



$B \rightarrow X_S l^+ l^-$ and forward backward asymmetry

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Introduction

- Measurement of $B \rightarrow X_s l^+ l^-$ decays is one of interesting physics at high-luminosity B factory.
- Today we will talk about a study of the measurement with 10^{36} luminosity based on the current analysis knowledge at BaBar and Belle.



Topics of discussion

- Motivation
 - Current results at BaBar and Belle
 - Expected results with 10^{36} luminosity
- Branching fraction
- Forward backward asymmetry
- High luminosity options
 - Summary

Motivation (I)

- Electroweak penguin $b \rightarrow sl^+l^-$ decay is sensitive to non-SM physics

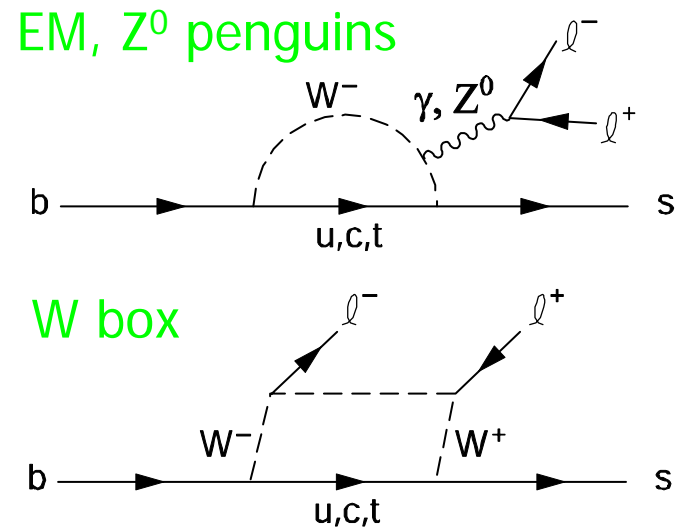
- Rare decay (FCNC process)

Ali, Lunghi, Greub, Hiller PRD66,
034002(2002)

$$BF(B \rightarrow Xse^+e^-) = (6.89 \pm 1.01) \times 10^{-6}$$

$$BF(B \rightarrow Xs\mu^+\mu^-) = (4.15 \pm 0.70) \times 10^{-6}$$

→ very interesting at
high-luminosity B factory





Motivation (II)

- $B \rightarrow X_s I^+ I^-$ observables
 $BF(B \rightarrow X_s I^+ I^-)$, $M(I^+ I^-)$, $M(X_s)$, $A_{FB}(M(I^+ I^-))$
- BF may hit theoretical uncertainty or be limited by systematic uncertainty
→ need study for high-luminosity B factory ($\sigma_{\text{stat}} \sim 2\%$)
- $A_{FB}(M(I^+ I^-))$ is not measured yet
→ What performance can we expect?



Current analysis method

- Both of BaBar and Belle uses

“Sum over exclusive modes” (semi-inclusive approach)

Reconstruct X_S with $1(K^\pm/K_S^0 \rightarrow \pi^+\pi^-) + n\pi$ ($n \leq 2(4), n\pi^0 \leq 2$)

($K^\pm l^+ l^-$, $K^\pm \pi^0 l^+ l^-$, $K^\pm \pi^\mp \pi^0 l^+ l^-$, ...)

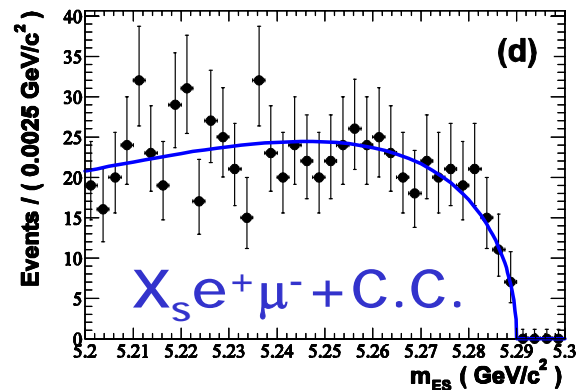
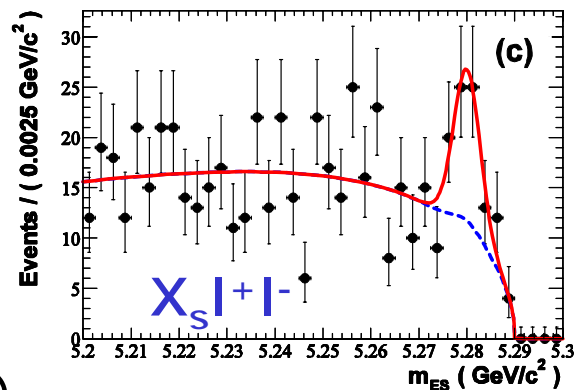
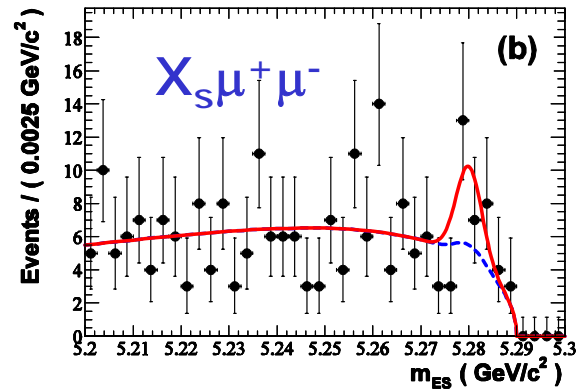
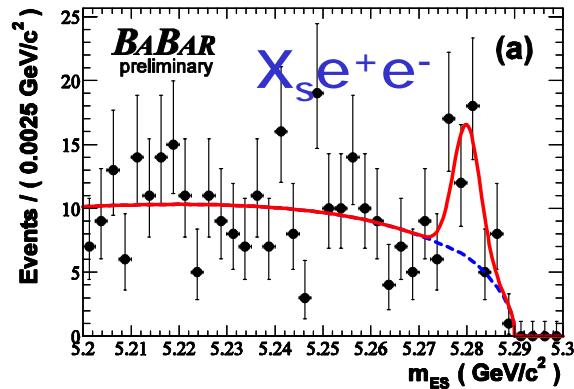
BaBar Belle

→ ~60% of $BF(B \rightarrow X_S l^+ l^-)$ for BaBar

- This method provides powerful kinematical constrains ($m_{ES}, \Delta E$)
- Not available to more inclusive techniques...

Selected events

Efficiency = 1 ~ 4%

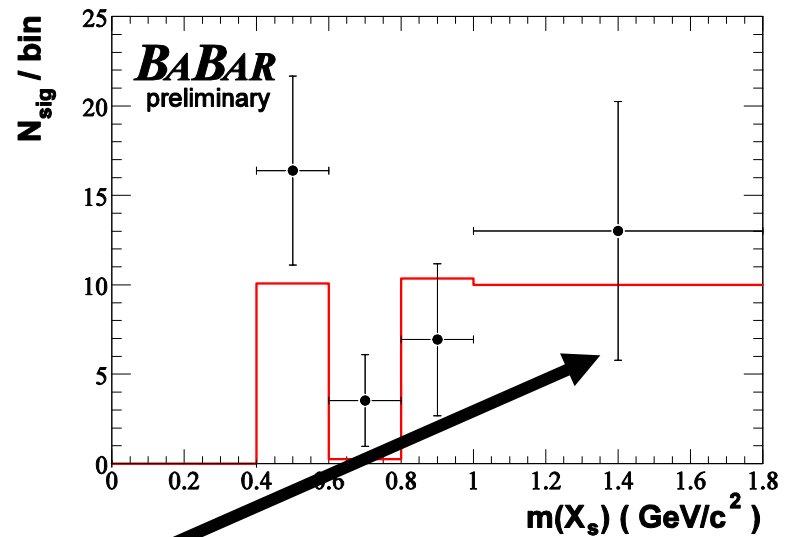
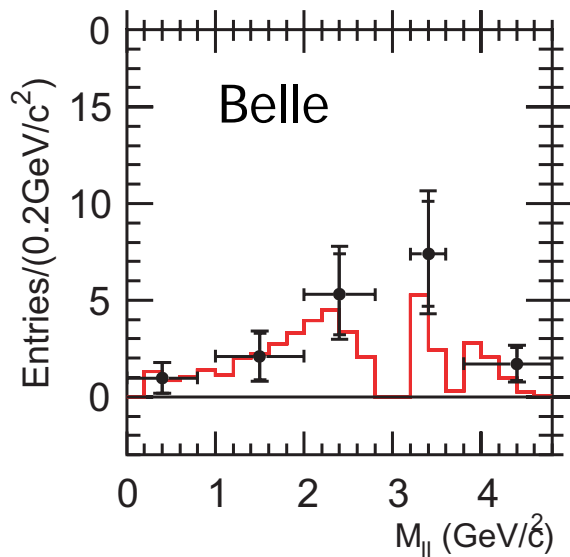


$$m_{ES} = \sqrt{(E_{\text{beam}})^2 - p_B^2}$$

10/22/2003

Signal is obtained from Argus+Gaussian fit 7

$m_{||}$ and m_{X_s}



BaBar and Belle show some evidence for signal at hadronic masses beyond K^*

Current results

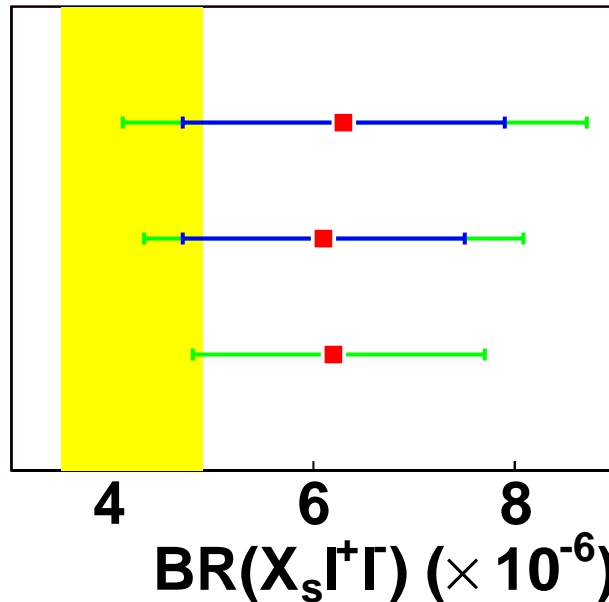
$(4.2 \pm 0.7) \times 10^{-6} \text{ } M(I^+\Gamma) > 0.2 \text{ GeV}$
 (Ali, Lunghi, Greub, Hiller) NNLO

Hep-ex/0308016

BaBar
 (82fb⁻¹)

Belle
 (60fb⁻¹)

Average



$(6.3 \pm 1.6^{+1.8}_{-1.5}) \times 10^{-6}$

$(6.1 \pm 1.4^{+1.4}_{-1.1}) \times 10^{-6}$

$(6.2^{+1.5}_{-1.4}) \times 10^{-6}$

PRL90,21801

Status of current measurements

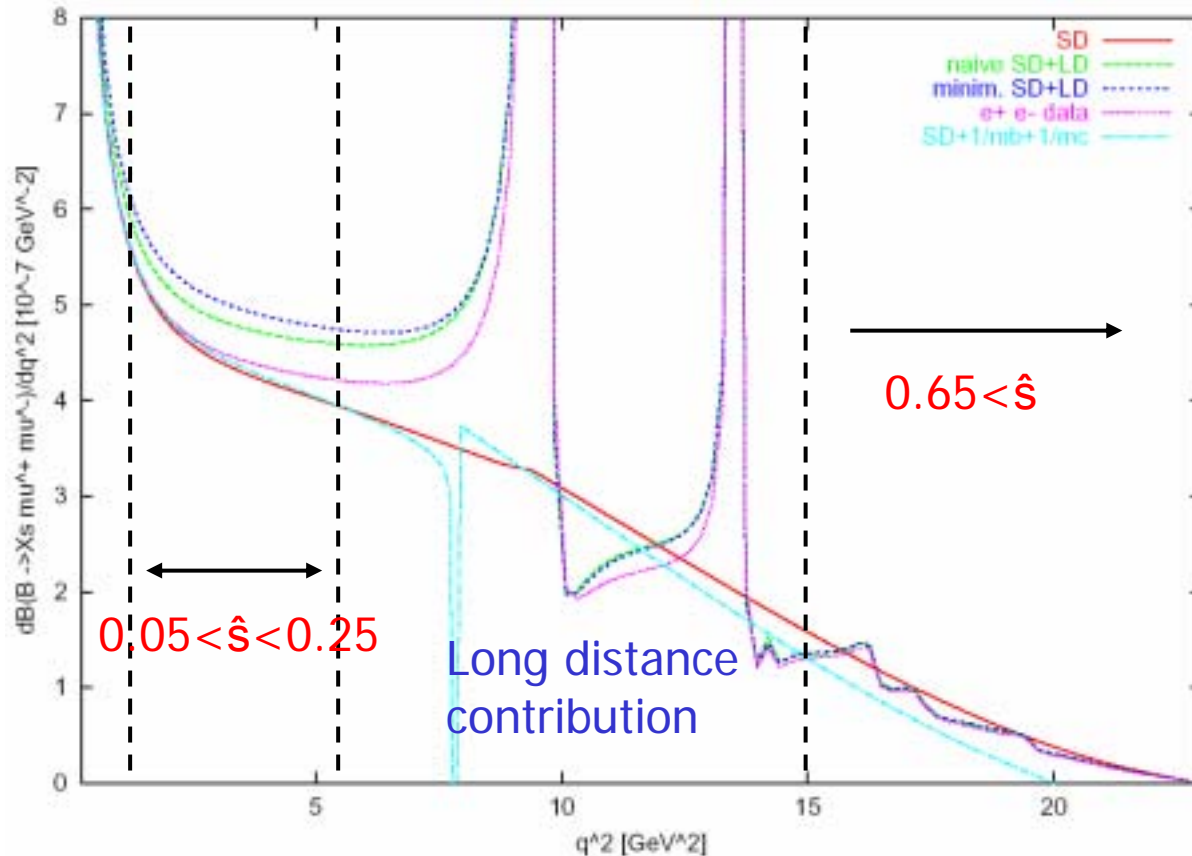
- Both of BaBar and Belle measures $BF(B \rightarrow X_s l^+ l^-)$, $M(l^+ l^-)$, and $M(X_s)$.
- Lepton forward-backward asymmetry $A_{FB}(M(l^+ l^-))$ is not measured yet because of statistics.
- Current systematic uncertainty in BF is 20%.
→ need better control and discuss later

Restricted $m_{||}$ region BF (I)

BF hits the theoretical uncertainty at $\sim 500\text{fb}^{-1}$

$$\hat{s} \equiv M_{||}^2 / m_b^2$$

$$m_b = 4.80\text{GeV}$$



G. Hiller



Restricted m_{\parallel} region BF (II)

- BFs in restricted m_{\parallel} region are studied
→ theory predictions are more reliable:

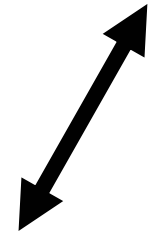
$$\text{BF}(B \rightarrow X_s |^+ |^-) = (1.36 \pm 0.08_{\text{scale}}) \times 10^{-6} \quad (6\%)$$

for $0.05 < \hat{s} < 0.25$

Asatryan et al. Ghinculov et al.

$$\text{BF}(B \rightarrow X_s |^+ |^-) = (4.2 \pm 0.7) \times 10^{-6} \quad (17\%)$$

for $0.042 (= 0.2/4.80) < \hat{s}$



BF($B \rightarrow X_s l^+ l^-$) projections

Signal yield $X_s e^+ e^- + X_s \mu^+ \mu^-$	500fb^{-1}	1000fb^{-1}	10ab^{-1}	50ab^{-1}
All \hat{s} (exc. J/ψ veto)	368 ± 35 (10%)	741 ± 50 (7%)	7414 ± 159 (2.1%)	37070 ± 356 (1.0%)
$0.05 < \hat{s} < 0.25$	135 ± 21 (16%)	272 ± 30 (11%)	2717 ± 93 (3.4%)	13585 ± 208 (1.5%)
$0.65 < \hat{s}$	58 ± 13 (22%)	117 ± 18 (15%)	1171 ± 59 (5.0%)	5855 ± 132 (2.3%)



Systematics

- Signal yield $\sigma_{\text{syst}}^{\text{yield}} \sim 11\%$: should scale mostly as $\sqrt{1/N}$
- Efficiency $\sigma_{\text{syst}}^{\text{expt}} \sim 11\%$: scale as $\sqrt{1/N}$?
(tracking eff. ($\sim 8\%$), particle ID ($\sim 7\%$))
→ 0.8% per track → $\sim 3\%$ overall?
→ hit this limit at very high luminosity? Limits for other single particle eff?
- Efficiency $\sigma_{\text{syst}}^{\text{model}} \sim 13\%$: direct measurements of K^+l^- and K^*l^- improve $11\% \rightarrow 3\%$?



Extrapolation from list of exclusive modes to all final states

~25% loss due to K^0_L component can be corrected from K^0_S modes

~20% loss due to modes with either $\#\pi^0 \geq 2$ or $\#(\pi^\pm + \pi^0) \geq 4$

Fraction of π^0 and K^0_S in X_S (efficiency varies for the different modes)

⇒ need to rely on hadronization model (Jetset)

→ calibrate with $B \rightarrow J/\psi X_S$ data? Need improved $BF(B \rightarrow J/\psi X_S)$ measurements

→ measure BF for each topology

$\sigma_{\text{syst}} 5\% \rightarrow 1-2\%$?

Summary on relative uncertainties

Signal yield $X_s e^+ e^- + X_s \mu^+ \mu^-$	500fb ⁻¹	1000fb ⁻¹	10ab ⁻¹	50ab ⁻¹
All \hat{s} (exc. J/ ψ veto)	$\sigma_{\text{stat}}=10\%$ $7\% < \sigma_{\text{syst}} < 14\%$	$\sigma_{\text{stat}}=7\%$ $5\% < \sigma_{\text{syst}} < 14\%$	$\sigma_{\text{stat}}=2.1\%$ $1.5\% < \sigma_{\text{syst}} < 6\%?$	$\sigma_{\text{stat}}=1.0\%$ $0.7\% < \sigma_{\text{syst}} < 6\%?$
$0.05 < \hat{s} < 0.25$	$\sigma_{\text{stat}}=16\%$	$\sigma_{\text{stat}}=11\%$	$\sigma_{\text{stat}}=3.4\%$	$\sigma_{\text{stat}}=1.5\%$
$0.65 < \hat{s}$	$\sigma_{\text{stat}}=22\%$	$\sigma_{\text{stat}}=15\%$	$\sigma_{\text{stat}}=5.0\%$	$\sigma_{\text{stat}}=2.3\%$

- Lower bound on σ_{syst} assumes pure (and unrealistic) $\sqrt{(1/N)}$ scaling
- Extrapolation of σ_{syst} to high-luminosity B Factory is rather tricky...
- Recall current uncertainties of $\sim 15\%$ for all \hat{s}
 $\sim 6\%$ for $0.05 < \hat{s} < 0.25$

Forward-backward asymmetry (I)

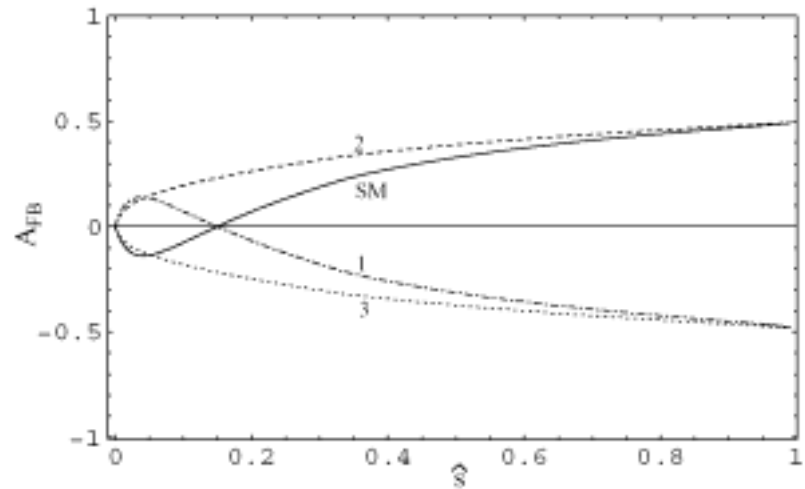
- Sensitive to new physics

$$A_{FB} = (N_F - N_B) / (N_F + N_B)$$

In dilepton rest frame:

$N_F = \#l^+$ along b-quark direction

$N_B = \#l^+$ opposite b-quark direction



(Ali, Lunghi, Greub, Hiller)

Forward-backward asymmetry (II)

- Zero point of the asymmetry :

$$A_{\text{FB}}=0 \text{ for } \hat{s} = \hat{s}_0 = 0.162 \pm 0.008 (\text{NNLL})$$

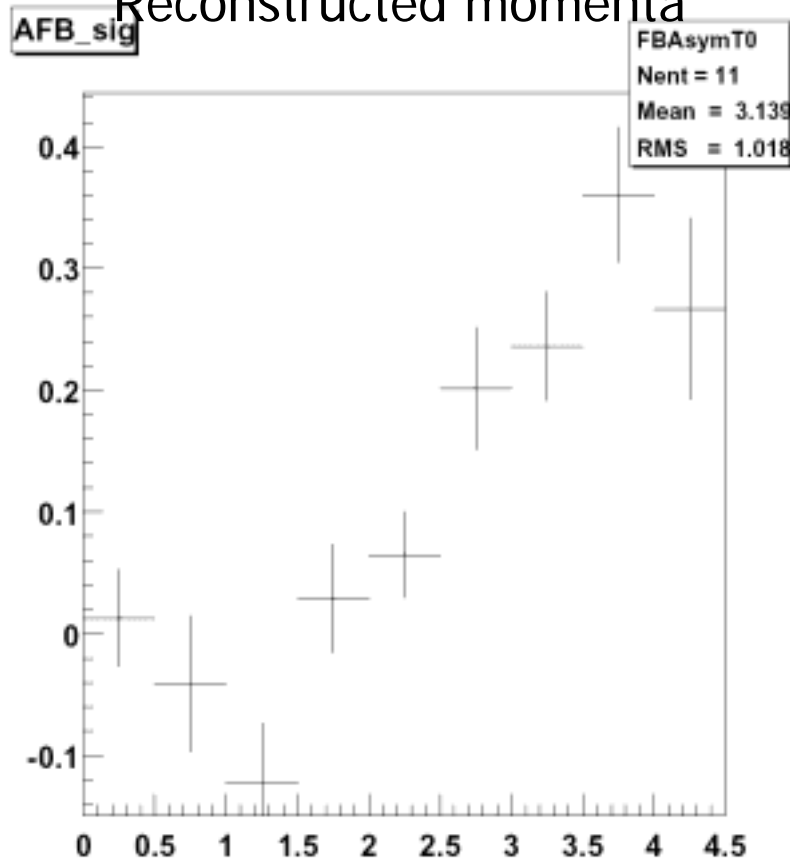
Ghinculov, Hurth, Isidori, Yao NPB648, 254 (2003)

prediction for \hat{s}_0 particularly robust

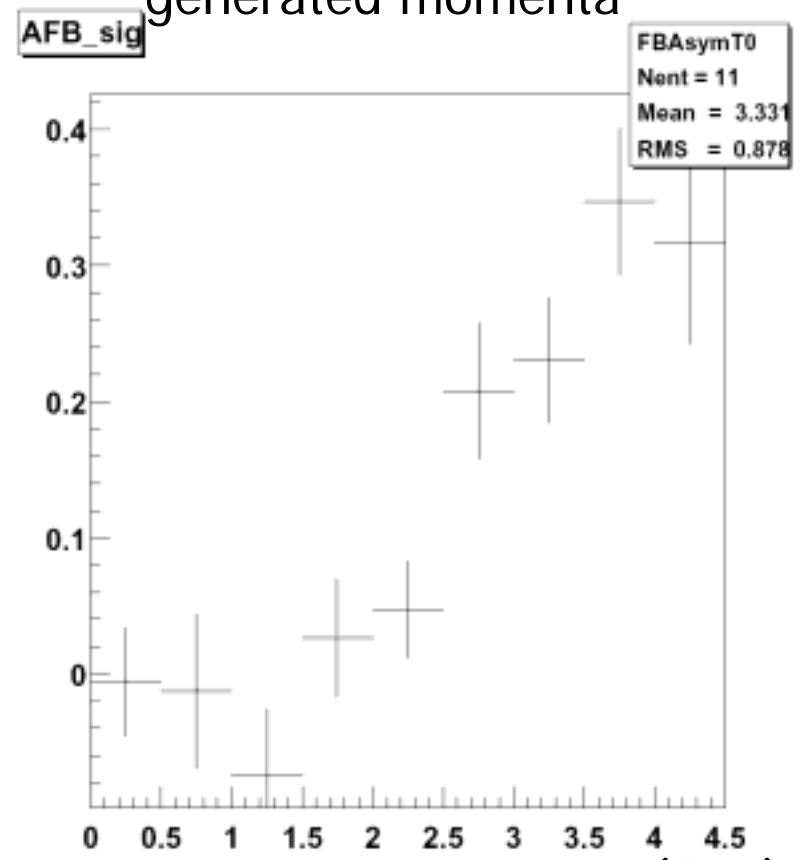
- Projections using BaBar analysis with $X_s \neq (K^+ \text{ or } K^0_s)$ and self-tagging modes only
- $A_{\text{FB}}=0$ for BF($B \rightarrow K l^+ l^-$)

A_{FB} for $10ab^{-1}$ and pure signal events

Reconstructed momenta



generated momenta



$M_{||}$ (GeV)

A_{FB} statistical uncertainties for pure signal and bkg-subtracted

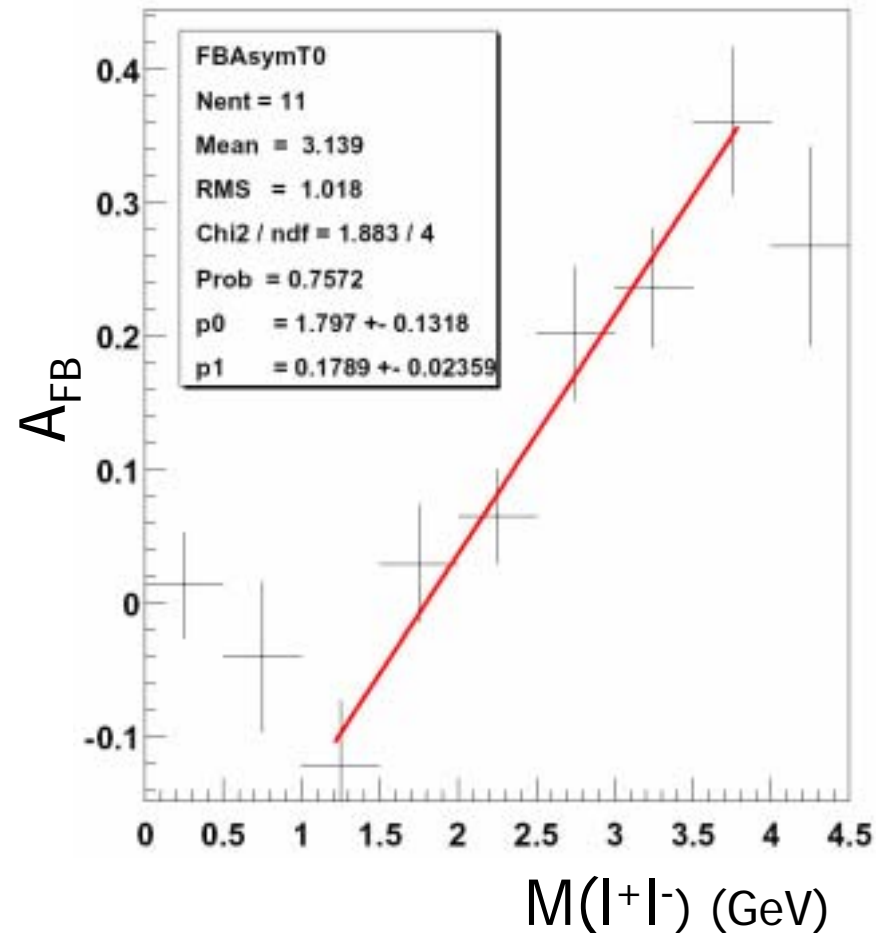
A_{FB} $X_s e^+e^- + X_s \mu^+\mu^-$	500fb ⁻¹	1000fb ⁻¹	10ab ⁻¹	50ab ⁻¹
$\hat{s} < \hat{s}_0$	-0.22±0.11 -0.02±0.17	-0.02±0.08 -0.02±0.12	-0.017±0.024 -0.017±0.039	-0.017±0.011 -0.017±0.017
$\hat{s}_0 < \hat{s}$	0.17±0.09 0.17±0.22	0.17±0.07 0.17±0.16	0.173±0.021 0.173±0.050	0.173±0.009 0.173±0.022

Upper: pure signal
Lower: bkg-subtracted

⇒ A_{FB} clearly needs high-luminosity B factory

A_{FB} zero-point with $10ab^{-1}$

- For pure signal :
 $M_{ll0} = 1.80 \pm 0.13(\text{stat})\text{GeV}$
 $\rightarrow \hat{s}_0 = 0.141 \pm 0.020(\text{stat})$
- For background-subtracted :
 $\hat{s}_0 = 0.14 \pm 0.04(\text{stat})$
- NNLL
 $\hat{s} = \hat{s}_0 = 0.162 \pm 0.008$





Fully inclusive approach (I)

- Fully inclusive approach using full B decay reconstruction
- Reconstruct hadronic decay $B \rightarrow D^{(*)} Y$ with fully reconstructed $D^{(*)}$ and $Y = n_1 \pi^\pm n_2 K^\pm n_3 K^0 n_4 \pi^0$
- Breco efficiency = 0.4% for BB events (BaBar)
 $\rightarrow 10 \text{ ab}^{-1} \rightarrow \sim 10^{10} \text{ BB} \rightarrow \sim 40 \text{ million B mesons recoiling against fully reconstructed B}$



Fully inclusive approach (II)

$B \rightarrow X_s l^+ l^-$ candidates : select $l^+ l^-$ pair and kaon in recoiling B

→ assume 35% efficiency

→ expect 118 signal events with
 $M(l^+ l^-) > 0.2 \text{ GeV}$

→ this becomes interesting with 50ab⁻¹
would get ~600 signal events
($\sigma_{\text{stat}} = 4\%$)



BF($B \rightarrow X_d l^+ l^-$)

- **CKM impact?** Compare rates for $b \rightarrow d l^+ l^-$ and $b \rightarrow s l^+ l^-$ transitions for $|V_{td}/V_{ts}|$ determination
- For $1 < s < 6 \text{ GeV}^2$, Ali & Hiller predict

$$\text{BF}(B \rightarrow X_s l^+ l^-) = (2.22^{+0.29}_{-0.30}) \times 10^{-6}$$

$$\text{BF}(B \rightarrow X_d l^+ l^-) = (9.61^{+1.32}_{-1.47}) \times 10^{-8}$$

10ab⁻¹ → working with a Breco sample would yield 62B → X_sl⁺l⁻ signal + 2.5B → X_dl⁺l⁻ signal

→ need a more efficient selection

(sum over exclusive modes? Very hard for inclusive $b \rightarrow d$ transitions)



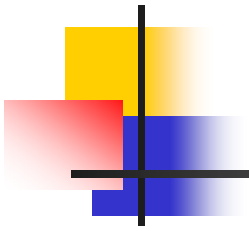
Summary (I)

- Test of new physics
Inclusive $B \rightarrow X_s l^+ l^-$ decays offer new sensitivity to extensions of the SM
- ▶ Measurements of the **BF** and **dilepton mass spectrum** should achieve interesting sensitivity by the end of BaBar/Belle (1000fb^{-1})
Degree of improvement at a high-luminosity B factory depends on **control of systematic uncertainties** (high luminosity needed for restricted “perturbative” \hat{s} ranges)



Summary (II)

- ▶ Lepton forward-backward asymmetry A_{FB} is particularly powerful and a high-luminosity B factory is needed to reach interesting sensitivity
- CKM impact
Theoretically clean determination of $|V_{td}/V_{ts}|$ but difficult to measure inclusive $b \rightarrow dl^+l^-$ rate \rightarrow needs more study

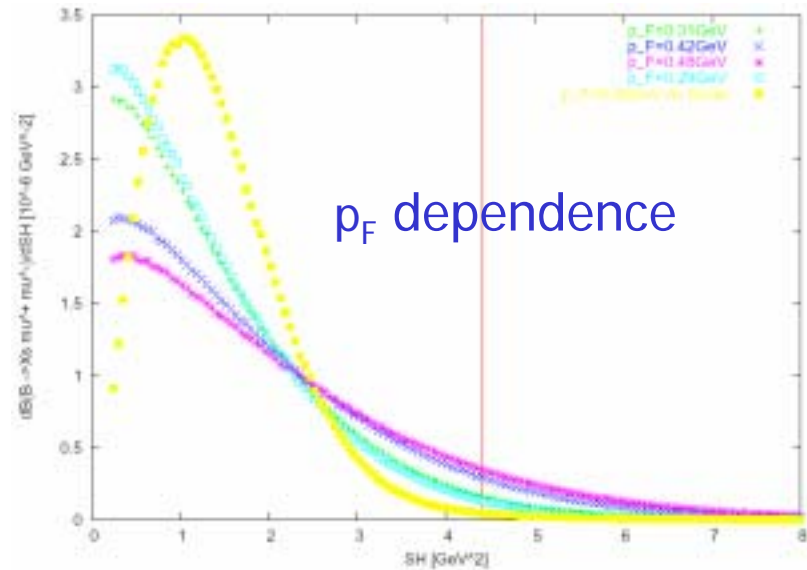


Backup slides

Extrapolation to full $M(X_S)$ spectrum

- Signal fraction with $M(X_S) < 2.1 \text{ GeV}$ is $(93 \pm 4)\%$
- Uncertainty due to Fermi motion σ_{syst} $4\% \rightarrow 1\%$?
determine from $X_{S\gamma}$

G. Hiller



Scaled $(M_{X_S})^2$