Summary of Hiroyuki Nakayama's Thesis

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$B \rightarrow X_s l^+ l^-$ meeting

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Outline

1. Background
   a. Sensitivity to Physics Parameters
2. Analysis Methods
   a. Semi-inclusive samples
   b. Analysis techniques
   c. Backgrounds and suppression
3. Results
   a. Observed Events
   b. Simple Case
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Sensitivity to Physics Parameters

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

$$\begin{aligned}
\mathcal{O}_1 &= (\bar{s}_\alpha \gamma_\mu L c_\beta)(\bar{c}_\beta \gamma^\mu L b_\alpha), \\
\mathcal{O}_2 &= (\bar{s}_\alpha \gamma_\mu L c_\alpha)(\bar{c}_\beta \gamma^\mu L b_\beta), \\
\mathcal{O}_3 &= (\bar{s}_\alpha \gamma_\mu L b_\alpha) \sum_{q=u,d,s,c,b} (\bar{q}_\beta \gamma^\mu L q_\beta), \\
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\mathcal{O}_5 &= (\bar{s}_\alpha \gamma_\mu L b_\alpha) \sum_{q=u,d,s,c,b} (\bar{q}_\beta \gamma^\mu R q_\beta), \\
\mathcal{O}_6 &= (\bar{s}_\alpha \gamma_\mu L b_\beta) \sum_{q=u,d,s,c,b} (\bar{q}_\beta \gamma^\mu R q_\alpha), \\
\mathcal{O}_7 &= \frac{e}{16\pi^2} \bar{s}_\alpha \sigma_{\mu\nu} (m_s L + m_b R) b_\alpha F^{\mu\nu}, \\
\mathcal{O}_8 &= \frac{g}{16\pi^2} \bar{s}_\alpha \sigma_{\mu\nu} (m_s L + m_b R) T^a_{\alpha\beta} b_\beta G^{a\mu\nu}, \\
\mathcal{O}_9 &= \frac{e}{16\pi^2} (\bar{s}_\alpha \gamma^\mu L b_\alpha)(\bar{\ell} \gamma_\mu \ell), \\
\mathcal{O}_{10} &= \frac{e}{16\pi^2} (\bar{s}_\alpha \gamma^\mu L b_\alpha)(\bar{\ell} \gamma_\mu \gamma_5 \ell),
\end{aligned}$$

Sensitivity to Physics Parameters

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\end{aligned}$$

$X_s l^+ l^-$: sensitive to $C_i(\mu)$ for:

EM Operator ($\mathcal{O}_7$)

Electroweak Penguin Vector Component ($\mathcal{O}_9$)

Electroweak Penguin Axial Component ($\mathcal{O}_{10}$)

Detecting New Physics

Deviations from Standard Model predictions could be indicative of new physics:

$$C_i(\mu)_{exp} = C_i(\mu)_{SM} + C_i(\mu)_{BSM}$$

Branching fractions in the dileption mass region $M^2_{l+l-} < (6\text{ GeV})^2$ range has a clean theoretical value, and thus is of particular interest.

$$\frac{d\Gamma(b \to s\ell^+\ell^-)}{d\hat{s}} = \left(\frac{\alpha_{EM}}{4\pi}\right)^2 \frac{G_F^2 m_b^5 |V_{ts}^* V_{tb}|^2}{48\pi^3}(1-\hat{s})^2 \times \left[(1+\hat{s})(|C_9|^2 + |C_{10}|^2) + 4(1+2/\hat{s})|C_7|^2 + 12\mathrm{Re}(C_7 C_9{}^*)\right],$$

where $\hat{s}$ is defined as $\hat{s} = M^2_{\ell^+\ell^-}/m^2_{b,pole}$.

Forward-backward asymmetry is also dependent on M^2_{l+l-} and thus is also of interest.

Semi-inclusive Analysis Approach

$B \rightarrow X_s l^+ l^-$ decays included in the analysis contain:

- Dilepton pair
- $K^\pm$ or K_S
- Up to 4 πs (at most one can be neutral)

} 18 states possible

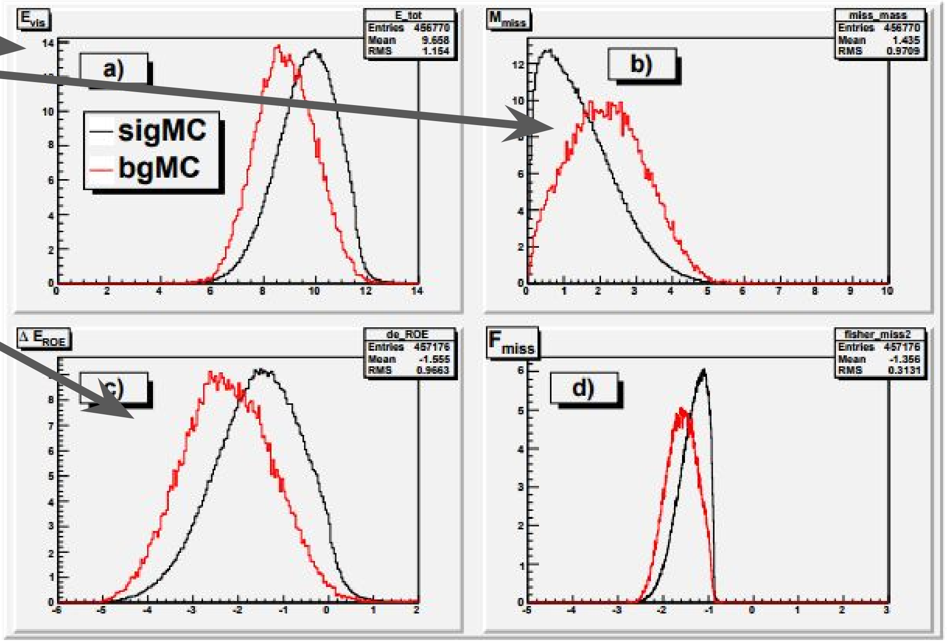
Provides strong kinematic discrimination against bg wrt fully-inclusive approach* using beam-energy contrained mass and ΔE between the reconstructed B and the beam energy.

According to MC, the samples included cover ~62% of the X_s decay states (41% $K^\pm$, 21% K_S) with K_L expected to provide similar numbers and ~18% unaccounted for.

*: I don't believe this is explained in the text

Background Suppression

- Backgrounds suppressed with a Fisher discriminant (provide link to citation [46])
- Largest bg source is random combinations from semileptonic B decays
  - (b→ c→ s,d decay chain)
  - Rejected with Fisher variable constructed from:
    - Visible energy
    - Missing mass
    - Energy difference for ‘Rest of Event’
      - (i.e., energy not included in B reco)



Likelihood cuts

- Use likelihood ratio with 6 variables to select most signal-like B
  - ΔE
  - $\cos(\theta_B)$ (θ_B = angle between B flight direction and e^- beam)
  - F_{miss} (same variable used in bg suppression)
  - F_{FW} (discriminant characterizing event topology)
  - χ^2_{VTX}/NDF
  - $|\Delta z_{l+l-}|$
- Log-likelihoods calculated and the candidate in each event with the largest ratio $L_{sig}/(L_{sig}+L_{bg})$ is retained

According to MC, probability that all daughters are selected and assigned correctly is 80% in $B \rightarrow X_s l^+ l^-$

Maximum Likelihood Fit

In (very) brief:

PDF component	Used function	fix or float
$X_s\ell^+\ell^-$ fit		
Signal (sig)	Gaussian	N_{sig}:float, shape:fix
Background (bkg)	ARGUS	N_{bkg}:float, shape:float(common)
Peaking background (pkg)	histogram shape	N_{pkg}:fix
Peaking background from higher psi (psi)	Gaussian	N_{psi}:fix, shape:fix
Self cross-feed (scf)	histogram shape	$N_{\mathrm{scf}}/N_{\mathrm{sig}}$:fix
$X_s e\mu$ fit		
Background (bkg, $e\mu$)	ARGUS	$N_{\mathrm{bkg},e\mu}$:float, shape:float (common)
Peaking background (pkg, $e\mu$)	histogram shape	$N_{\mathrm{pkg},e\mu}$:fix

- Peaking background refers to:
  - Charmonium peaking background: (note: according to Hiro, this is the major complication)
    - $B \to J/\psi X_s$ or $B \to \psi(2S) X_s$ where the J/ψ or $\psi(2S)$ decays to l^+l^-
    - Higher ψ resonances (ψ(3770), ψ(4040), ψ(4160))
  - Hadronic peaking background:
    - $B \to X_s hh$, hadrons mis-ID'd as leptons
    - $B \to X_s hl\nu$ with a mis-ID'd hadron

Systematics

Overall largest contribution →

Source	$X_s\, e^+e^-$	$X_s\, \mu^+\mu^-$
Signal Gaussian shape	± 0.3	± 0.1
$J/\psi, \psi(2S)$ peaking background	± 1.2	± 0.9
Higher ψ peaking background	± 0.9	± 0.9
Hadronic peaking background	$^{+0.4}_{-0.5}$	$^{+0.2}_{-0.3}$
Self Cross-feed error	± 0.1	± 0.1
Signal yield subtotal	± 1.6	± 1.3
Tracking efficiency	± 3.6	± 3.6
Lepton identification efficiency	± 2.1	± 2.2
Kaon identification efficiency	± 0.4	± 1.0
$\pi^\pm$ identification efficiency	± 3.4	± 3.0
K^0_S efficiency	± 0.9	± 0.9
π^0 efficiency	± 0.5	± 0.5
$\mathcal{R}$ cut efficiency	± 5.3	± 2.6
Detector model subtotal	± 7.6	± 6.0
Fermi motion model	$^{-4.9}_{+1.3}$	$^{-2.0}_{+0.6}$
$\mathcal{B}(B \to K\ell^+\ell^-)$	± 6.0	± 6.8
$\mathcal{B}(B \to K^*\ell^+\ell^-)$	± 6.8	± 6.8
K^*–X_s transition	$^{-6.8}_{+2.3}$	$^{-7.1}_{+2.7}$
Hadronization	± 5.8	± 5.5
Missing modes	± 1.7	± 1.7
Signal model subtotal	$^{+11.2}_{-13.7}$	$^{+11.5}_{-13.4}$
Monte Carlo statistics	< 0.1	< 0.1
$B\bar{B}$ counting	± 1.4	± 1.4
Total	$^{+13.6}_{-15.8}$	$^{+13.1}_{-14.8}$
$M_{X_s} > 2.0\mathrm{GeV}/c^2$ extrapolation	$^{+6.5}_{-10.9}$	$^{+3.0}_{-5.0}$
Total(extrapolated)	$^{+15.1}_{-19.2}$	$^{+13.4}_{-15.6}$

Results

Two methods for obtaining final results:

- Simple: Use fit results with syst. uncertainty calculations to obtain a global branching fraction.
    - Intuitive, but suffers from a large systematic error from signal MC mixing ratio
- Sum-up: calculate branching fractions in each bin and sum.
    - Simplifies the systematics, but bin-by-bin stat errors are poor.

Results

Mode	Candidates	ARGUS shape	N_{sig}	Significance
$B \to X_s e^+ e^-$	578	-14.8 ± 1.8	$123.6 \pm 19.5 \pm 2.0$	7.0
$B \to X_s \mu^+ \mu^-$	432	-15.4 ± 1.9	$118.3 \pm 17.3 \pm 1.5$	7.9
$B \to X_s \ell^+ \ell^-$	1010	-15.7 ± 1.7	$237.8 \pm 26.4 \pm 2.5$	10.0

Mode	N_{sig}	Significance	ϵ (%)	$\mathcal{B}$ ($\times 10^{-6}$)
$B \to X_s e^+ e^-$	$123.6 \pm 19.5 \pm 2.0$	7.0	$2.56 \pm 0.01^{+0.34}_{-0.33}$	$3.67 \pm 0.58^{+0.49}_{-0.47}$
$B \to X_s \mu^+ \mu^-$	$118.3 \pm 17.3 \pm 1.5$	7.9	$2.67 \pm 0.01^{+0.36}_{-0.34}$	$3.38 \pm 0.49^{+0.46}_{-0.44}$
$B \to X_s \ell^+ \ell^-$	$237.8 \pm 26.4 \pm 2.5$	10.0	$2.62 \pm 0.00^{+0.35}_{-0.33}$	$3.46 \pm 0.38^{+0.47}_{-0.45}$

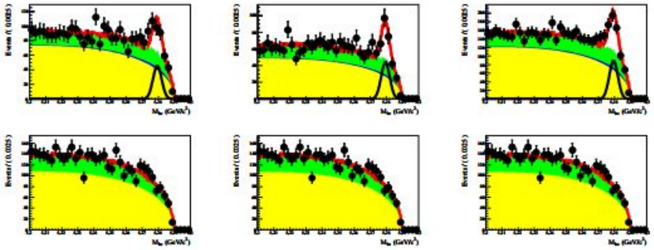
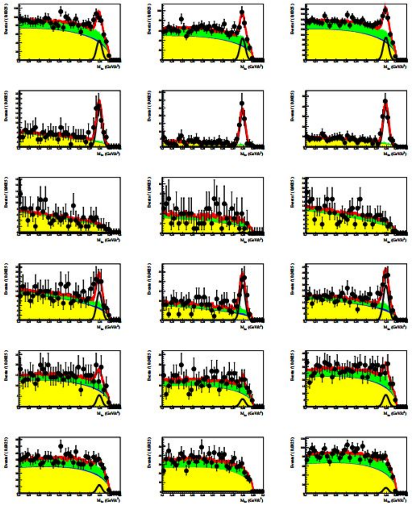


Figure 6.1: M_{bc} distribution of the $605\,\mathrm{fb}^{-1}$ of $B \to X_s \ell^+ \ell^-$ sample(upper) and $605\,\mathrm{fb}^{-1}$ of $B \to X_s e^{\pm} \mu^{\mp}$ sample(lower). Each column corresponds to e^+e^-(left), $\mu^+\mu^-$(center) and $\ell^+\ell^-$ (right) cases. Background, peaking background, self cross feed components are shown in yellow, green, blue areas, respectively. Signal component is shown in the black line.

Sum-up method results (reported as final)

Mode	$\mathcal{B}$ ($\times 10^{-6}$)
$B \to X_s e^+ e^-$	$4.59 \pm 1.15^{+0.56}_{-0.51}$
$B \to X_s \mu^+ \mu^-$	$1.91 \pm 1.02^{+0.15}_{-0.14}$
$B \to X_s \ell^+ \ell^-$	$3.22 \pm 0.79^{+0.28}_{-0.25}$



Conclusions

- Results consistent with SM predictions and previous results
- non-SM-like C_7 disfavored in updated constraints on Wilson coefficients

Table 9.1: The $B \to X_s \ell^+ \ell^-$ branching fractions (in $\times 10^{-6}$) measured in this thesis and predicted by the theoretical calculations. The new results shows that the non SM-like sign of C_7 is unlikely.

$M_{\ell^+\ell^-}$ range	World average in 2005 [1]	Measured by this thesis	SM	C_7 = -C_7^{SM}
$M_{\ell^+\ell^-} > 0.2\,\mathrm{GeV}/c^2$	4.5±1.1	3.3 ±0.80 $^{+0.37}_{-0.44}$	4.4± 0.7	8.8 ± 0.7
$1 < M^2_{\ell^+\ell^-} < 6\,(\mathrm{GeV}/c^2)^2$	1.60±0.5	0.99 ±0.20 $^{+0.09}_{-0.08}$	1.57 ± 0.16	3.30 ± 0.25

Backup Material

Event Selection Criteria

Table 4.1: Summary of the particle selection criteria.

Particle	Selection criteria
Charged track	$\lvert dr \rvert < 1.0\,\mathrm{cm}$
	$\lvert dz \rvert < 5.0\,\mathrm{cm}$
Electron	$P_{lab} > 0.4\,\mathrm{GeV/c}$
	electron probability > 0.8
Muon	Not selected as electron
	$P_{lab} > 0.8\,\mathrm{GeV/c}$
	muon likelihood > 0.97
	`atc_pid` probability < 0.6 (muon-like)
Kaon	Not selected as electron, muon
	`atc_pid` probability > 0.6 (kaon-like)
Pion	Remaining tracks after selecting the lepton and $K^{\pm}$ tracks.
K_S^0	K_S^0-like vertex,impact parameters
	$\lvert m(\pi^+\pi^-) - m(K_S^0) \rvert < 15\,\mathrm{MeV/c^2}$
π^0	$E_\gamma > 50\,\mathrm{MeV}$
	$E_{\pi^0} > 400\,\mathrm{MeV}$
	$\lvert m(\gamma\gamma) - m(\pi^0) \rvert < 10\,\mathrm{MeV/c^2}$