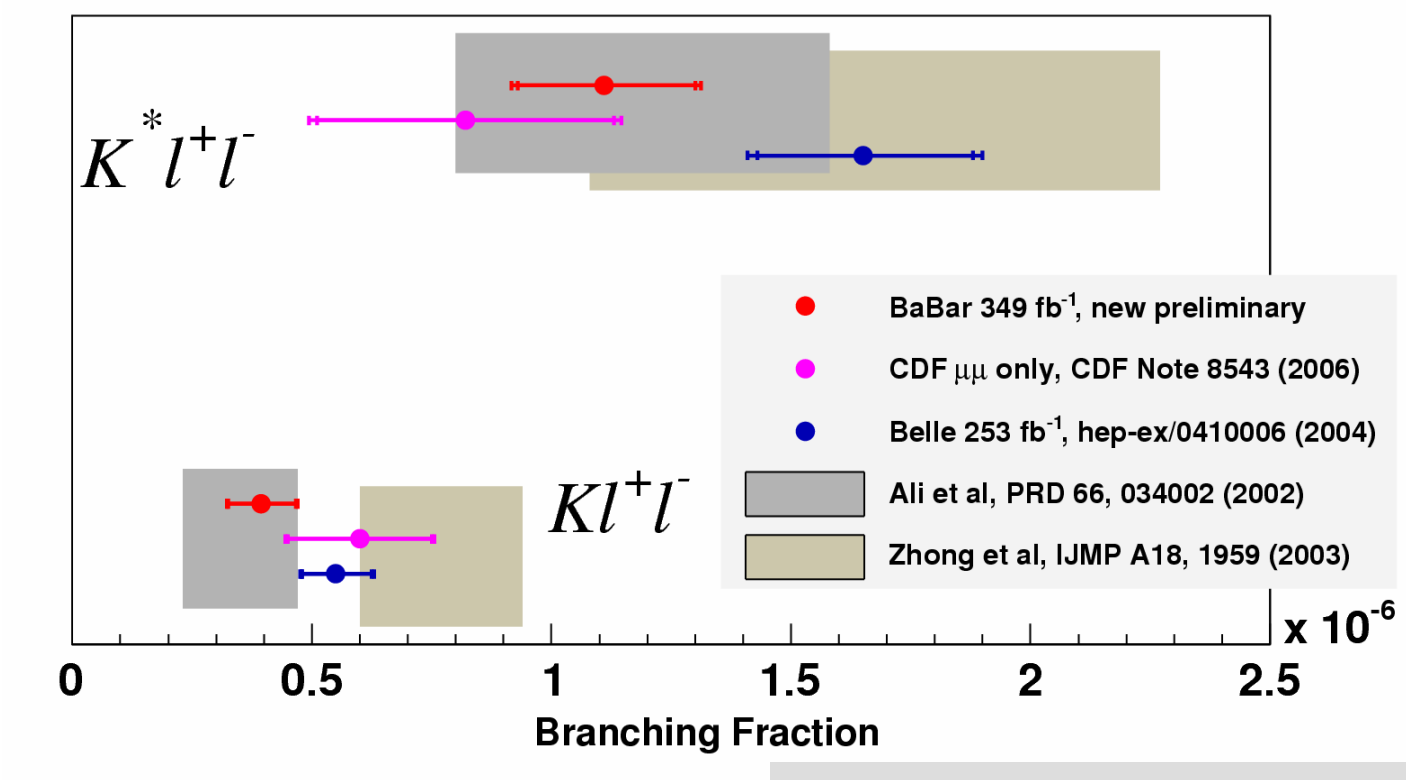
$B \to K^{(*)}\, l^+ l^-$ q^2 regions

$$q^2 = m^2_{\ell\ell}$$





$B \to K^{(*)} l^+ l^-$ Branching Fractions



new BaBar preliminary (349 fb^{-1})

$$\mathrm{B}(B \to K^* \ell^+ \ell^-) = (11.1^{+1.9}_{-1.8} \pm 0.7) \times 10^{-7}$$
$$\mathrm{B}(B \to K \ell^+ \ell^-) = (3.9 \pm 0.7 \pm 0.2) \times 10^{-7}$$

Consistent with theory.
Next level of SM tests from rate asymmetries and angular information (as functions of $q^2 = s = m_{ll}^2$)

$B \to K^{(*)} l^+ l^-$ Direct CP

$$A_{CP} \equiv \frac{\mathrm{B}(\overline{B} \to \overline{K}^{(*)}\ell^+\ell^-) - \mathrm{B}(B \to K^{(*)}\ell^+\ell^-)}{\mathrm{B}(\overline{B} \to \overline{K}^{(*)}\ell^+\ell^-) + \mathrm{B}(B \to K^{(*)}\ell^+\ell^-)}$$

:

Test for direct CP violation; less than 1% in Standard Model

BaBar preliminary (349 fb^{-1})

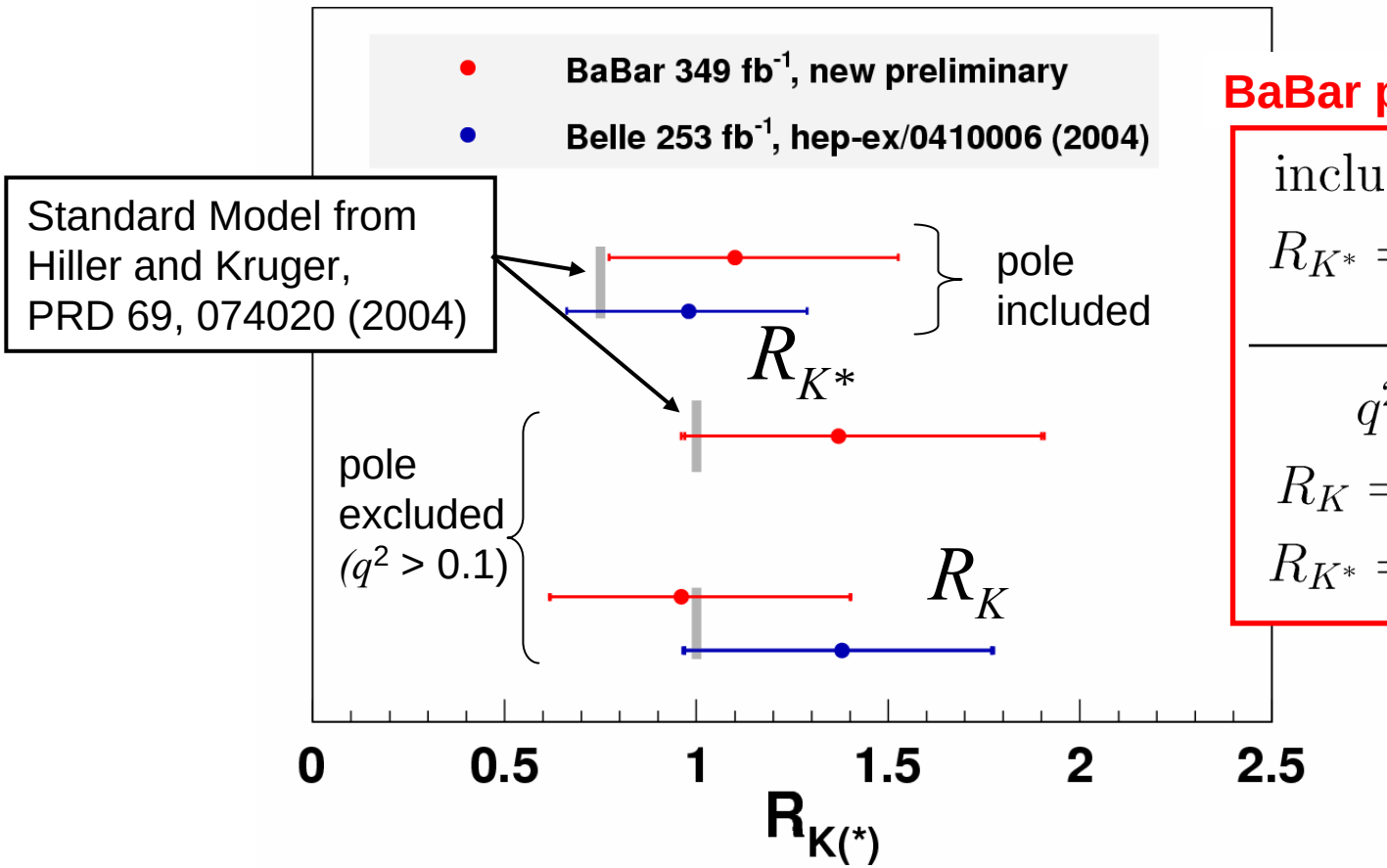
Mode	combined q^2	$0.1 < q^2 < 7.02$ (GeV^2/c^4)	$q^2 > 10.24$ (GeV^2/c^4)
$B^+ \to K^+\ell^+\ell^-$	$-0.18^{+0.18}_{-0.18} \pm 0.01$	$-0.18^{+0.19}_{-0.19} \pm 0.01$	$-0.09^{+0.36}_{-0.39} \pm 0.02$
$B^0 \to K^{*0}\ell^+\ell^-$	$0.02^{+0.20}_{-0.20} \pm 0.02$	$-0.23^{+0.38}_{-0.38} \pm 0.02$	$0.17^{+0.24}_{-0.24} \pm 0.02$
$B^+ \to K^{*+}\ell^+\ell^-$	$0.01^{+0.26}_{-0.24} \pm 0.02$	$0.10^{+0.25}_{-0.24} \pm 0.02$	$-0.18^{+0.45}_{-0.55} \pm 0.04$
$B \to K^*\ell^+\ell^-$	$0.01^{+0.16}_{-0.15} \pm 0.01$	$0.01^{+0.21}_{-0.20} \pm 0.01$	$0.09^{+0.21}_{-0.21} \pm 0.02$

All results consistent with zero.

Lepton Flavor Asymmetries

$$R_{K^{(*)}} \equiv \frac{\mathrm{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathrm{B}(B \to K^{(*)}e^+e^-)}$$

Enhanced in models with two-Higgs doublets, including SUSY with a neutral Higgs at large tan β



BaBar preliminary (349 fb^{-1})

including pole region

$$R_{K^*} = 1.10^{+0.42}_{-0.32} \pm 0.07$$

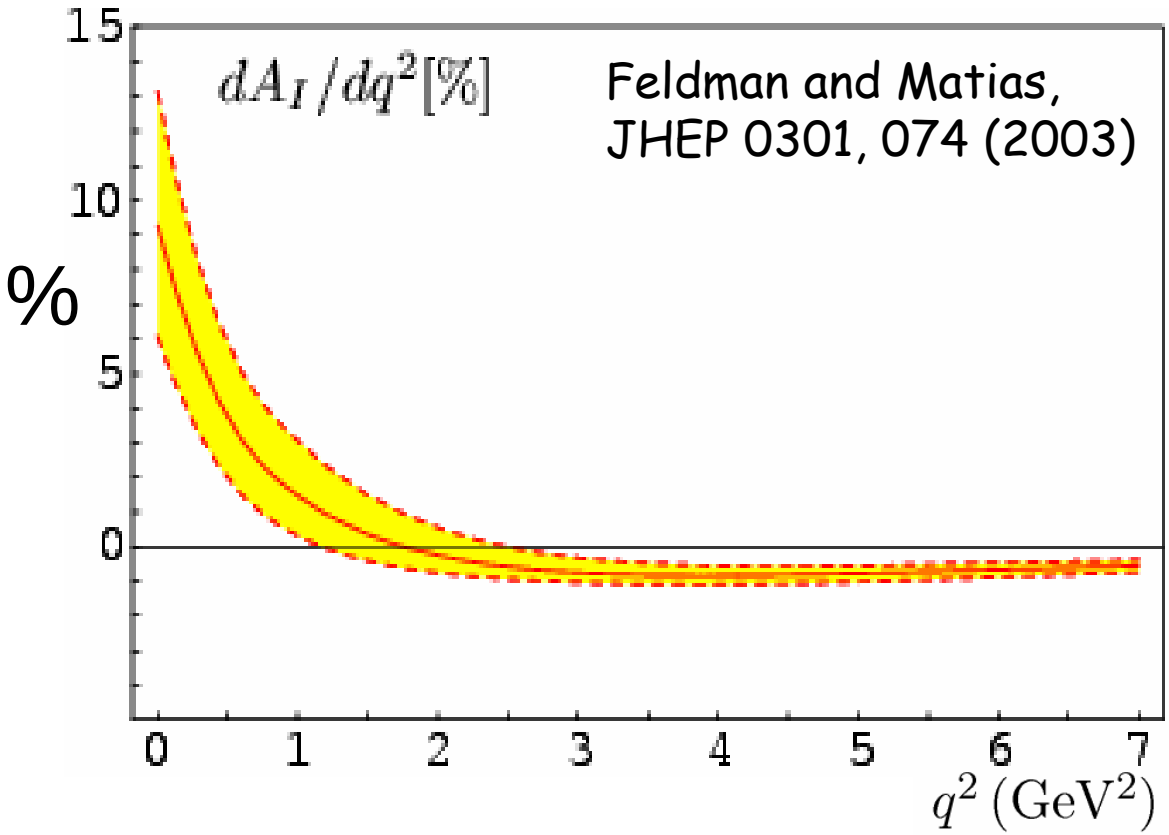
$$q^2 > 0.1\,\mathrm{GeV}^2$$

$$R_K = 0.96^{+0.44}_{-0.34} \pm 0.05$$

$$R_{K^*} = 1.37^{+0.53}_{-0.40} \pm 0.09$$

$B \to K^{(*)} l^+ l^-$ Isospin Asymmetry

$$A_I \equiv \frac{\mathrm{B}(B^0 \to K^{(*)0}\ell^+\ell^-) - (\frac{\tau_0}{\tau_+})\mathrm{B}(B^\pm \to K^{(*)\pm}\ell^+\ell^-)}{\mathrm{B}(B^0 \to K^{(*)0}\ell^+\ell^-) + (\frac{\tau_0}{\tau_+})\mathrm{B}(B^\pm \to K^{(*)\pm}\ell^+\ell^-)}$$



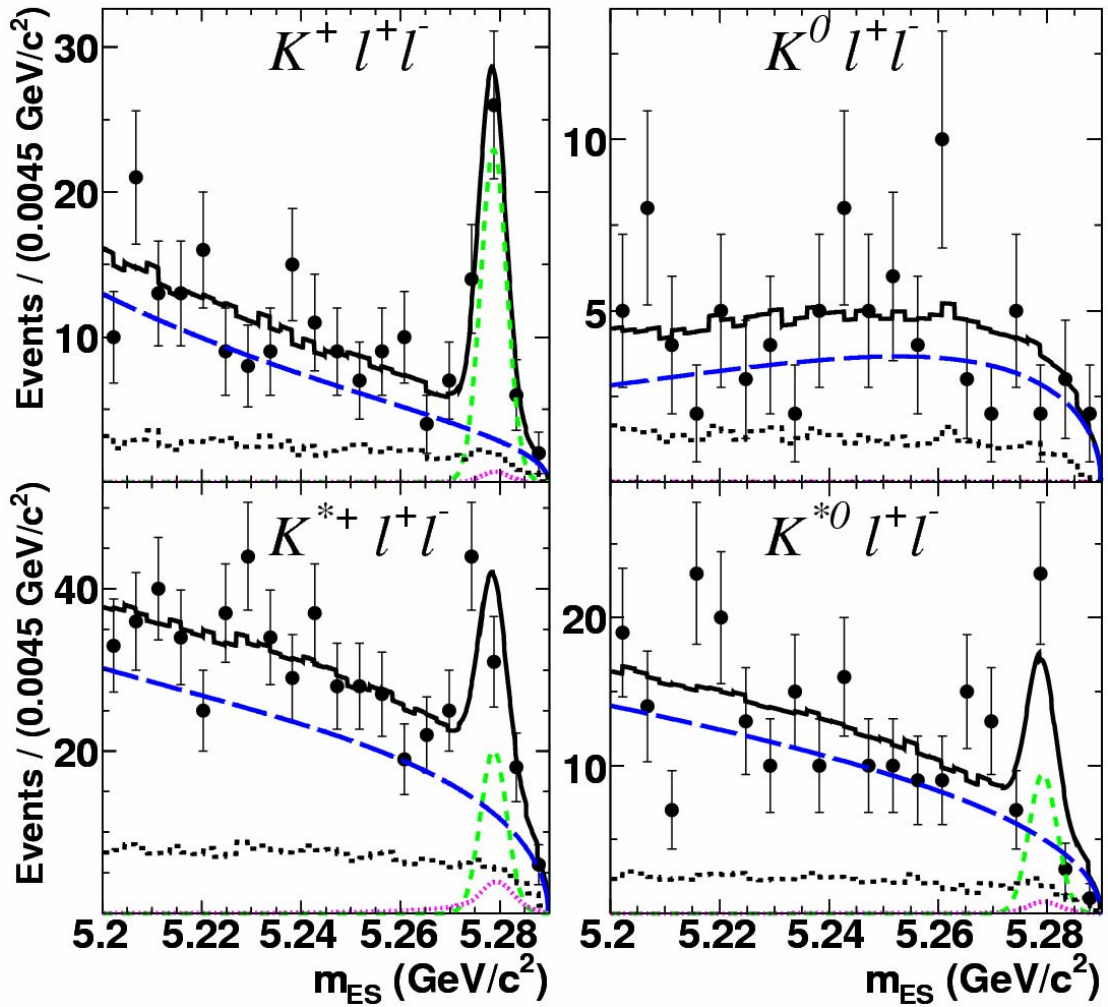
Small in Standard Model, with some variation at low- q^2.

Some sensitivity to the sign of C_7

B^0 vs $B^\pm \to K^{(*)} l^+ l^-$ Comparison

BABAR preliminary

$0.1 < q^2 < 7.02$



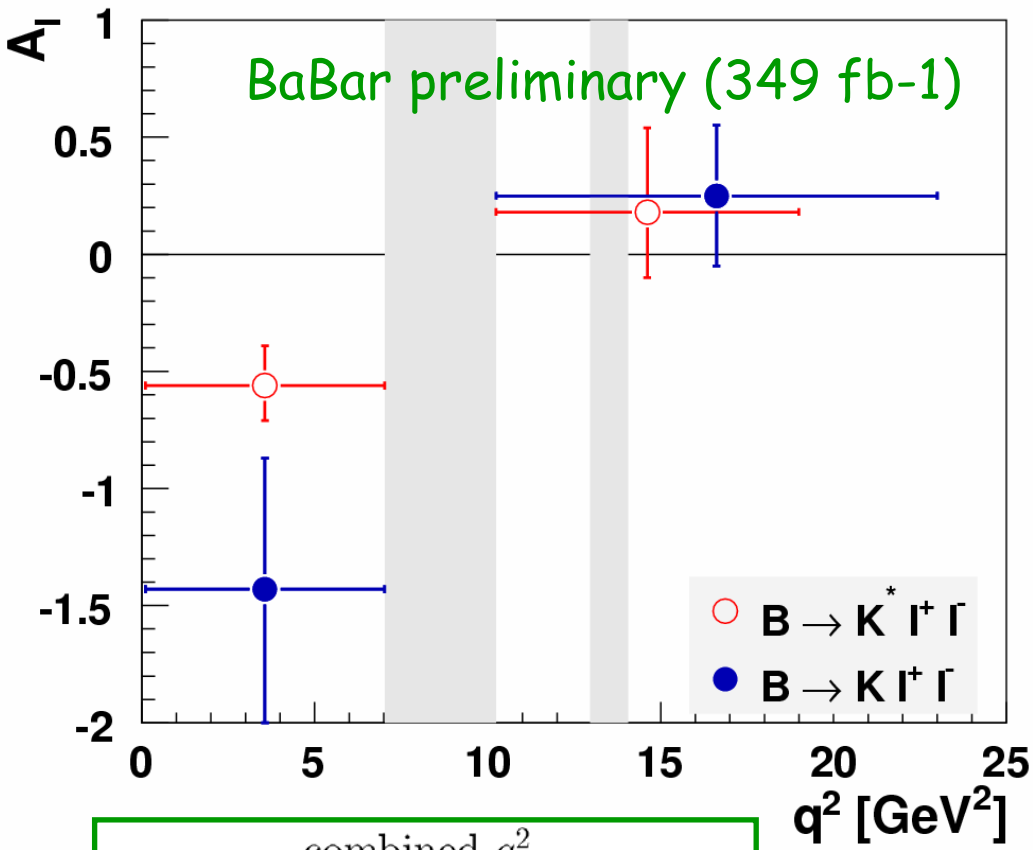
$$\mathrm{B}(B^\pm \to K^\pm \ell^+ \ell^-) = (2.5^{+0.52}_{-0.47} \pm 0.1) \times 10^{-7}$$

$$\mathrm{B}(B^0 \to K^0 \ell^+ \ell^-) < 0.9 \times 10^{-7} \ (90\% \ \mathrm{CL})$$

$$\mathrm{B}(B^0 \to K^{*0} \ell^+ \ell^-) = (2.6^{+1.1}_{-1.0} \pm 0.2) \times 10^{-7}$$

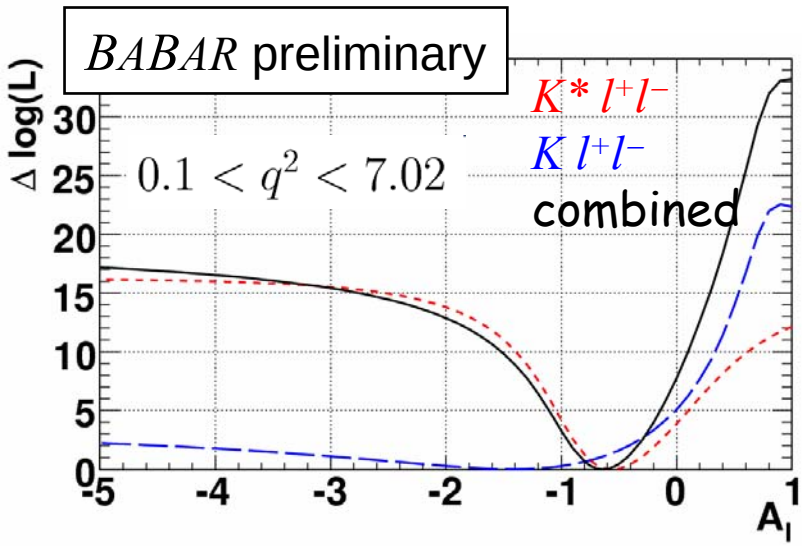
$$\mathrm{B}(B^\pm \to K^{*\pm} \ell^+ \ell^-) = (9.8^{+2.6}_{-2.4} \pm 0.6) \times 10^{-7}$$

$B \to K^{(*)} l^+ l^-$ Isospin Asymmetry



In low-q^2 bin,
A_I is significantly less than zero:

- 3.0 σ for $K\, l^+ l^-$
- 2.7 σ for $K^* l^+ l^-$
- 4.0 σ combined



combined q^2

$$A_I(K\ell^+\ell^-) = -0.37^{+0.27}_{-0.34} \pm 0.04$$

$$A_I(K^*\ell^+\ell^-) = -0.12^{+0.18}_{-0.16} \pm 0.04$$

$B \to K^* l^+ l^-$ Angular Analysis

Angular distributions as functions of q^2 are particularly sensitive to possible new physics.

K* longitudinal polarization F_L

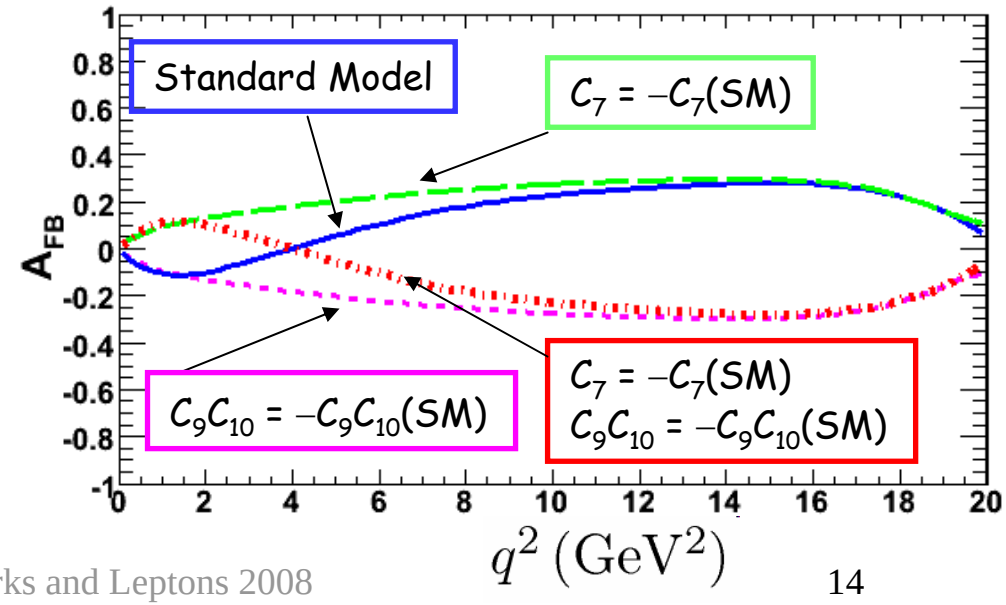
From distribution of the angle θ_K between the K and B in the K* rest frame

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_K} = \frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K)$$

Lepton forward-backward asymmetry A_{FB}

From distribution of the angle θ_ℓ between the l^+ and B in the $l^+ l^-$ rest frame

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\ell} = \frac{3}{4}F_L(1-\cos^2\theta_\ell) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\ell) + A_{FB}\cos\theta_\ell$$



$B \to K^* l^+ l^-$ Angular Analysis

Two q^2 bins:

low - $0.1 < q^2 < 6.25\ \mathrm{GeV}^2$

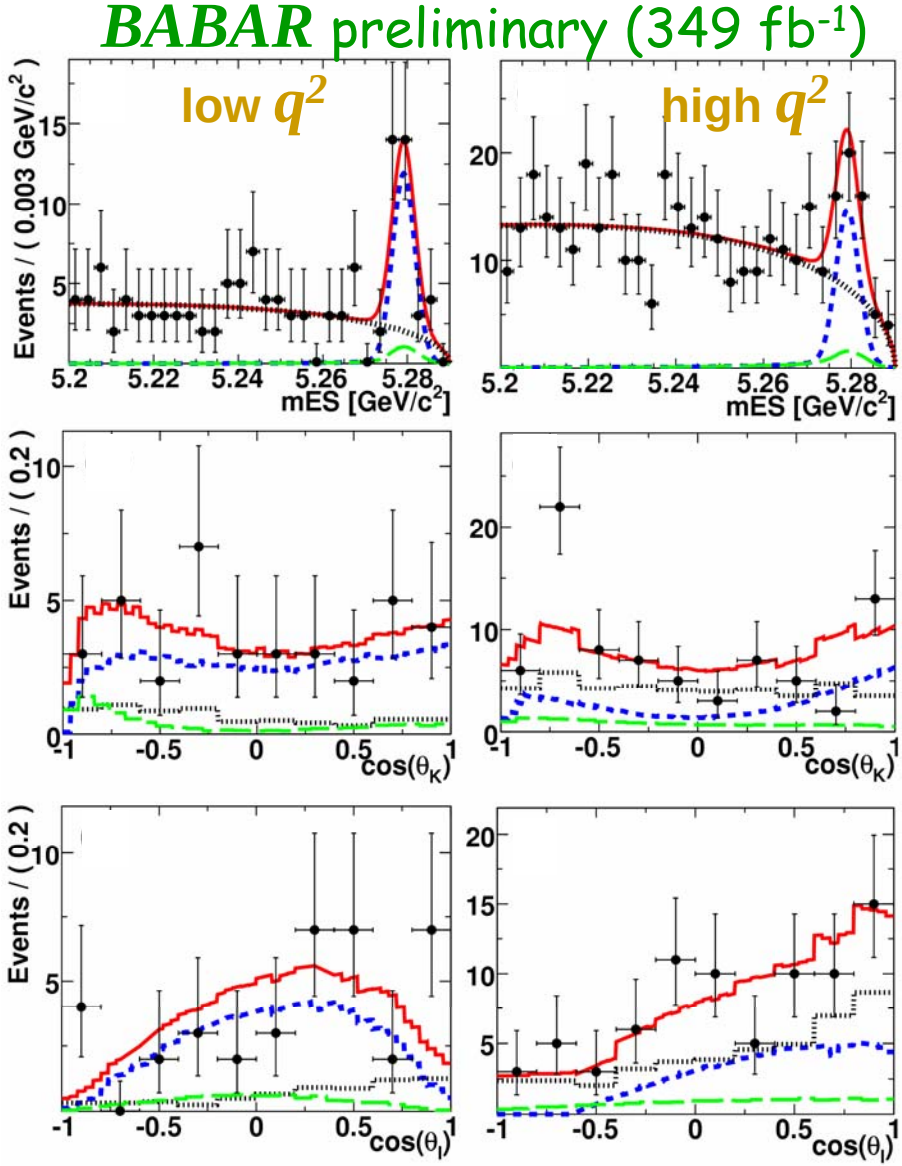
high - $q^2 > 10.24\ \mathrm{GeV}^2$

except $12.96 < q^2 < 14.06$

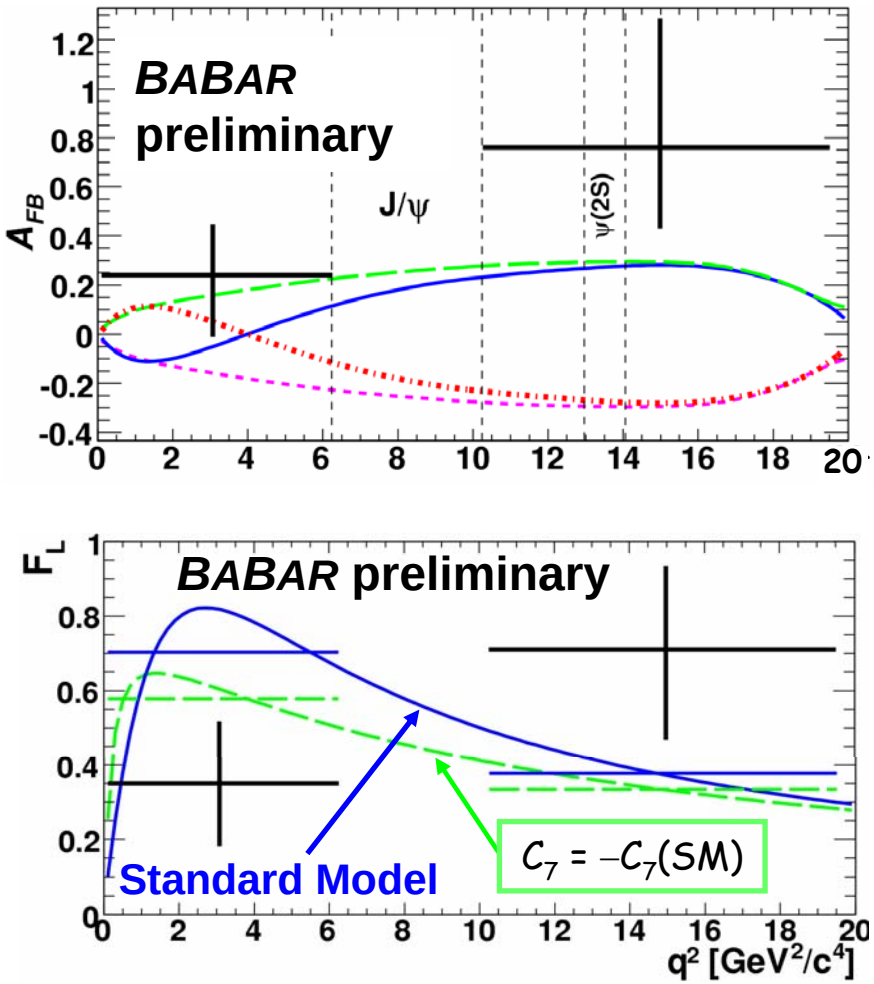
Three Step Fit Procedure:

1. Combine $K^* l^+ l^-$ modes, fit for yields.
2. Fix yields. For m_{ES}>5.27, fit $\cos(\theta_K)$ for F_L
3. Fix F_L, fit $\cos(\theta_\ell)$ for A_{FB}

Angular PDFs
- Signal weighted by detector eff from MC
- Combinatorial bkg from sidebands in data



$B \to K^* l^+ l^-$ Angular Analysis



Results submitted to PRL
arXiv: 0804.4412

$$A_{FB}^{\text{low}\,q^2} = 0.24^{+0.18}_{-0.23} \pm 0.05$$

$$A_{FB}^{\text{high}\,q^2} = 0.76^{+0.52}_{-0.32} \pm 0.07$$

$$F_L^{\text{low}\,q^2} = 0.35 \pm 0.16 \pm 0.04$$

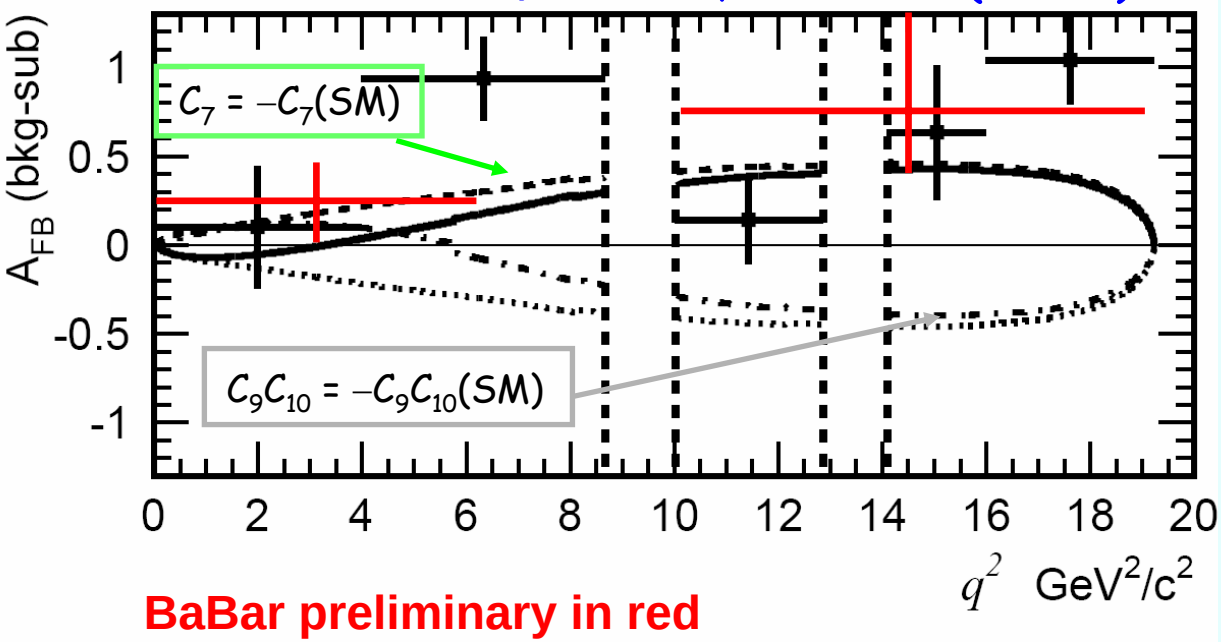
$$F_L^{\text{high}\,q^2} = 0.71^{+0.20}_{-0.22} \pm 0.04$$

Fit method tested on $B \to J/\psi\, K^*$ events, for which BFs and K^* polarization are known, and A_{FB}=0.
Also, A_{FB} consistent with zero for $B \to K\, l^+ l^-$

A_{FB} from Belle and BaBar

Belle approach differs from BaBar
- For events in the signal box, fits for ratios of Wilson coefficients using (q^2, $\cos\theta_\ell$) distribution
- F_L not determined, A_{FB} from projected fit result

Belle 357 fb^{-1}, PRL 96, 2511801 (2006)



BaBar preliminary in red

Belle and BaBar results consistent
- low-q^2 A_{FB} favors flipped-sign C_7
- high-q^2 A_{FB} strongly disfavors flipped-sign C_9C_{10}

BaBar F_L result also favors flipped-sign C_7

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

Same diagrams as $b \to s\, l^+ l^-$, suppressed by $|V_{td}/V_{ts}|^2$ (≈ 0.04)

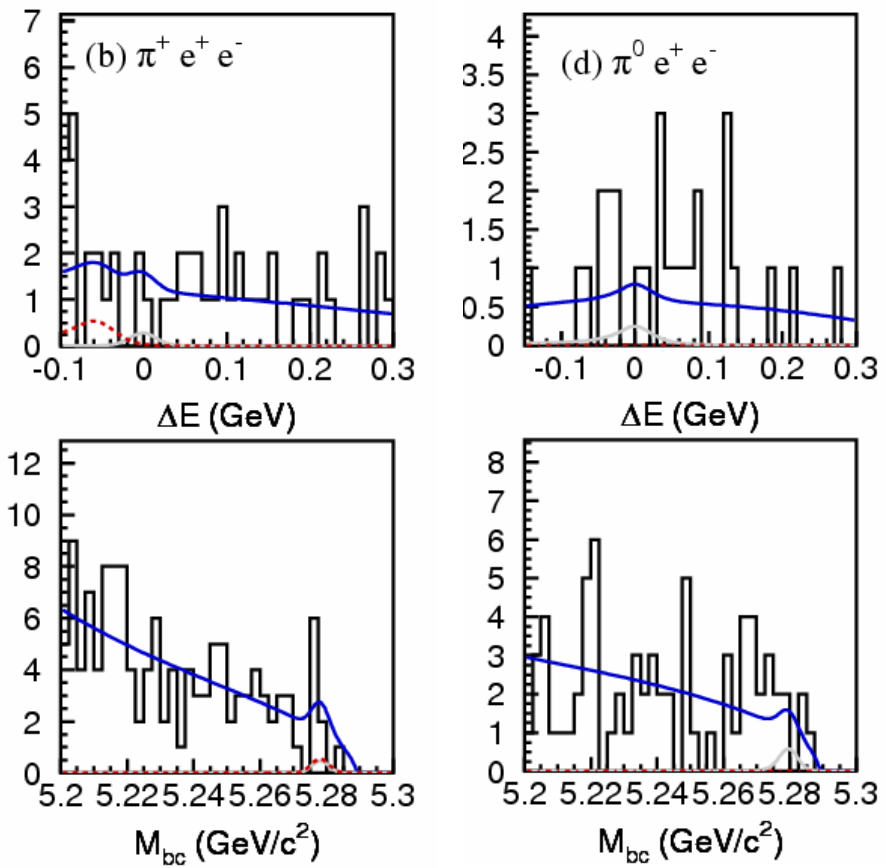
SM expectation:

$$\mathrm{B}(B^+ \to \pi^+ \ell^+ \ell^-) = 3.3 \times 10^{-8}$$
$$\mathrm{B}(B^0 \to \pi^0 \ell^+ \ell^-) = 1.7 \times 10^{-8}$$

Aliev and Savci, RPD 60, 104005 (1999)

New Belle result – submitted to PRD(RC), arXiv: 0804.3656

- from 657M $B\bar{B}$ pairs ($\approx$607 fb^{-1})
- continuum and B semi-leptonic bkgs rejected with likelihood ratios that include shape, vertex and other info
- Unbinned max likelihood fits in ΔE–m_{bc} for each sub-mode



$B \to \pi l^+ l^-$ Limits

90% Confidence Level Upper Limits

Mode	NEW Belle	BABAR
$B^+ \to \pi^+ \ell^+ \ell^-$	$< 4.9 \times 10^{-8}$	$< 12 \times 10^{-8}$
$B^0 \to \pi^0 \ell^+ \ell^-$	$< 15.4 \times 10^{-8}$	$< 12 \times 10^{-8}$
$B \to \pi \ell^+ \ell^-$	$< 6.2 \times 10^{-8}$	$< 9.1 \times 10^{-8}$

Belle - arXiv: 0804.3656

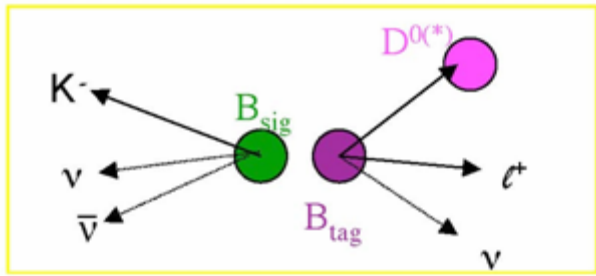
BaBar - PRL 99, 051801 (2007)

Standard Model

$$\mathrm{B}(B^+ \to \pi^+ \ell^+ \ell^-) = 3.3 \times 10^{-8}$$
$$\mathrm{B}(B^0 \to \pi^0 \ell^+ \ell^-) = 1.7 \times 10^{-8}$$

For the π^+ mode, the experimental limit is close to SM level.

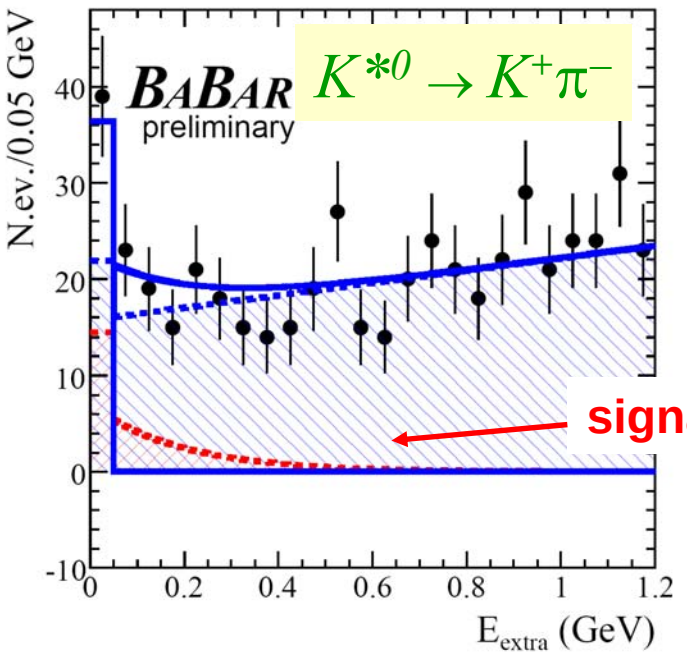
$B \to K^{(*)} \nu\bar{\nu}$

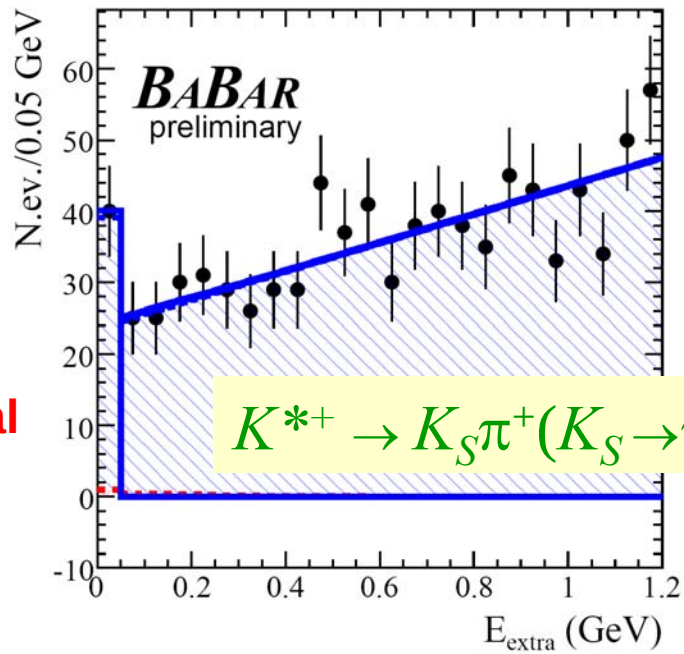


New BaBar $K^* \nu\bar{\nu}$ analysis: 413 fb^{-1}
- Reconstruct "tag" B via $B \to D^{(*)} l^{\pm} \nu$
- Reconstruct K^* ($K^+\pi^-$,$K_S\pi^+$,$K^+\pi^0$)
- Extract signal via fit of E_{extra}

$$E_{\text{extra}} = \sum_{i \in ROE} E_i$$

New BaBar $K\nu\bar{\nu}$ analysis: 319 fb^{-1}
- Reconstruct tag B via $B \to D^{(*)} l^{\pm} \nu$
- Use a Random Forest algorithm to separate signal and background





$B \to K^{(*)} \nu\bar{\nu}$ Limits

SM expectation: $\mathrm{B}(B \to K^* \nu\bar{\nu}) = 1.3 \times 10^{-5}$

$\mathrm{B}(B \to K \nu\bar{\nu}) = 0.4 \times 10^{-5}$

} Buchalla et al., RPD 63, 014015 (2000)

90% Confidence Level Upper Limits

Mode	Belle	BABAR
$B^+ \to K^{*+} \nu\bar{\nu}$	$< 14 \times 10^{-5}$	$< 9 \times 10^{-5}$
$B^0 \to K^{*0} \nu\bar{\nu}$	$< 34 \times 10^{-5}$	$< 21 \times 10^{-5}$
$B \to K^+ \nu\bar{\nu}$	$< 1.4 \times 10^{-5}$	$< 4.2 \times 10^{-5}$
$B \to K^0 \nu\bar{\nu}$	$< 16 \times 10^{-5}$	

new prelim

Belle 492 fb^{-1} - PRL 99, 221802 (2007)

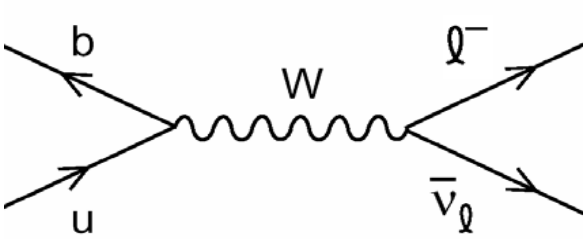
$B^0 \to l^+ l^-$ Status

Same diagrams as $b \to d\, l^+ l^-$ in Standard Model

- μ and e modes helicity suppressed
- possible large enhancement from non-SM scalar currents (e.g., MSSM); window for New Physics

mode	SM	90% CL limits (Belle , *BABAR*)
$\tau^+ \tau^-$	$\approx 10^{-7}$	$< 4.1 \times 10^{-3}$, PRL 96, 241802 (2006) 210 fb^{-1}
$\mu^+ \mu^-$	$\approx 10^{-10}$	$< 1.6 \times 10^{-7}$, PRD 68, 111101 (2003) 78 fb^{-1} $< 5.2 \times 10^{-8}$, PRD 77, 032007 (2008) 347 fb^{-1} $< 1.8 \times 10^{-8}$, CDF PRL 100, 101802 (2008)
$e^+ e^-$	$\approx 10^{-15}$	$< 1.9 \times 10^{-7}$, PRD 68, 111101 (2003) $< 1.1 \times 10^{-7}$, PRD 77, 032007 (2008)

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



Depends on f_B $|V_{ub}|$

- with $|V_{ub}|$ from $b \to u l \nu$, measures f_B

$$\mathcal{B}(B^+ \to \ell^+ \nu_\ell) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_{B^+}$$

Enhancements possible (e.g., MSSM charged Higgs)

mode	SM	90% CL limits (Belle , *BABAR*)
$\tau^+ \nu$	$\approx 10^{-4}$	See Matthew Barrett's talk
$\mu^+ \nu$	$\approx 5\times10^{-7}$	$< 1.6 \times 10^{-6}$, Phys.Lett. B 647, 67 (2007) 253 fb^{-1} $< 6.6 \times 10^{-6}$, PRL 92, 221803 (2004) 81 fb^{-1}
$e^+ \nu$	$\approx 10^{-11}$	$< 9.8 \times 10^{-7}$, Phys.Lett. B 647, 67 (2007)

Summary

- The B-factory experiments have made great progress in rare B-decay studies
- $b \to s\, l^+ l^-$ decays are experimentally accessible and provide a rich menu of observables
  - … but results so far are statistically limited
  - Asymmetry and angular measurements beginning to be important
- The significant isospin asymmetry observed at low-q^2 (by BaBar) is unexpected
- A_{FB} measurements from both Belle and BaBar seem to favor the "flipped-sign" C_7 scenario and strongly disfavor a flipped-sign $C_9 C_{10}$ scenario.
- Progress has been made toward SM-level in $B \to \pi\, l^+ l^-$ and $B \to K^{(*)} \nu \bar{\nu}$