$B \to X_s\, l^+ l^-$ Experimental Issues

1. Motivation
2. Analysis method
3. Results
4. Future prospects and limitations

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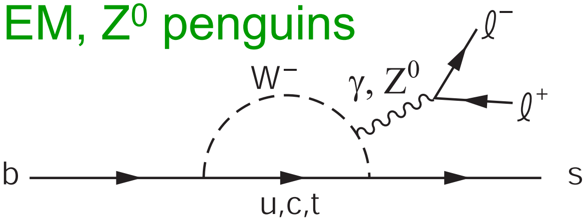
Note: Exclusive $B \to K^{(*)}\, l^+ l^-$ decays covered in parallel session

Motivation

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

  - rare decay (FCNC process)

EM, Z^0 penguins



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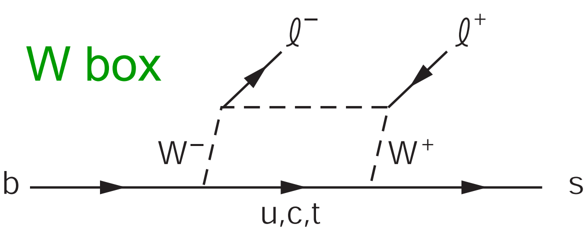


> Ali, Lunghi, Greub, Hiller PRD66, 034002 (2002)
>
> $BF(B \to X_s\, e^+e^-) = (6.89 \pm 1.01) \times 10^{-6}$
>
> $BF(B \to X_s\, \mu^+\mu^-) = (4.15 \pm 0.70) \times 10^{-6}$

  - inclusive BF has smaller theoretical uncertainty (15-17%) than exclusive $BF(B \to K^{(*)}\, l^+l^-)$ (31-34%)
  - global fit to FCNC effective Hamiltonian Wilson coefficients quantifies deviations from SM

- $B \to X_s\, l^+l^-$ observables

  - $BF(B \to X_s\, l^+l^-)$, $M(l^+l^-)$, $M(X_s)$, lepton FB asymmetry $A_{FB}(M(l^+l^-))$

Analysis Method (I)

- "*Sum of exclusive modes*" semi-inclusive approach (BaBar and Belle)
  - select high energy e^+e^- or $\mu^+\mu^-$ pair
  - consider X_s with 1 $K^\pm$ or $K^0_S \to \pi^+\pi^-$, # $(\pi^\pm + \pi^0) \leq 3$ (4), # $\pi^0 \leq 1$:
    $\to$ ~55% of BF($B \to X_s\, l^+l^-$) for BaBar
    [~80% if $K^0_L(n\pi) = K^0_S(n\pi)$ is assumed]

- Design selection criteria to suppress the following backgrounds
  - $B\bar{B}$ events
    (1) dominant peaking bkg:
    $B \to J/\Psi\, X_s$ and $B \to \Psi'\, X_s$ with $J/\Psi\ (\Psi') \to l^+l^-$
    (2) other peaking bkg:
    $B \to D^{(*)}\, n\pi\ (n \geq 1)$ with $\pi^+\pi^- \to l^+l^-$ mis-ID (mostly $\mu^+\mu^-$)
    (3) dominant combinatorial bkg:
    double semileptonic B (or D) decay with l^+l^- from 1 or 2 B decays
  - continuum $q\bar{q}$ events

Analysis Method (II)

- Backgrounds: (numbers from Belle analysis)
  - ◆ $B \to J/\Psi X_s$, $\Psi' X_s$ well suppressed by $M(l^+l^-)$ cuts ~0.5 evt in each mode
  - ◆ $B \to D^{(*)} n\pi$ measured to be 2.6 ± 0.2 ($X_s \mu^+\mu^-$) and 0.1 ± 0.05 ($X_s e^+e^-$)
  - ◆ Combinatorial $B\bar{B}$ and continuum bkg suppressed by kinematics and event shape cuts (e.g. E_{tot} and $\cos\theta_{thrust}$)

  $\to$ remaining bkg is dominated by semileptonic B decays (~70%)
- Sum of exclusive modes technique:

PRO: provides powerful kinematical constraints (m_{ES}, ΔE) not available to more inclusive techniques

CON: some *model dependence* due to missing modes and varying efficiencies & $M(X_s)$ cut →

$\varepsilon(K\, l^+l^-) = 11\%$

$\varepsilon(K^*\, l^+l^-) = 4\%$

$\varepsilon(X_s\, l^+l^-) = 3\%$ for $1.2 < M(X_s) < 2.0$ GeV

Current Results (I)

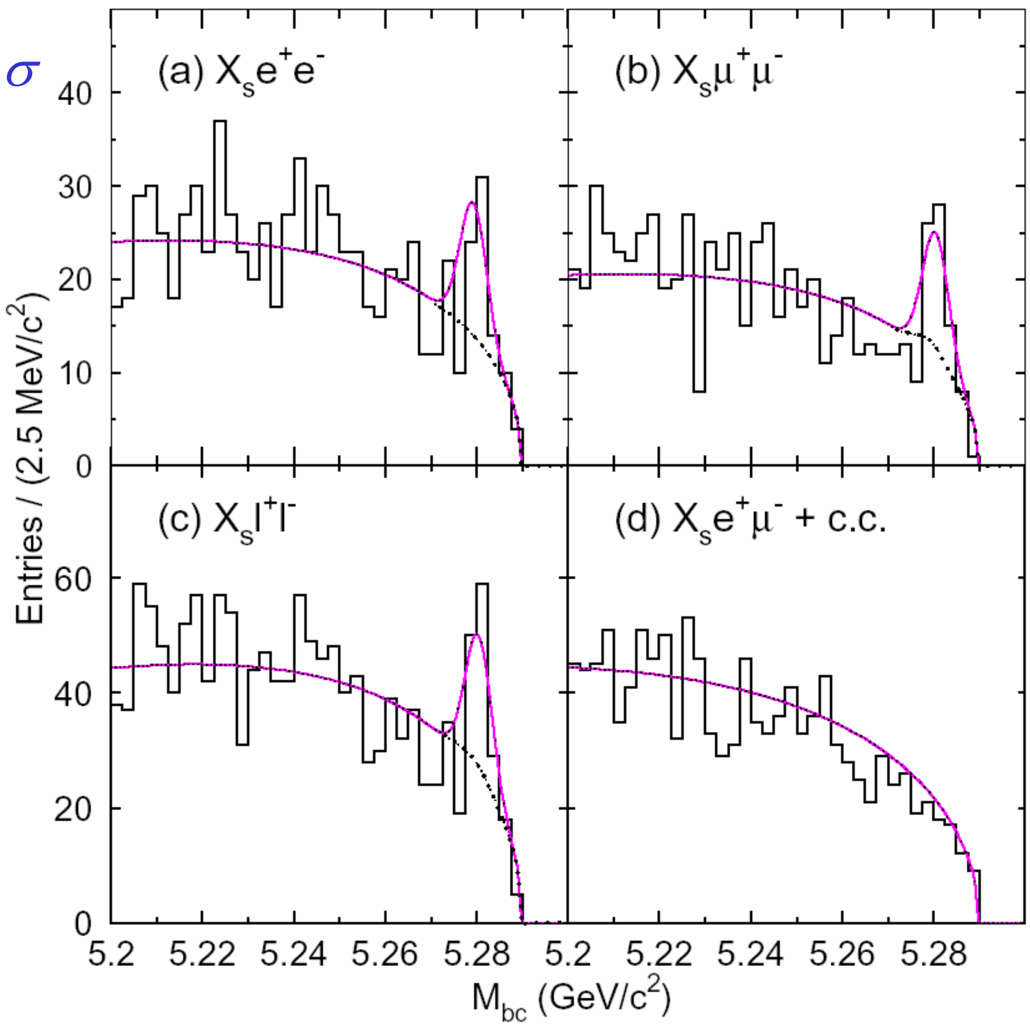
PRL90, 021801 (2003)

First observation by Belle

Signal statistical significance = 5.4 σ

65 M $B\bar{B}$ $M(l^+l^-) > 0.2$ GeV

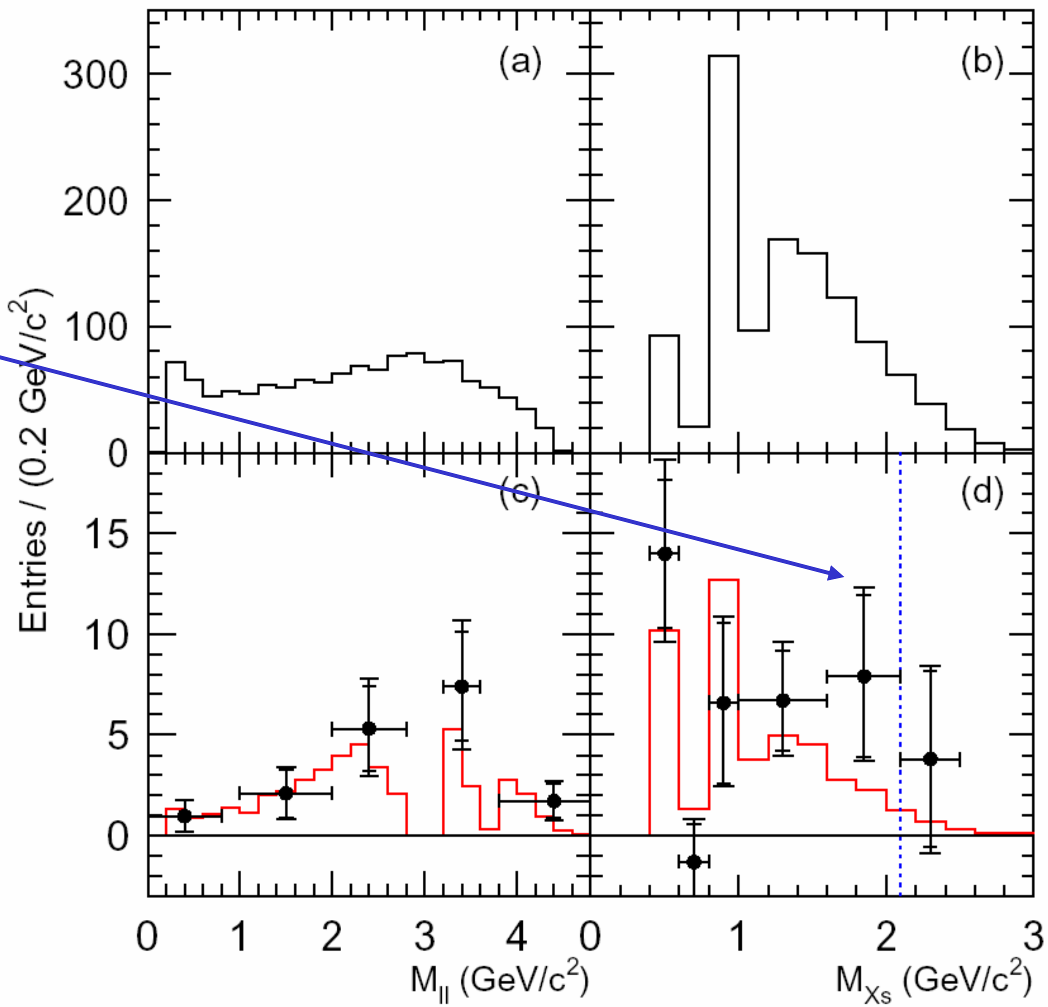
Signal yield (candidates)	Efficiency (%)	BF (10^{-6})
$X_s e^+e^-$ (96) $25.5 \pm 11.2^{+4.8}_{-3.8}$	$3.9 \pm 0.4 \pm 0.5$	$5.0 \pm 2.3^{+1.3}_{-1.1}$
$X_s \mu^+\mu^-$ (92) $37.3 \pm 9.7^{+7.2}_{-3.8}$	$3.6 \pm 0.4 \pm 0.5$	$7.9 \pm 2.1^{+2.1}_{-1.5}$
$X_s l^+l^-$ (188) $60.1 \pm 13.9^{+8.6}_{-5.4}$	$3.7 \pm 0.4 \pm 0.5$	$6.1 \pm 1.4^{+1.4}_{-1.1}$



SM NNLO (Ali, Lunghi, Greub, Hiller): $(4.2 \pm 0.7)\ 10^{-6}$ for $M(l^+l^-) > 0.2$ GeV

Current Results (II)

- Belle data shows some evidence for signal at hadronic masses beyond K*



- BaBar result with a similar analysis is expected for Summer 2003 conferences

Results (III)

- Belle: $$\mathrm{BF}(B \to X_s l^+ l^-) = \left(6.1 \pm 1.4(\mathrm{stat})^{+1.4}_{-1.1}(\mathrm{syst}) \right) \times 10^{-6}$$

- Systematic uncertainties:

Signal yield σ_{syst}^{yield} ~ 11% from uncertainties in signal and bkg shapes

Efficiency σ_{syst}^{expt} = 11% from uncertainties in

1. tracking efficiency (2.0% per track) $\rightarrow$ ~8%
2. particle ID efficiencies for e, μ, $\pi^{\pm}$, π^0, $K^{\pm}$, K^0_s $\rightarrow$ ~7%
3. modeling of background suppression $\rightarrow$ 3%

Efficiency σ_{syst}^{model} = 13% from uncertainties in

1. fraction of exclusive decays (K l^+l^- and K* l^+l^-) $\rightarrow$ 11%
2. hadronization $\rightarrow$ 5%
3. extrapolation to $M(X_s) > 2.1$ GeV $\rightarrow$ 4%

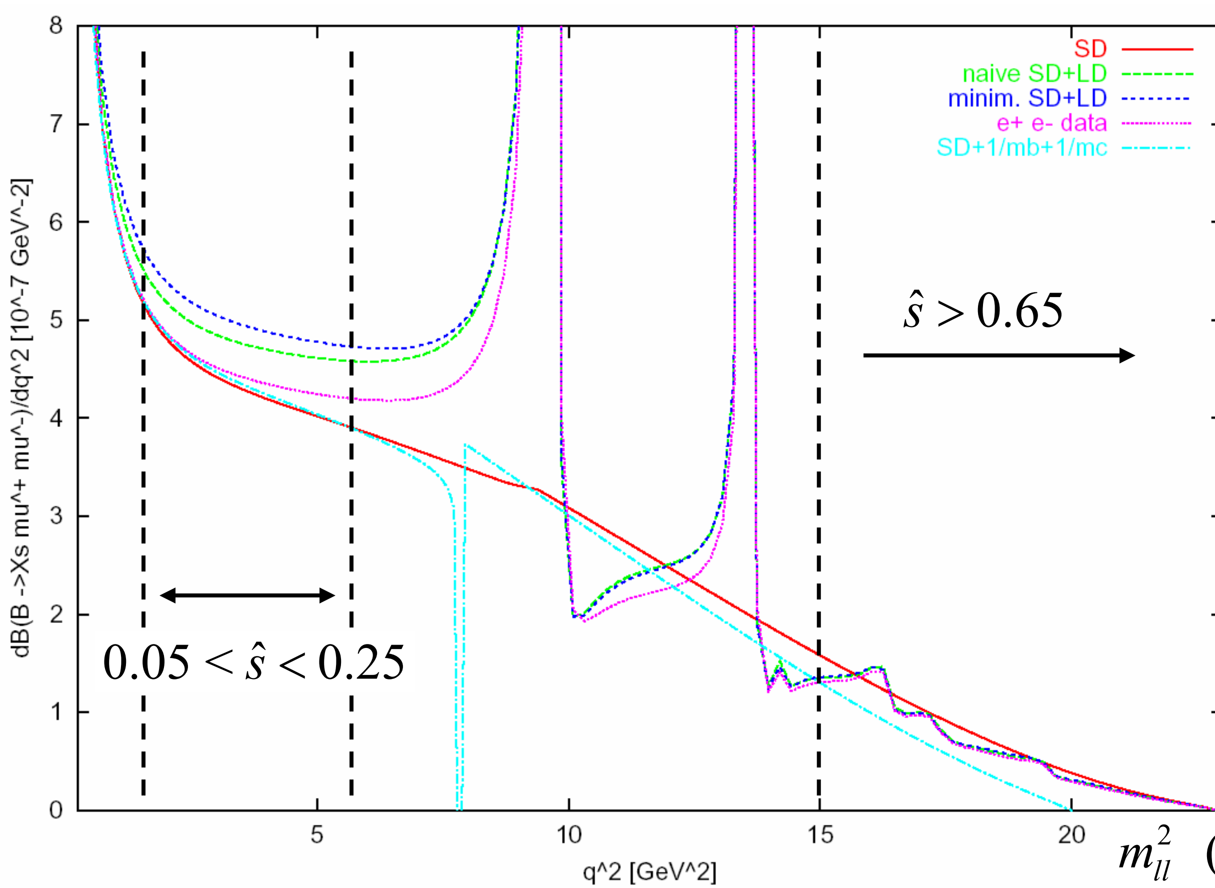
$\Rightarrow$ ~ 20% overall systematic uncertainty in BF

BF($B \to X_s\, l^+ l^-$) Projections (I)

- In addition to the broad spectrum, restricted dilepton mass regions are chosen to minimize long distance contributions from $c\,\bar{c}$ states

  $\to$ theory predictions are more reliable:

  BF($B \to X_s\, l^+ l^-$) = $(1.36 \pm 0.08_{scale}) \times 10^{-6}$ for $0.05 < \hat{s} < 0.25$ Asatryan *et al.* Ghinculov *et al.*



$$\hat{s} \equiv \frac{m_{ll}^2}{m_b^2}$$

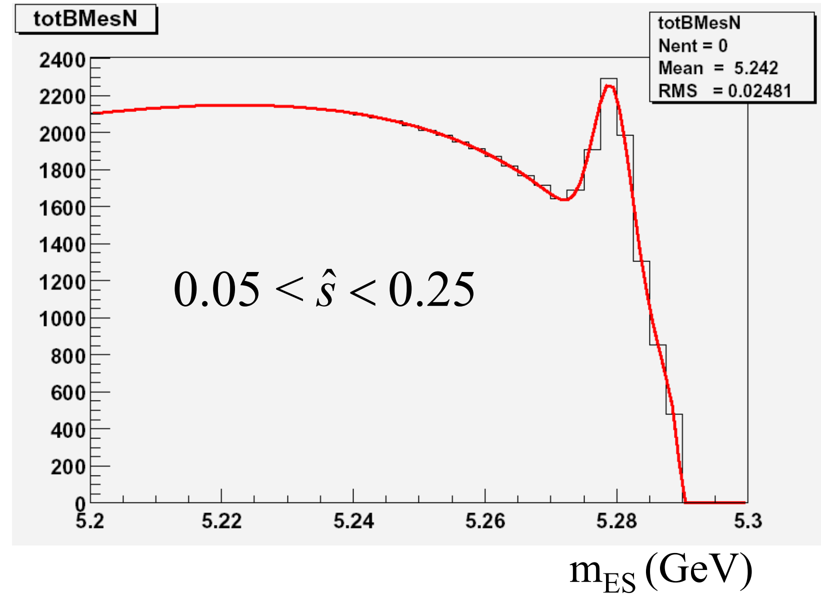
$$m_b = 4.80 \text{ GeV}$$

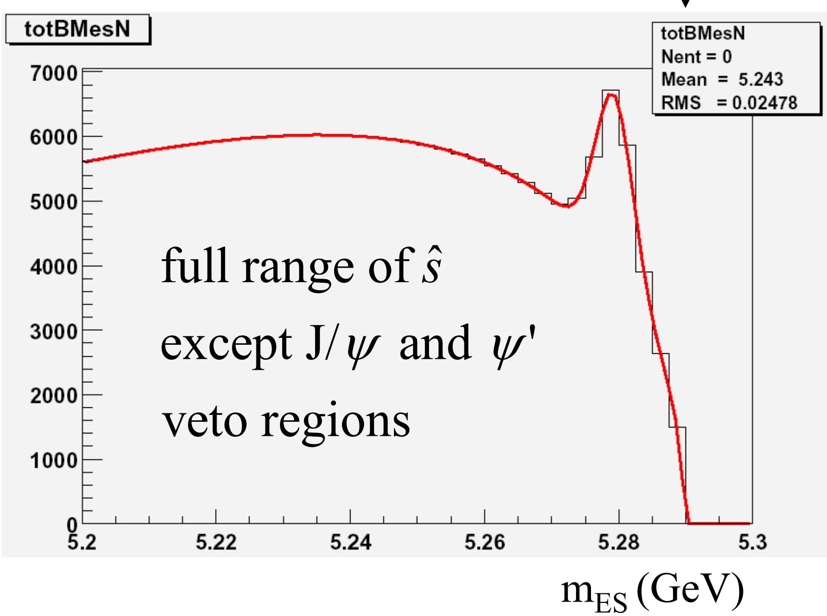
Fig. from G.Hiller

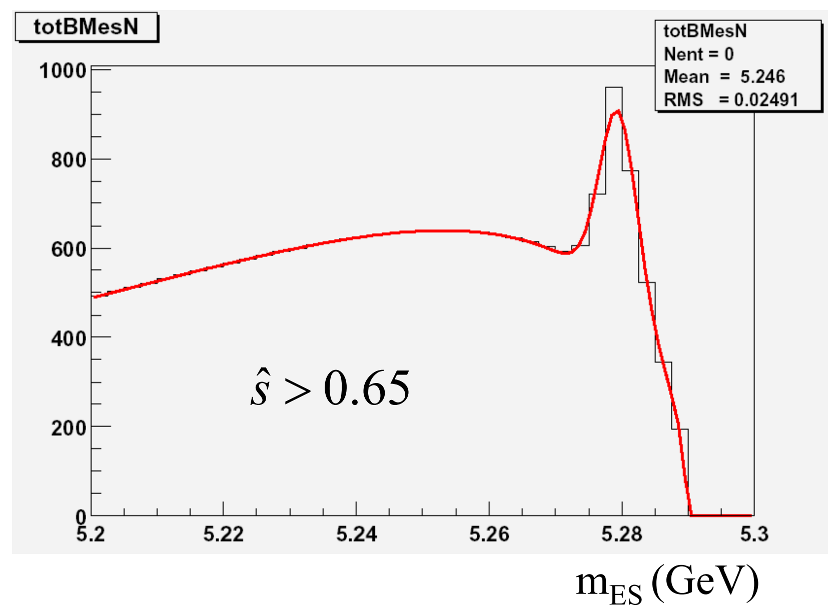
m_{ll}^2 (GeV^2)

BF($B \to X_s\, l^+l^-$) Projections (II)

- Extrapolate current BaBar analysis based on fully simulated MC
  - $B \to X_s\, e^+e^-$: 6.3 ab^{-1}
  - $B \to X_s\, \mu^+\mu^-$: 11.4 ab^{-1}
  - $B \to X$: 150 fb^{-1}
  - udsc : 47 fb^{-1}
- m_{ES} distributions for <u>10 ab^{-1}</u> (with smoothed background)







BF($B \to X_s\, l^+l^-$) Projections (III)

- Extrapolate current BaBar analysis (relative statistical errors shown in %)

Signal yield $X_s\, e^+e^- + X_s\, \mu^+\mu^-$	500 fb^{-1}	1000 fb^{-1}	10 ab^{-1}	50 ab^{-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%)
$\hat{s} > 0.65$	58 ± 13 (22%)	117 ± 18 (15%)	1171 ± 59 (5.0%)	5855 ± 132 (2.3%)

- Systematics: (start from current Belle numbers)

► Signal yield σ_{syst}^{yield} = 11% : should scale mostly as $\sqrt{1/N}$

► Efficiency σ_{syst}^{expt} = 11% : scale as $\sqrt{1/N}$?

possible exception for track efficiency → 0.8% per track ⇒ ~3% overall?

⇒ hit this limit at very high luminosity? limits for other single particle eff?

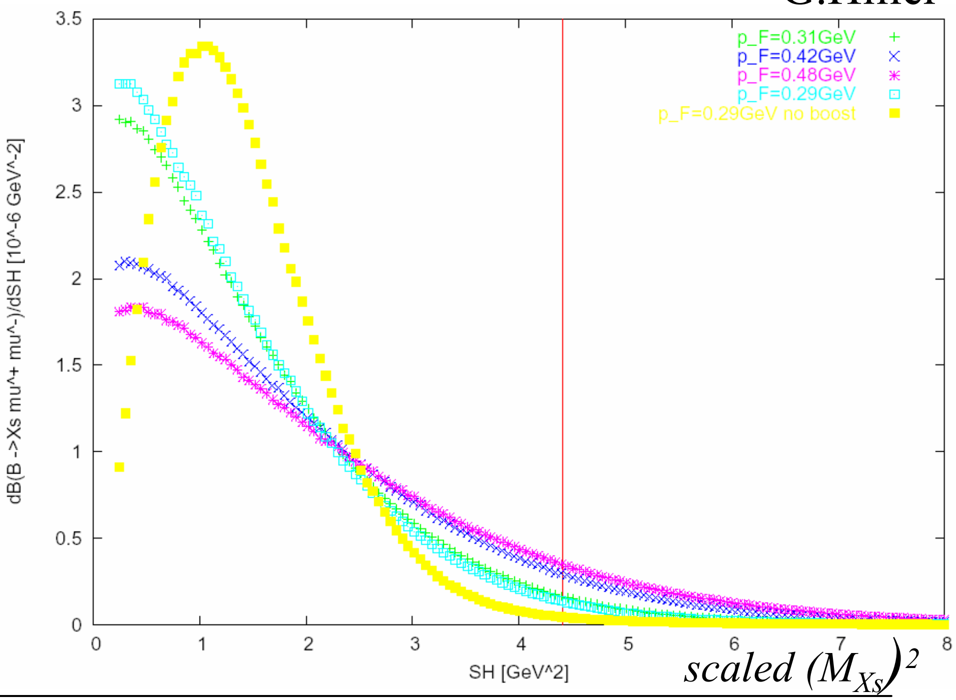
► Efficiency σ_{syst}^{model} = 13% : direct meas. of $K\, l^+l^-$ and $K^*\, l^+l^-$ improve 11% → 3%?

BF($B \to X_s\, l^+l^-$) Projections (IV)

- Extrapolation from list of exclusive modes to all final states:
  - ~25% loss due to K^0_L component can be corrected for 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)
  - $\Rightarrow$ need to rely on hadronization model (Jetset)
  - $\to$ calibrate with $B \to J/\psi\, X_s$ data? Need improved BF($B \to J/\psi\, X_s$) measts.
  - $\to$ measure BF for each topology
  - σ_{syst} 5% $\to$ 1-2%?

- Extrapolation to full $M(X_s)$ spectrum:
  - signal fraction with $M(X_s) < 2.1$ GeV is (93 ± 4)%
  - uncertainty due to Fermi motion
  - σ_{syst} 4% $\to$ 1%?

G.Hiller



BF($B \to X_s\, l^+ l^-$) Projections (V)

- Summary on relative uncertainties:

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

Lower bound on σ_{syst} assumes pure (and unrealistic) $\sqrt{1/N}$ scaling

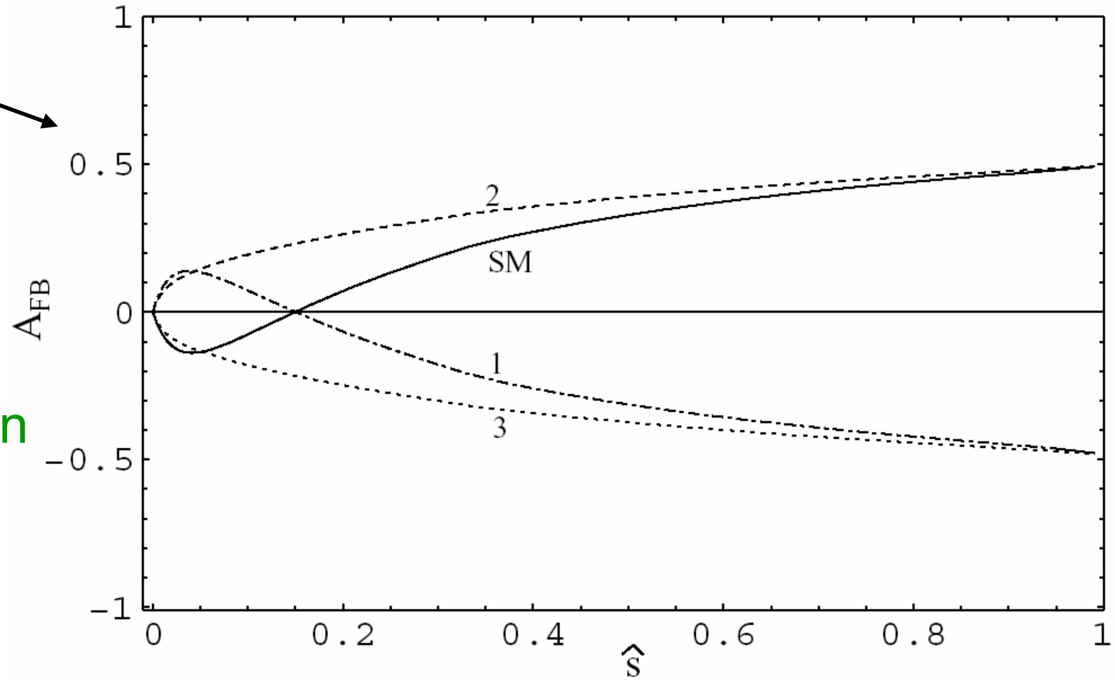
Extrapolation of σ_{syst} to high-luminosity B Factory is rather tricky…

Recall current theory uncertainties of ~15% for all $\hat{s}$
~6% for 0.05 < $\hat{s}$ < 0.25

Forward-Backward Asymmetry (I)

- Sensitive to new physics

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$



In dilepton rest frame:

N_F = # l^+ along b-quark direction

N_B = # l^+ opposite b-quark dir.

- Zero point of the asymmetry: $A_{FB} = 0$ for $\hat{s} = \hat{s}_0 = 0.162 \pm 0.008$ (NNLL)

prediction for $\hat{s}_0$ particularly robust

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

- Projections using BaBar analysis with $X_s \neq (K^+ \text{ or } K^0_S)$ and self-tagging modes only

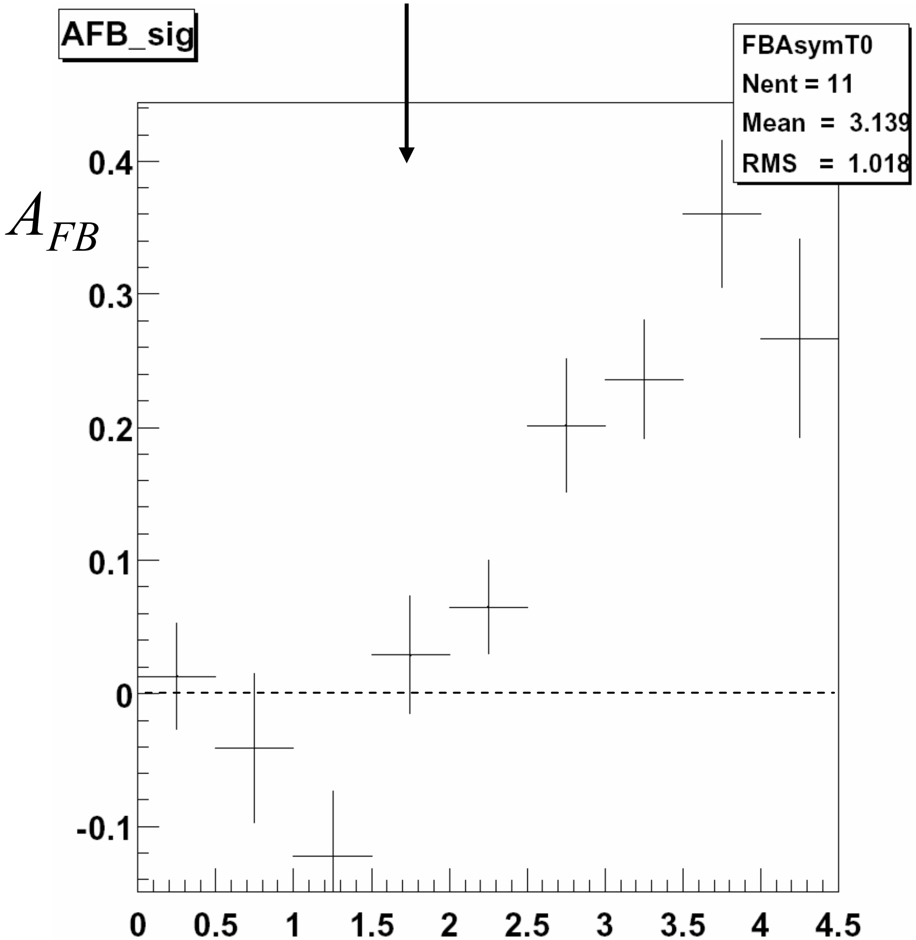
↑

$A_{FB} = 0$ for BF($B \rightarrow K\, l^+l^-$)

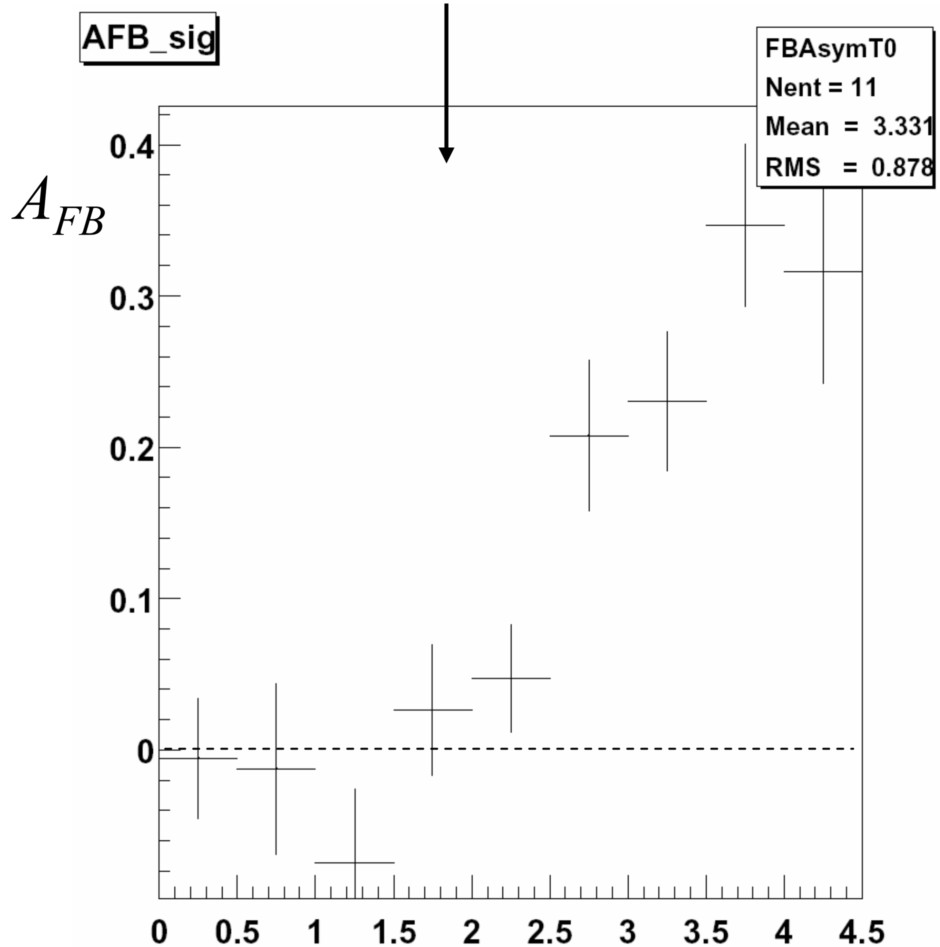
Forward-Backward Asymmetry (II)

- A_{FB} distributions for 10 ab^{-1} & pure signal events

reconstructed momenta



generated momenta



Momentum reconstruction does not affect asymmetry

m_{ll} (GeV)

Forward-Backward Asymmetry (III)

- A_{FB} statistical uncertainties for pure signal

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

zero point of the asymmetry: $A_{FB} = 0$ for $\hat{s} = \hat{s}_0 = 0.162 \pm 0.008$ (NNLL)

- A_{FB} statistical uncertainties for background-subtracted full sample

A_{FB} $X_s e^+e^- + X_s \mu^+\mu^-$	500 fb^{-1}	1000 fb^{-1}	10 ab^{-1}	50 ab^{-1}
$\hat{s} < \hat{s}_0$	-0.02 ± 0.17	-0.02 ± 0.12	-0.017 ± 0.039	-0.017 ± 0.017
$\hat{s} > \hat{s}_0$	0.17 ± 0.22	0.17 ± 0.16	0.173 ± 0.050	0.173 ± 0.022

$\Rightarrow$ A_{FB} clearly needs high-luminosity B Factory

Forward-Backward Asymmetry (IV)

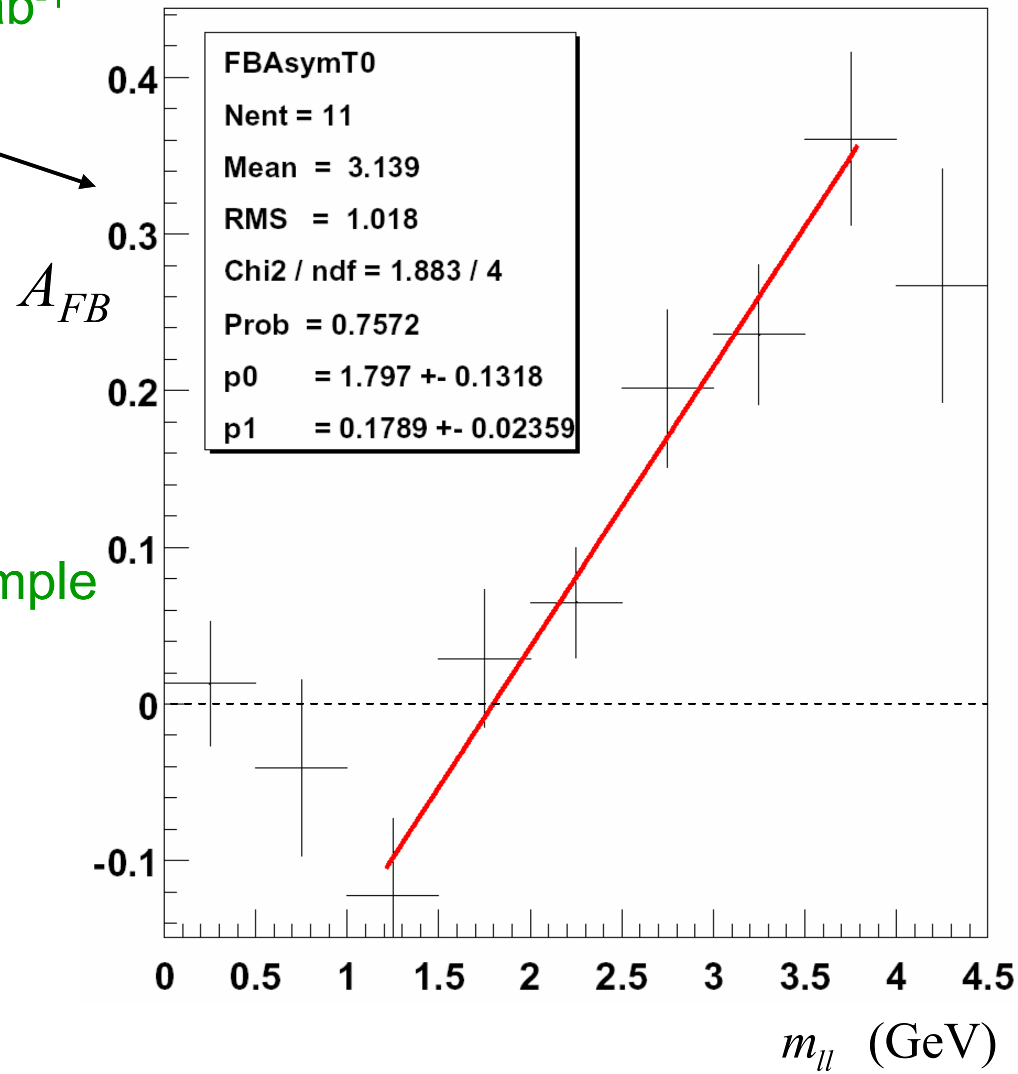
- A_{FB} zero-point for pure signal 10 ab^{-1}

$M_{ll0} = 1.80 \pm 0.13(\text{stat})$ GeV

$\Rightarrow \hat{s}_0 = 0.141 \pm 0.020(\text{stat})$

- For background-subtracted full sample

$\Rightarrow \hat{s}_0 \simeq 0.14 \pm 0.04(\text{stat})$



High Luminosity Options (I)

- Fully inclusive approach using full B decay reconstruction

Reconstruct hadronic decay $B \to D^{(*)} Y$

with fully reconstructed $D^{(*)}$ and $Y = n_1\pi^{\pm}\, n_2K^{\pm}\, n_3K^0{}_S\, n_4\pi^0$

Breco efficiency = 0.3% for $B^0\bar{B}^0$ and 0.5% for B^+B^- events (BaBar)

$\Rightarrow$ 10 ab^{-1} $\to$ ~10^{10} $B\bar{B}$ $\to$ 15 x 10^6 $B^0\bar{B}^0$ reco

25 x 10^6 B^+B^- reco

$\to$ ~40 million B mesons recoiling against fully reconstructed B

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

$\to$ assume 35% efficiency

$\Rightarrow$ expect 118 $B \to X_s\, l^+\, l^-$ signal events with $M(l^+l^-) > 0.2$ GeV

$\Rightarrow$ this becomes interesting with 50 ab^{-1}

would get ~600 signal events (σ_{stat} = 4%)

High Luminosity Options (II)

- <u>CKM impact</u>? Compare rates for b $\rightarrow$ d $l^+ l^-$ and b $\rightarrow$ s $l^+ l^-$ transitions

  $|V_{td} / V_{ts}|$ can be determined precisely from the ratio

$$\Delta R = \frac{\int_{1GeV^2}^{6GeV^2} ds \frac{dBF\left(B \to X_d l^+ l^-\right)}{ds}}{\int_{1GeV^2}^{6GeV^2} ds \frac{dBF\left(B \to X_s l^+ l^-\right)}{ds}} = \left(4.32 \pm 0.03\right)\%$$

Ali, Hiller EPJC8, 619 (1999)

[choosing dilepton mass range to avoid ρ^0, ω and J/ψ]

For $1 \leq s \leq 6$ GeV^2, Ali & Hiller predict

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

$$BF\left(B \to X_s l^+ l^-\right) = \left(9.61^{+1.32}_{-1.47}\right) \times 10^{-8}$$

10 ab^{-1} $\rightarrow$ working with a Breco sample would yield

62 B $\rightarrow$ X_s $l^+ l^-$ signal + 2.5 B $\rightarrow$ X_d $l^+ l^-$ signal

$\Rightarrow$ need a more efficient selection

(sum of exclusive modes? very hard for inclusive b $\rightarrow$ d transitions)

Summary

- Test of New Physics

  Inclusive $B \to X_s\ l^+ l^-$ 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 (1000 fb^{-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)

  - **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 $b \to d\ l^+ l^-$ rate $\to$ needs more study