Review of $b \to s l^+ l^-$ and $B^0 \to l^+ l^-$ Decays

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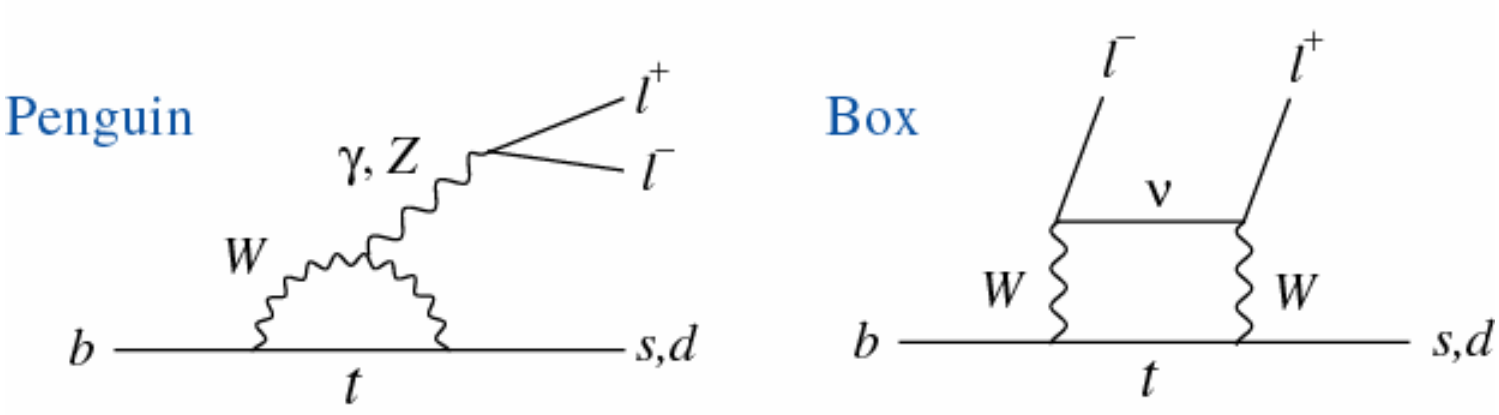
b → s l^+ l^- Decays

- b→s l^+ l^-
  - Flavor-Changing Neutral Current decay
  - induced through Penguin diagrams or Box diagrams at lowest order
  - sensitive to new physics (SUSY, charged Higgs)

- compared to b→s γ
  - Additional operators with q^2 dependence $(q^2 = M^2(\ell^+\ell^-))$
  - rare : suppressed by additional α_{em}



Wilson Coefficients

BF described in term of Wilson Coefficients C_7^{eff}, C_9^{eff} and C_{10}^{eff}

- $\Gamma(b \to s\gamma) = \dfrac{G_F^2 \alpha_{em} m_b^5 \left|V_{ts}^* V_{tb}\right|^2}{32\pi^3} \left|C_7^{\text{eff}}\right|^2 \qquad \left(+1/m_{b,c}\text{corrections}\right)$

C_7^{eff} can be measured with two fold ambiguity

$C_{7\ SM}^{eff} = -0.313$ (theory)

Good agreement !

$BF(B \to X_s\gamma)_{\text{exp}} = (3.40^{+0.42}_{-0.37}) \times 10^{-6}$ ⇒ $-0.37 < C_7^{eff} < -0.17$ or $0.21 < C_7^{eff} < 0.43$ (exp)

Lunghi hep-ph/0210379

- $\dfrac{d\Gamma(b \to s\ell^+\ell^-)}{d\hat{s}} = \left(\dfrac{\alpha_{em}}{4\pi}\right)^2 \dfrac{G_F^2 m_b^5 \left|V_{ts}^* V_{tb}\right|^2}{48\pi^3} (1-\hat{s})^2$

$$\times \left[(1+2\hat{s}) \left(\left|C_9^{\text{eff}}\right|^2 + \left|C_{10}^{\text{eff}}\right|^2 \right) + 4\left(1+\frac{2}{\hat{s}}\right) \left|C_7^{\text{eff}}\right|^2 + 12\,\text{Re}\left(C_7^{\text{eff}} C_9^{\text{eff}*}\right) \right]$$

C_7^{eff}, C_9^{eff} and C_{10}^{eff} can be measured from BF(b→s l^+ l^-) and A_{FB} (b→s l^+ l^-)

New Physics changes the Wilson Coefficients.

Predictions

- Branching Fraction
  - Exclusive decays (large theoretical uncertainty, typically ~30%)

$$BF(B \to K\ell^+\ell^-) = (0.3 \sim 0.6)\times 10^{-6}$$

$$BF(B \to K^*\ell^+\ell^-) = (1.1 \sim 2.1)\times 10^{-6}$$

  - Inclusive decays (theoretically clean , typically ~15%)

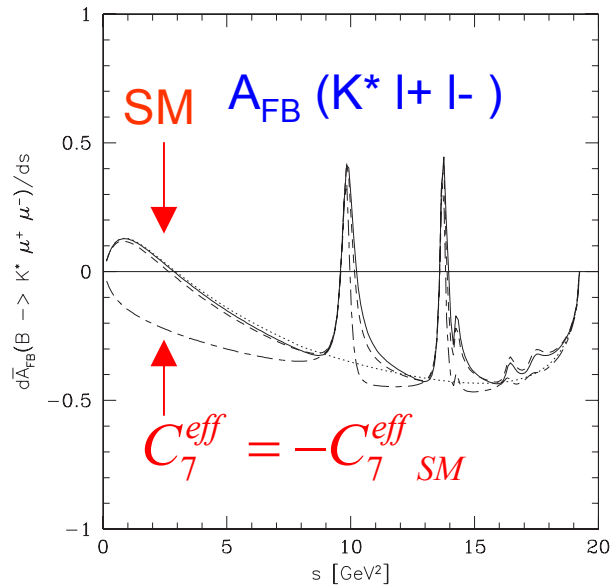
$$BF(b \to s\ell^+\ell^-) = (3.5 \sim 7.9)\times 10^{-6}$$

- Forward-Backward Asymmetry
  - B → K $l^+ l^-$

    No A_{FB}

  - B → K* $l^+ l^-$, b → s $l^+ l^-$

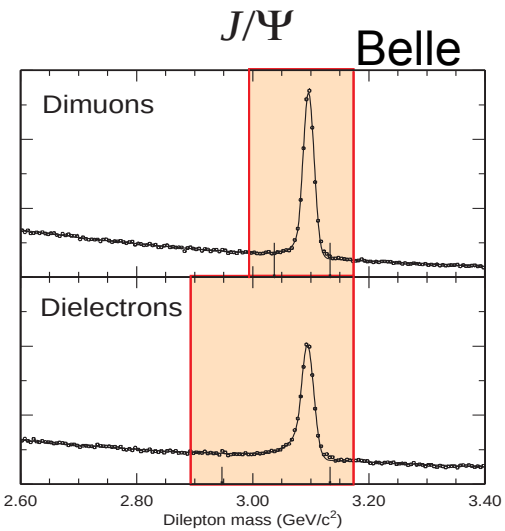
    Large !
    theoritically clean !!
    New physics modify the shape



Ali et al. Phys.Rev. D61 (2000) 074024

$B \rightarrow K^{(*)} l^+ l^-$ Analysis

- Tight lepton ID
- J/ψ and ψ' veto

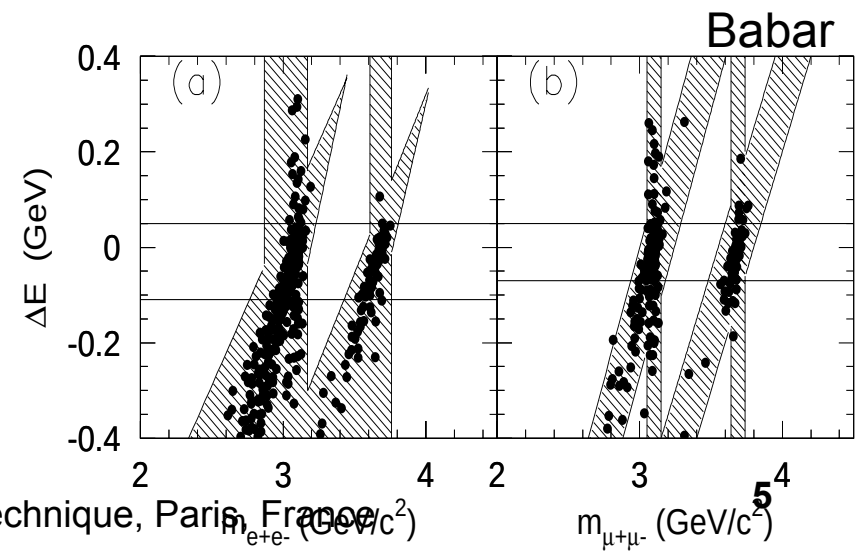


$e^+ e^-$ B factories (Belle, Babar, CLEO)

- continuum suppressed by event shape
- BB background suppressed by E_{miss}, $\cos\theta_B$
- Signal is selected from ΔE and M_{bc}

CDF

- background suppresssion
  - track isolation
  - impact parameter
  - vertex quality
- Signal is selected from M_B



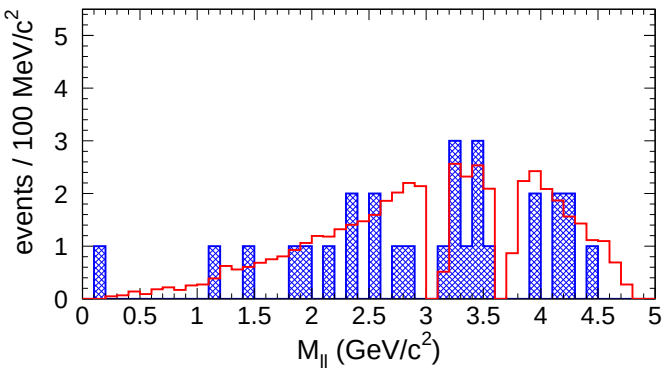
B → K(*) l+ l− (Belle)

Belle 60 fb^{-1}
ICHEP2002 preliminary
(First observed with 29 fb^{-1})

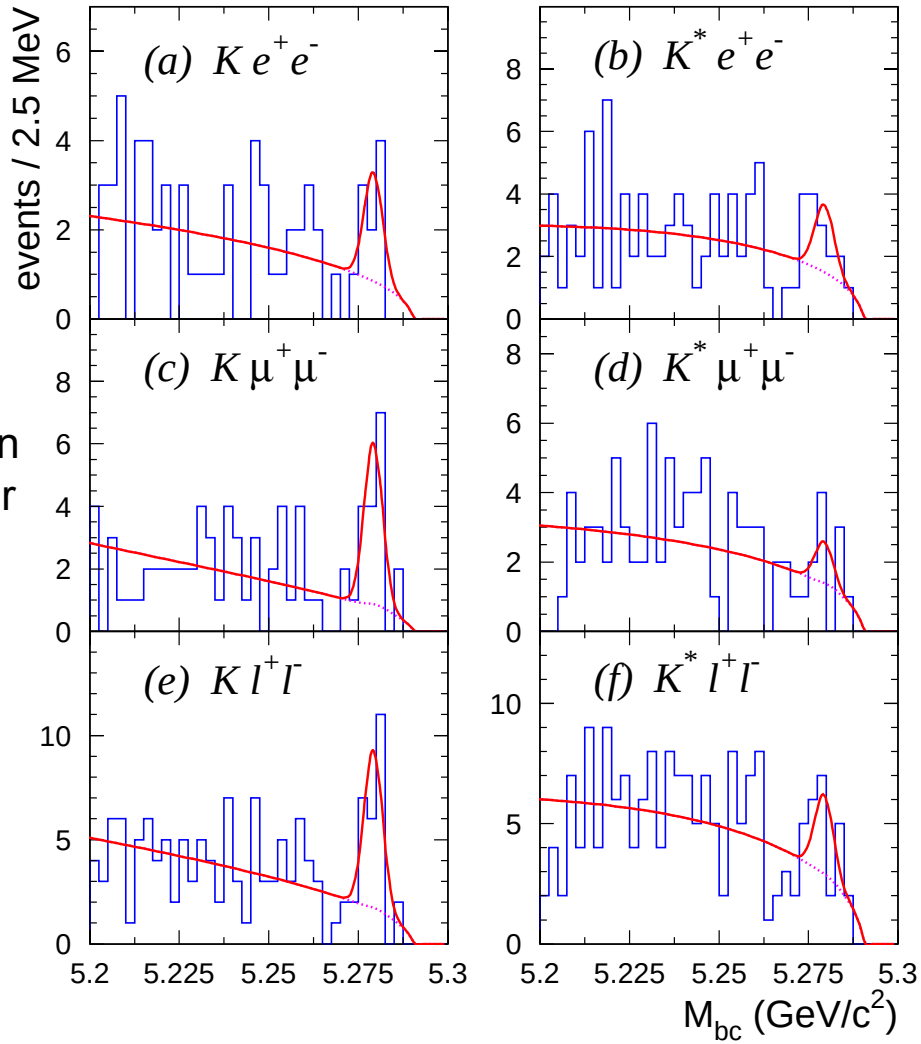
- K l+ l- is seen

  $19.0\,^{+5.5\ +1.0}_{-4.8\ -1.2}$ events

  dilepton invariant mass distribution is consistent with prediction, so far



- K* l+ l- is not clear



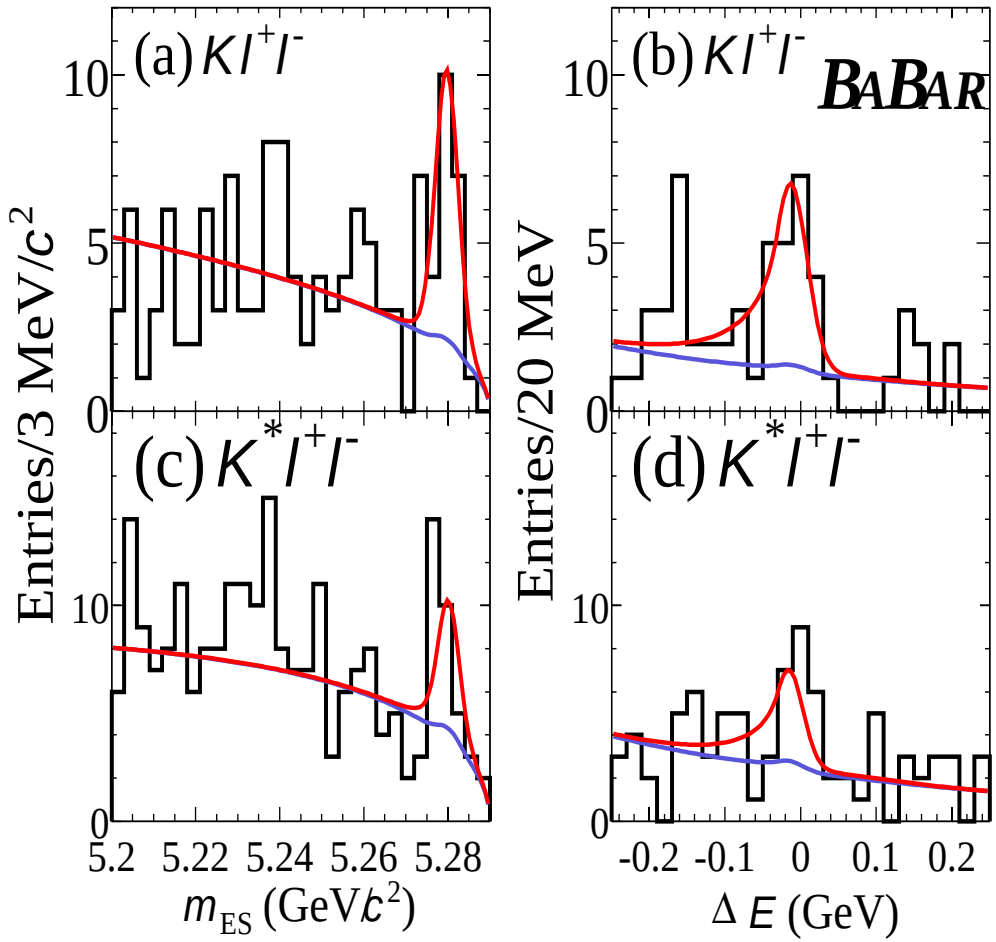
B → $K^{(*)}$ l^+ l^- (Babar)

Babar 78 fb^{-1}

ICHEP2002 preliminary

- K l^+ l^- is clear
- Excess in K* l^+ l^-

  but not significant (2.8σ)



BF of B → $K^{(*)}$ l^+ l^-

- B → K l l is established.
  - experimental error is already comparable to theoretical error.
- B → K* l l
  - No significant signals yet

BF or UL (10^{-6})	K l^+ l^-	K* l^+ l^-
Belle (60 fb^{-1}) Prelim.	$0.58\ ^{+0.17}_{-0.15} \pm 0.06$	< 1.4 (ave. of ee and $\mu\mu$)
Babar (78 fb^{-1}) Prelim.	$0.78\ ^{+0.24}_{-0.20}\ ^{+0.11}_{-0.18}$.	< 3.0 (scaled to ee)
CLEO (9 fb^{-1})	< 1.7	< 3.3
CDF (88 pb^{-1})	< 5.2	< 4.0

$B \rightarrow X_S l^+ l^-$ Analysis

Belle and CLEO study this decay mode.

Belle

reconstructed from dilepton, 1 kaon and 0 to 4 pions (at most 1 π^0).

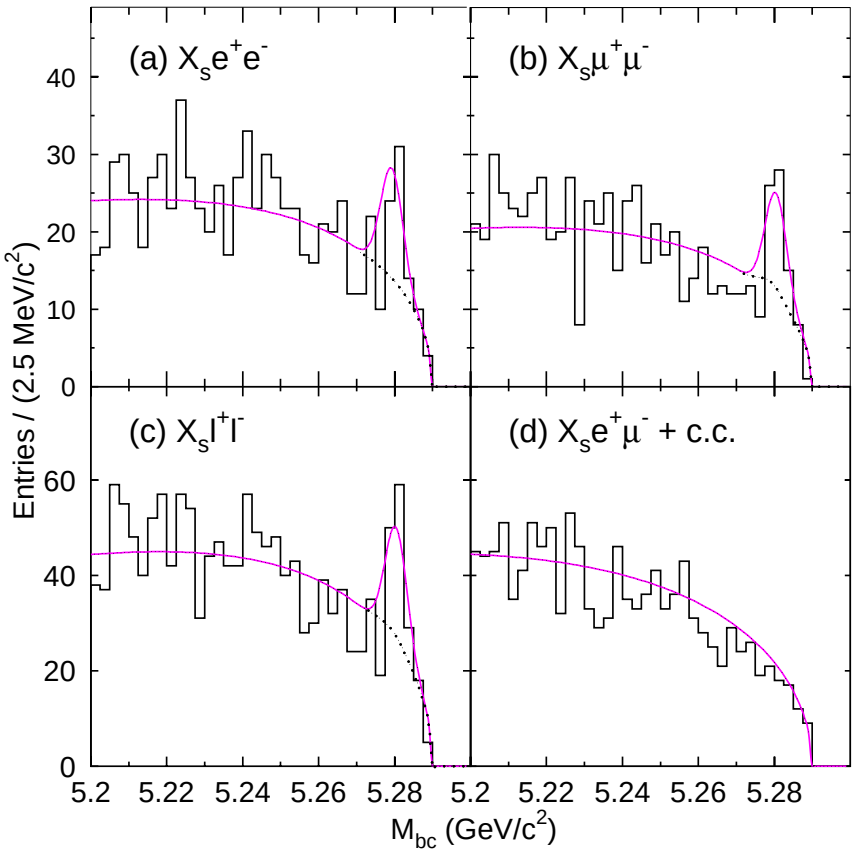
Inclusive analysis is basically same as exclusive one.

- Tight lepton ID
- Tight J/ψ and ψ' veto
- converted γ and π^0 Dalitz decay veto $M_{ll} > 0.2$ GeV/c^2
- continuum suppressed by event shape
- BB background suppressed by E_{miss}, M_{miss}
- Best candidate selected from ΔE, $\cos\theta_B$
- $M_{Xs} < 2.1$ GeV/c^2
- signal yield determined by fit to M_{bc}

$B \rightarrow X_S\, l^+\, l^-$ Results (Belle)

- Published 60 fb^{-1}
- signal is seen in both electron and muon mode
- No signal event is seed in LFV $B \rightarrow X_S\, e\, \mu$ mode.

	yield	signif
$X_S\, e\, e$	$25.5 \pm 11.2\,^{+4.8}_{-3.8}$.	3.4
$X_S\, \mu\, \mu$	$37.3 \pm 9.7\,^{+7.2}_{-3.8}$.	4.7
$X_S\, e\, \mu$	$60.1 \pm 13.9\,^{+8.6}_{-5.4}$.	5.4

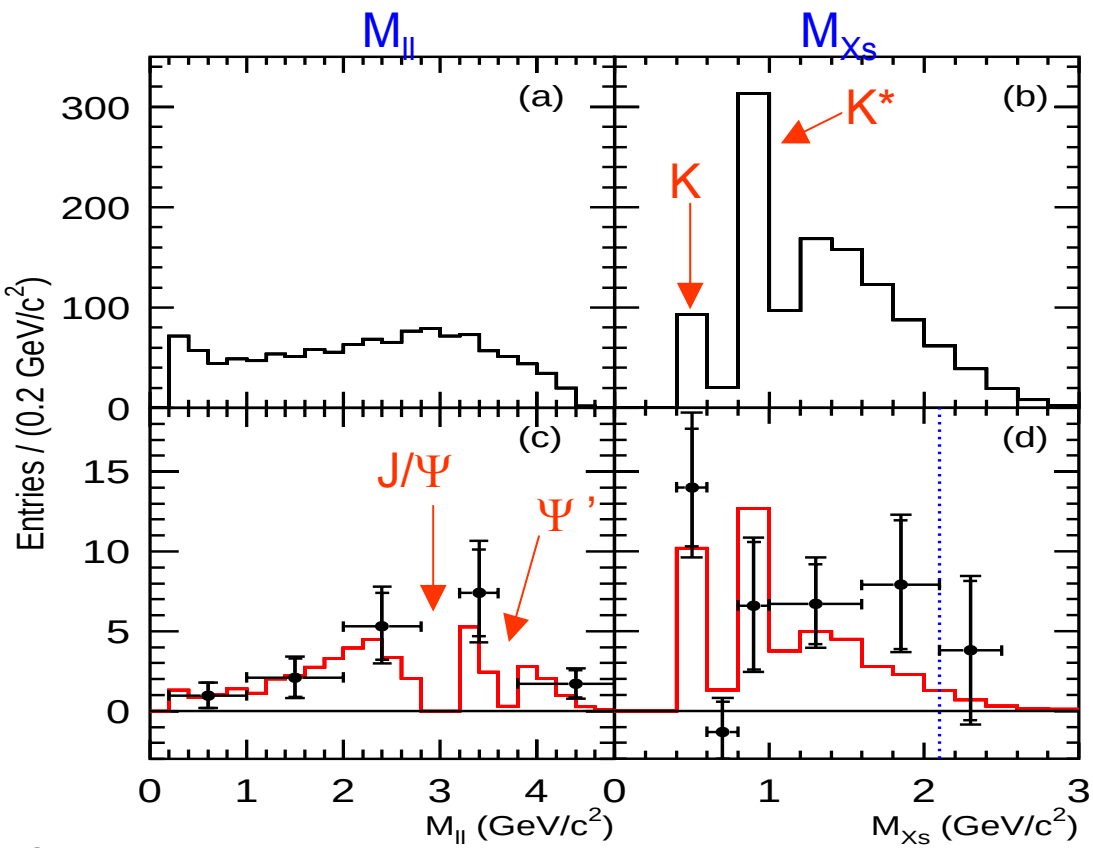


M_{ll} and M_{Xs} in $B \rightarrow X_S l^+ l^-$ (Belle)

- clear signal in $M_{Xs} > M_{K^*}$
- large K and small K* are consistent with exclusive analysis
- dilepton invariant mass distribution is consistent with prediction, so far.

MC generated

Reconstructed



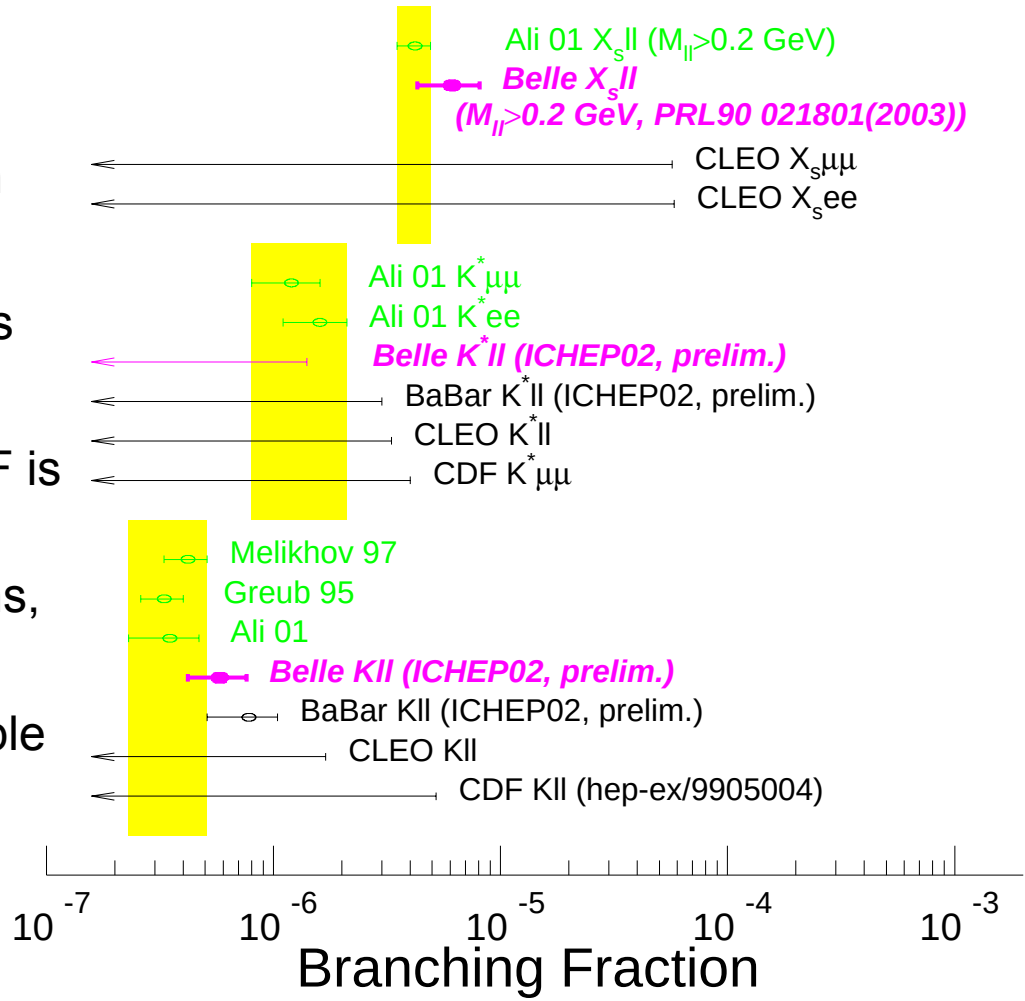
BF of B → X_S l^+ l^-

- First measurement by Belle (PRL 90, 021801 (2003))
  - Electron mode and muon mode are consistent within an error
  - systematic error (~20%) is already comparable to statistical error
    - Largest one is uncertainty in exclusive farction (~11% error)
      - (can be reduced by using measured BF.)
    - Second largest one is track finding (~8% error → ~4% error)

BF or UL (10^{-6})	X_s e e	X_s μ μ	X_s l l
Belle (60 fb^{-1}) (M_{ll} >0.2 GeV/c^2)	$5.0 \pm 2.3\ ^{+1.3}_{-1.1}$.	$7.9 \pm 2.1\ ^{+2.1}_{-1.5}$.	$6.1 \pm 1.4\ ^{+1.4}_{-1.1}$.
CLEO (3 fb^{-1})	< 57	< 58	< 42

b → s $l^+ l^-$ Comparison

- Xs l l
  - Consistent with prediction
- K* l l
  - Just above the predictions
- K l l
  - Belle, Babar combined BF is $(0.63\ ^{+0.17}_{-0.15}) \times 10^{-6}$
  - Consistent with predictions, so far
  - Error is already comparable to theoretical error.



Constraint on C_9 and C_{10}

- C_9 and C_{10} can be constrained from BF(B→Xs l l)
  - $C_i^{NP} = C_i - C_i^{SM}$
  - (0,0) if the SM holds. Dot shows Extended-MFV.
  - Strong constraint on C_9 and C_{10} but sgn(C_7) is not determined yet.

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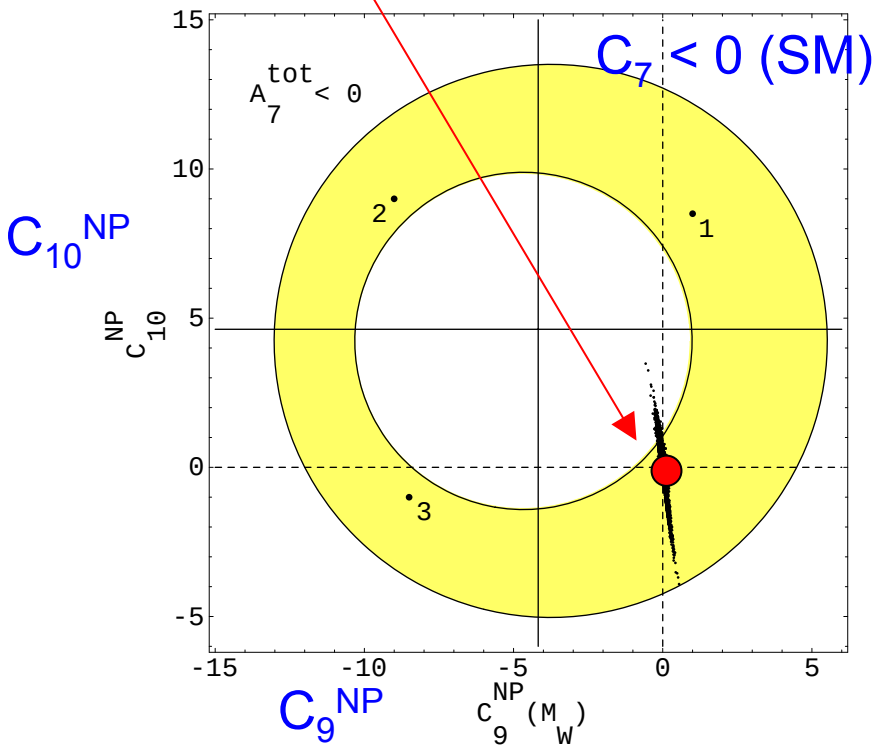
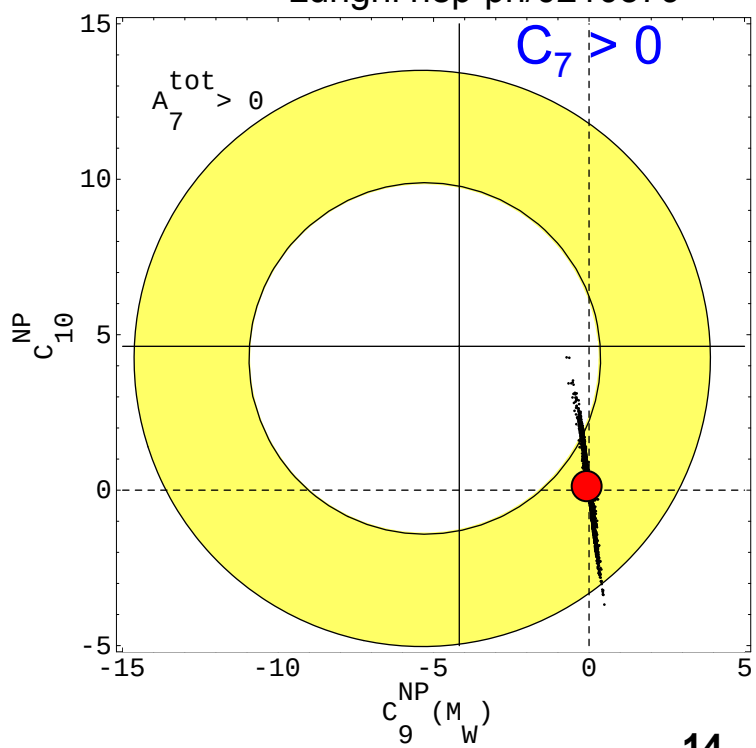




$B^0 \rightarrow l^+ l^-$ Decays

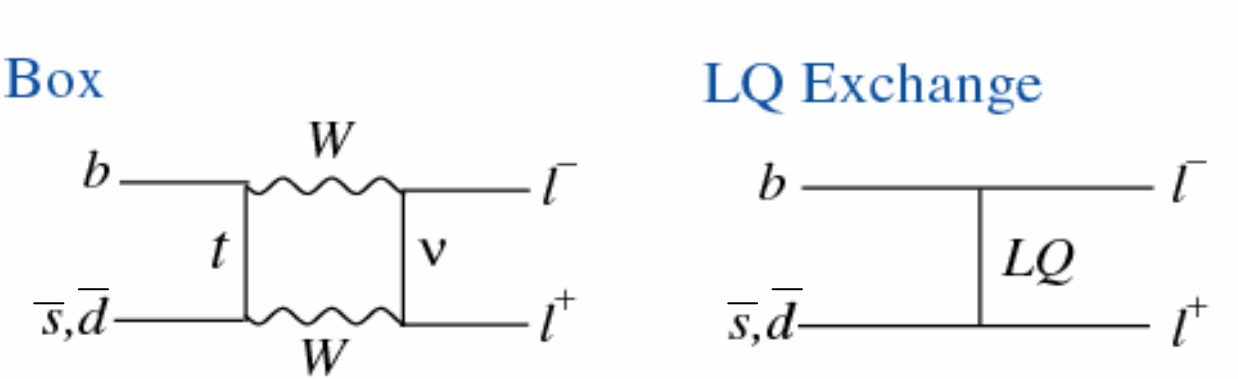
$B \rightarrow l^+ l^-$

- induced through box or penguin annihilation diagrams at lowest order
- very small BF (FCNC decays, helicity suppression)

$$BF(B \rightarrow e^+ e^-) \sim 10^{-15}$$

$$BF(B \rightarrow \mu^+ \mu^-) \sim 10^{-10}$$

- new physics(2HDM, Z-FCNC) enhances the BF by 2 to 3 order of magnitude larger
- Pati-Salam LQ can be searched with LFV decay B → e μ



$B^0 \rightarrow l^+ l^-$ Analysis

Tight lepton ID

Belle (*New !*)

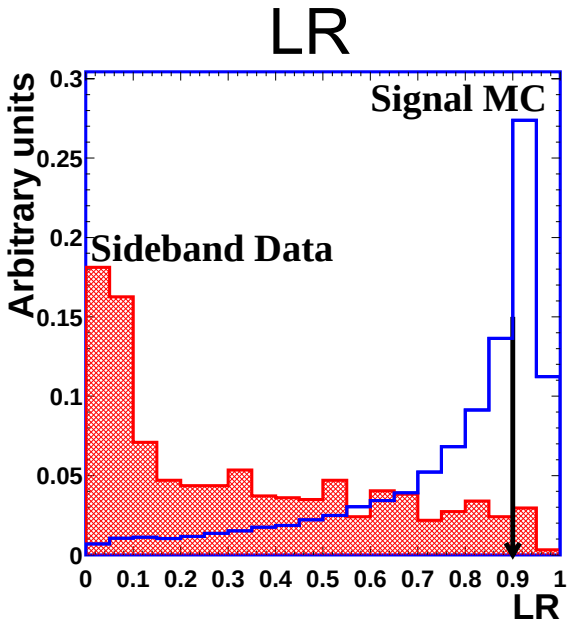
- continuum background suppressed by LR (event shape, $F(E_{miss}, M_{miss})$) ⇨
- background estimated from data and MC

Babar

- multiplicity and track polar angle cut to reduce QED background.
- continuum background suppressed by event shape
- no background subtraction for UL calculation

CDF

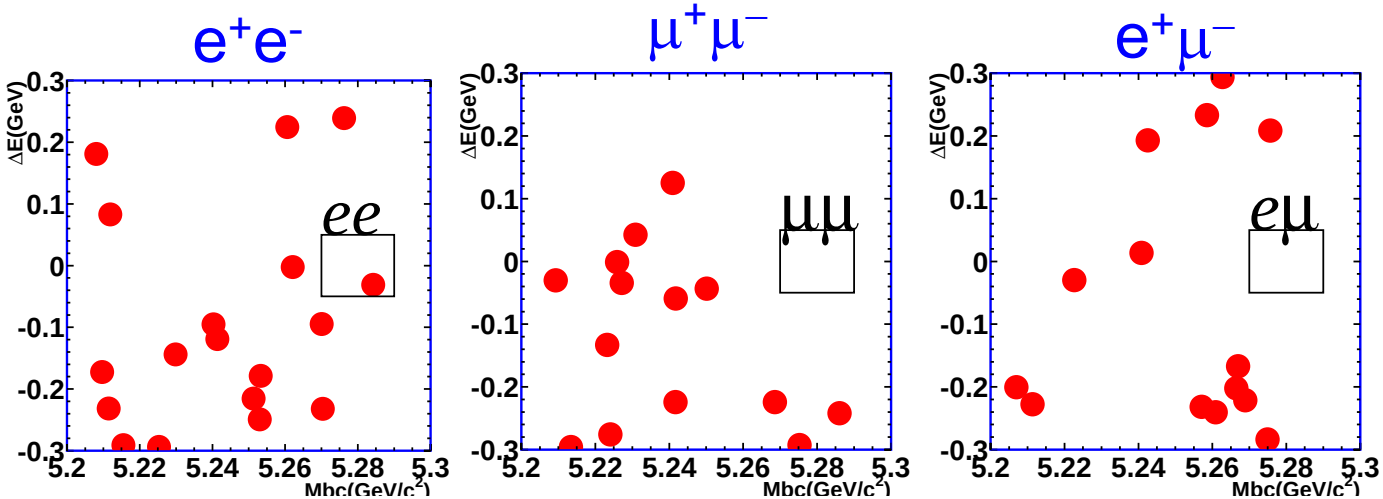
- track isolation
- vertex quality and vertex displacement from IP



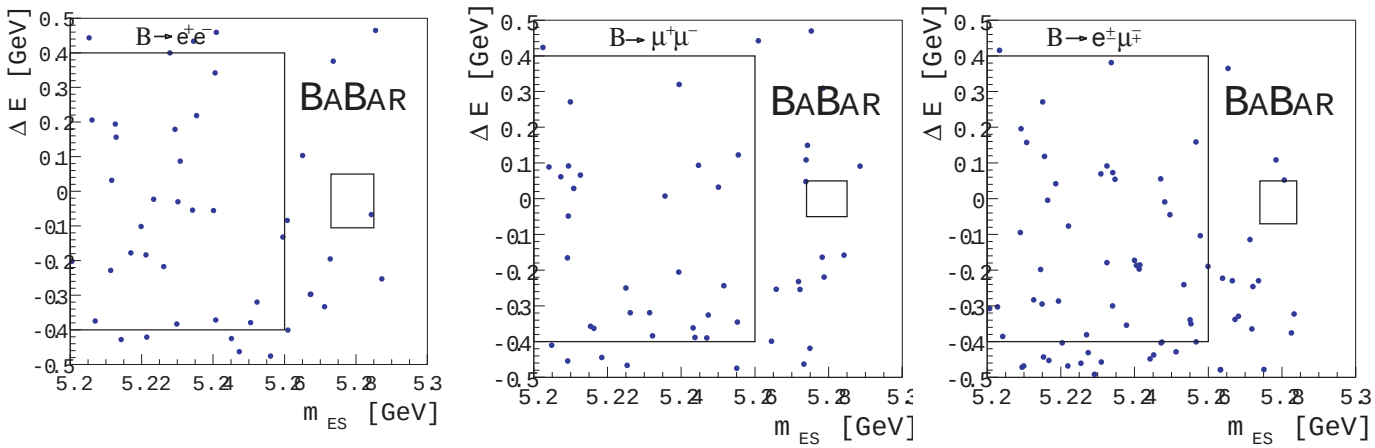
$B^0 \rightarrow l^+ l^-$ (Belle, Babar)

Both Belle and Babar observe 1 event in ee mode which is consistent with background. No event is observed in μμ and em modes.

Belle *New !*
78 fb^{-1}
prelim.

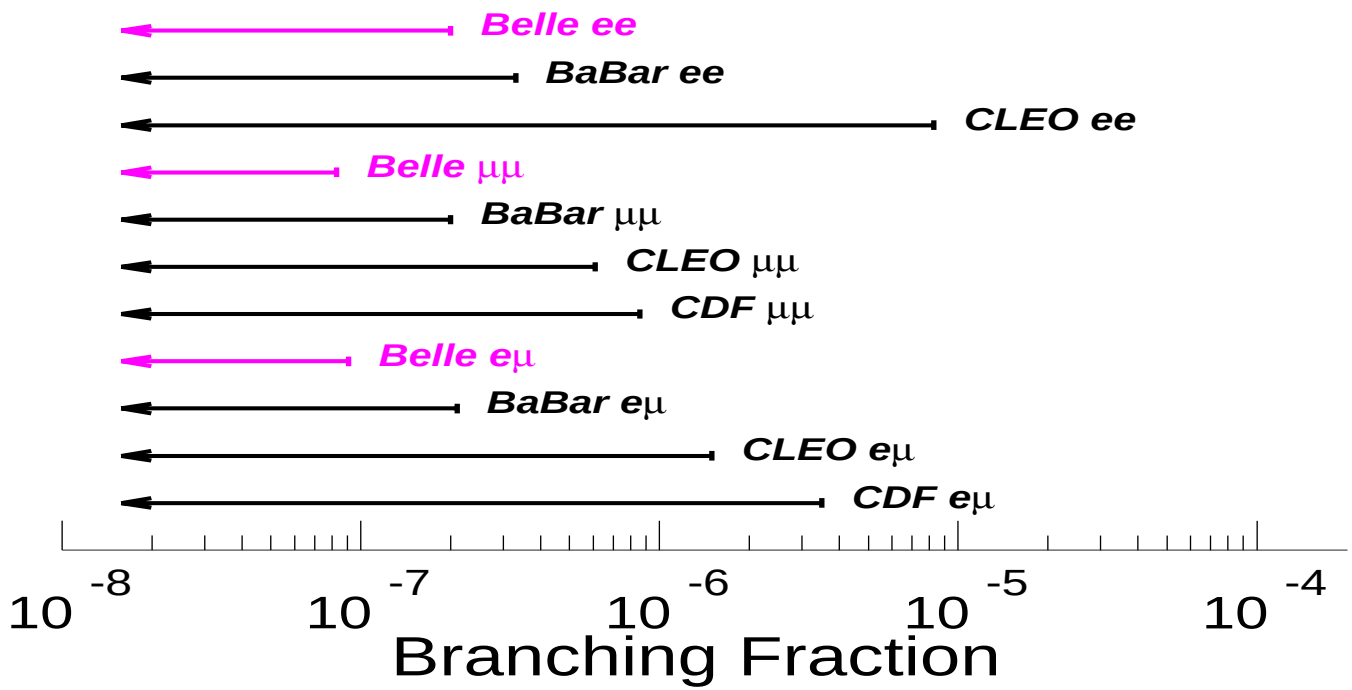


Babar
54 fb^{-1}
prelim.



limit on BF($B^0 \rightarrow l^+ l^-$) and M_{LQ}

UL (10^{-8})	e e	$\mu\ \mu$	e μ	$M_{LQ}(TeV/c^2)$
Belle (78 fb^{-1}) prelim.	< 20	< 8.3	< 9.1	> 54
Babar (54 fb^{-1}) prelim.	< 33	< 20	< 21	----
CLEO (3 fb^{-1})	< 830	< 61	< 150	> 27
CDF (102, 110 pb^{-1})	----	< 86	< 350	> 22



Summary

B factories study FCNC decays extensively .

- $B \rightarrow K\, l^+ l^-$
  - First observed by Belle. Recently confirmed by Babar
  - BF is consistent with theoretical predictions
- $B \rightarrow K^*\, l^+ l^-$
  - Signal is not significant
  - UL is just above theoretical predictions
- $B \rightarrow X_S\, l^+ l^-$
  - First measured by Belle
  - BF consistent with theoretical predictions
  - Stringent limit on C_9 and C_{10}
- $B \rightarrow l^+ l^-$
  - Most stringent limits by Belle
  - Limit on Pati-Salam leptoquark mass $> 54\ \mathrm{TeV}/c^2$

Future Prospects

- This summer (LP2003 at Fermilab, USA)

  Belle and Babar will accumulate more than 130 fb^{-1} data

  stat. error of BF(B → K l l) reduced by $\sqrt{2}$ (~20%)

  observation of K* l l ? (if the BF is ~ 1.4×10^{-6})

  CDF and D0 can also contribute to these topics.

- 2005 (LP2005 at Uppsala Universitet, Sweden)

  Belle and Babar ~400 fb^{-1} data

  CDF and D0 ~3 fb^{-1}?? data

  precise BF (~10% error) and q^2 distribution in B → K l l

  BF, q^2 and F_{AB} in K* l l and X_s l l

  new physics effects can be seen ?!

Back Up Slides

Systematics in BF(B → X_S l^+ l^-)

- Model
  - Exclusive fraction (~11%) (can be reduced !)
    change the exclusive BFs
  - Fragmentation (~5%)
    compare inclusive production of π^0, Ks, η and ϕ btw continuum data and JETSET
  - X_S mass distribution (~4%)
    change p_F and m_q
  - Fraction of unmeasured mode (~2%)
- Reconstruction efficiency
  - Tracking (~8%) (can be reduced !)
  - Lepton ID (~3%) (can be reduced !)
  - Background suppression (~3%)
  - Ks (~2%) (can be reduced !)
  - π^0 (~2%) (can be reduced !)
  - Kaon ID (~2%) (can be reduced !)
  - Pion ID (~0.6%)
- Signal extraction
  - Signal and background PDF (+14−10%) (can be reduced !)