Improved Measurement of the Electroweak Penguin Process $B \to X_s l^+l^-$ at Belle

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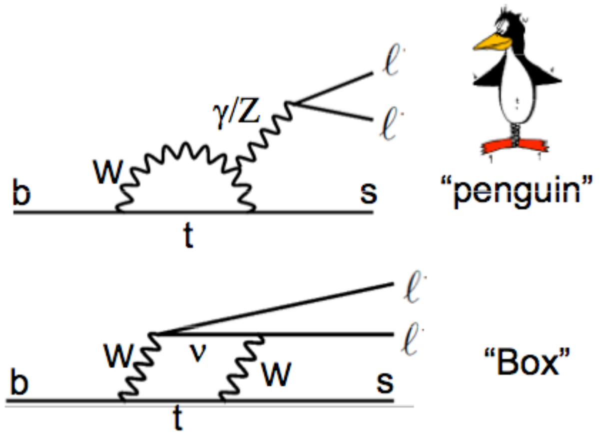
24 July 2010, Paris, France

35th International Conference on High Energy Physics

Theoretical Motivation

- The FCNC (Flavor Changing Neutral Current) process is forbidden at tree level, and can only occur at high order via electroweak penguin and W^+W^- box diagrams:

$b \rightarrow s\, l^+ l^-$



- This decay mode is sensitive to the new physics that may contribute in the loops [A. Ali *et al.*, PRD 66, 034002 (2002); T. Hurth, hep-ph/0212304, SLAC-PUB-9604 (2003); U. Egede *et al*, arXiv: 0807.2589; J. Matias, arXiv: 0807.2579].

Wilson Coefficient

- In the effective Hamiltonian, Wilson coefficient is the strength of corresponding short distance operator:

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

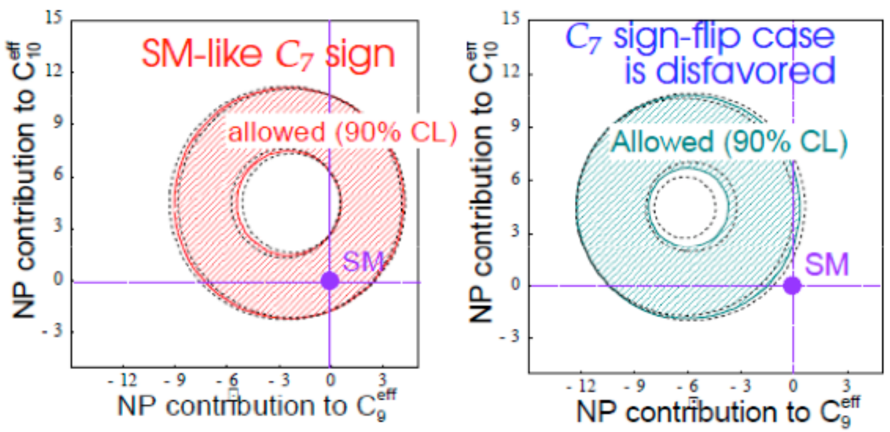
$$\text{where} \begin{cases} O_7 = \frac{e}{16\pi^2} \bar{s}_\alpha \sigma_{\mu\nu} (m_s L + m_b R) b_\alpha F^{\mu\nu}, \\ O_9 = \frac{e^2}{16\pi} \bar{s}_\alpha \gamma^\mu L b_\alpha \bar{l} \gamma_\mu l, \\ O_{10} = \frac{e^2}{16\pi} \bar{s}_\alpha \gamma^\mu L b_\alpha \bar{l} \gamma_\mu \gamma_5 l, \end{cases}$$

- For $b \to s\, l^+ l^-$ case, only O_7, O_9 and O_{10} appear in effective Hamiltonian
- Constraining the Wilson coefficient by $b \to s\, l^+ l^-$ decay can probe New Physics

Observables

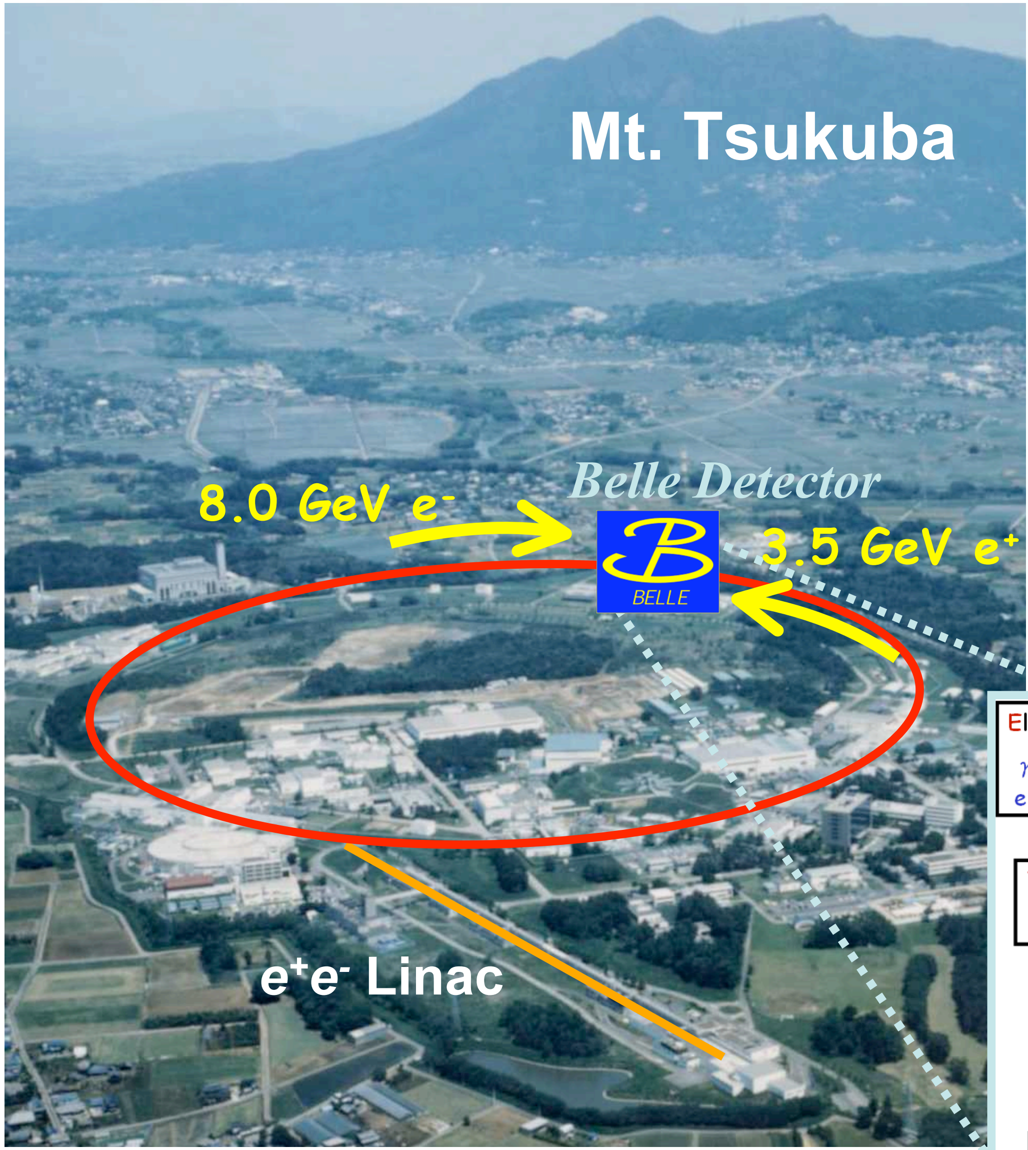
- The Wilson coefficients, C_9, C_{10} and sign C_7, can be constrained by measuring the branching fraction (BF) of $B \to X_s l^+ l^-$
- The M_{Xs} and M_{l+l-}^2 distributions can also test the fragmentation model and non-SM effect **($\hat{s} = M_{l+l-}^2 / m_b^2$)**

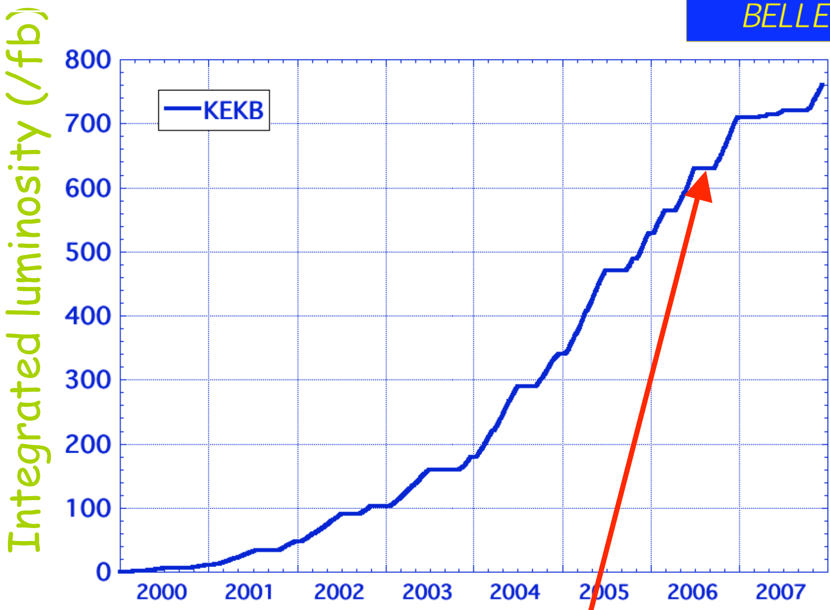
$$\frac{dBF(B \to X_s l^+ l^-)}{d\hat{s}} \propto (4 + \frac{8}{\hat{s}})\left|C_7^{eff}\right|^2 + (1 + 2\hat{s})(\left|C_9^{eff}\right|^2 + \left|C_{10}^{eff}\right|^2) + 12\mathrm{Re}(C_7^{eff} C_9^{eff*})$$



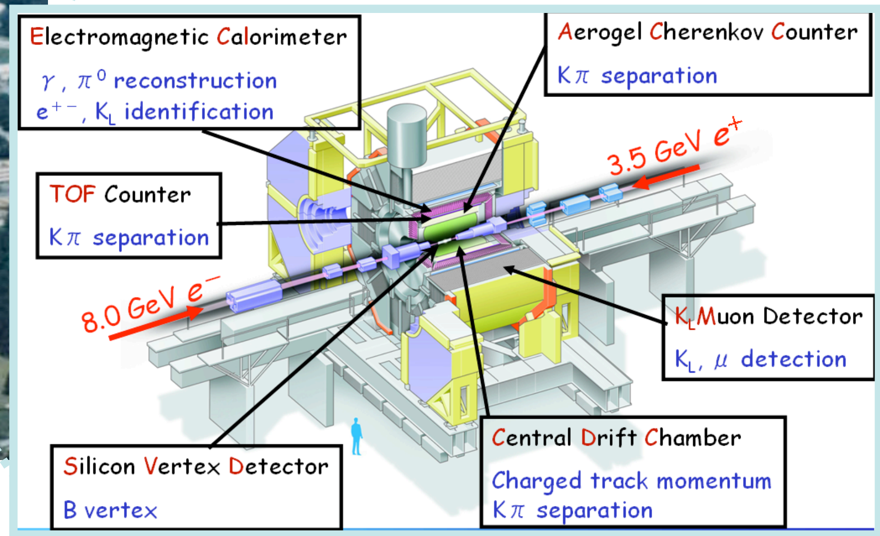
P.Gambino, U.Haisch and M.Misiak PRL 94 061803 (2005)

KEKB & Belle





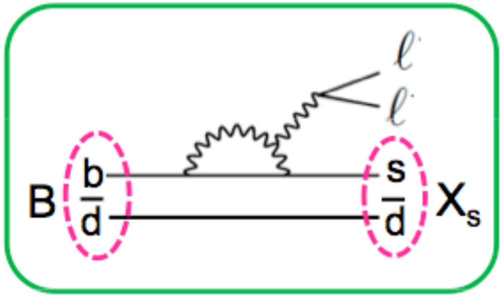
Results are based on 657 M$B\bar{B}$ pairs



$B \to X_s l^+l^-$ Analysis

- For $B \to X_s l^+l^-$ analysis, we sum up 36 exclusive modes:

X_s : $K^{\pm}/K^0_S + n\pi^{\pm}/m\pi^0$ ($n \le 4$, $m \le 1$); l^+l^- : $e^+e^-/\mu^+\mu^-$



$B^0 \to K^+\pi^-l^+l^-$

$K^+\pi^-\pi^0l^+l^-$

$K^+\pi^-\pi^+\pi^-l^+l^-$

$K^+\pi^-\pi^+\pi^-\pi^0l^+l^-$

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

$K^+\pi^0l^+l^-$

$K^+\pi^+\pi^-l^+l^-$

$K^+\pi^+\pi^-\pi^0l^+l^-$

$K^+\pi^+\pi^-\pi^+\pi^-l^+l^-$

$B^0 \to K^0_sl^+l^-$

$K^0_s\pi^0l^+l^-$

$K^0_s\pi^+\pi^-l^+l^-$

$K^0_s\pi^+\pi^-\pi^0l^+l^-$

$K^0_s\pi^+\pi^-\pi^+\pi^-l^+l^-$

$B^+ \to K^0_s\pi^+l^+l^-$

$K^0_s\pi^+\pi^0l^+l^-$

$K^0_s\pi^+\pi^-\pi^+l^+l^-$

$K^0_s\pi^+\pi^-\pi^+\pi^0l^+l^-$

+ charge conjugate

~60% coverage of all X_S state

~80% coverage assuming $BF(K^0_LX_S)=BF(K^0_SX_S)$

Event Reconstruction and Background Suppression

- Particle selection: $K^{\pm}$, K_s^0, $\pi^{\pm}$, π^0, $e^{\pm}$, $\mu^{\pm}$
- Event reconstruction variables:

  - Beam constrain mass: $M_{bc} = \sqrt{E_{beam}^2 - \left| \sum \vec{P}_{X_s l^+ l^-} \right|^2}$ $\left(E_{beam} = \frac{\sqrt{s}}{2} \approx 5.29 GeV \right)$

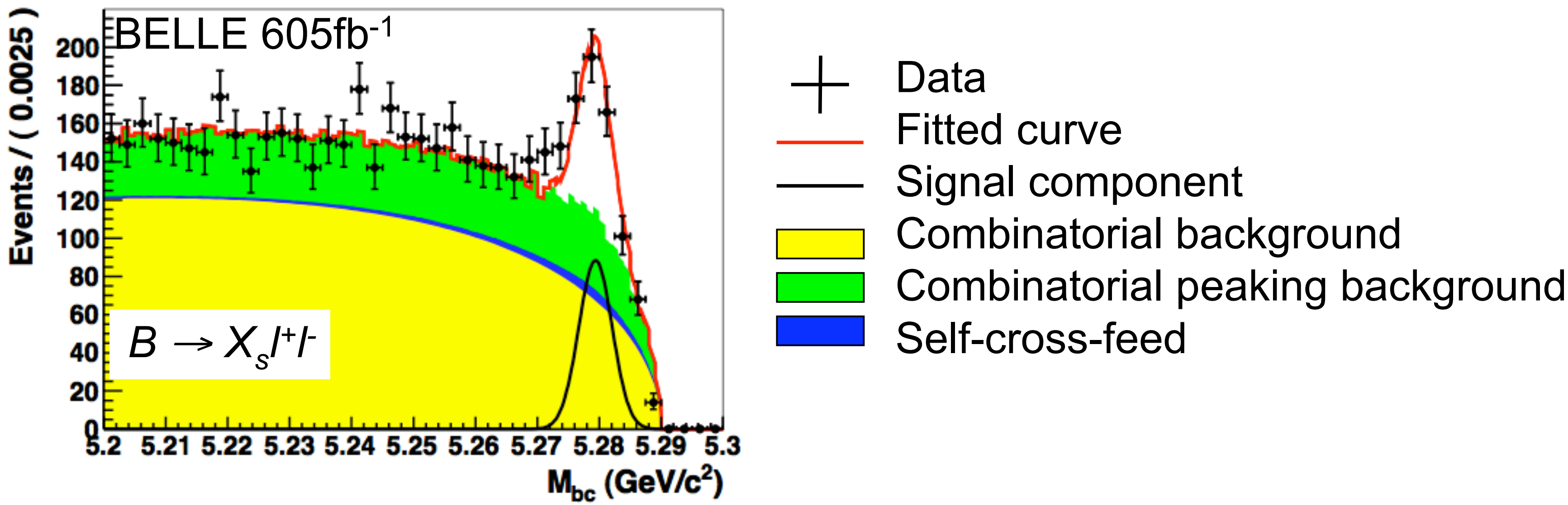
  - Energy difference: $\Delta E = E_B - E_{beam}$

  - $M(X_s, l^+l^-)$: $M(X_s, l^+ l^-) = \sqrt{E_{Xs,l^+l^-}^2 - \left| \sum \vec{P}_{Xs,l^+l^-} \right|^2}$ [Also apply J/ψ and $\psi(2S)$ veto]

- Background suppression:
  - For $b \to c \to s,d$ background: using missing mass and missing energy information (since ν is produced from these decays)
  - For $e^+e^- \to q\bar{q}$ $(q=u,d,s,c)$ background: using Fox-Wolfram momentum information (since this decay shape is jet-like)
- Multiple candidates: we select best candidate using ΔE, vertex χ^2, etc.
- We extract signals fit to M_{bc}

M_{bc} Fit Results

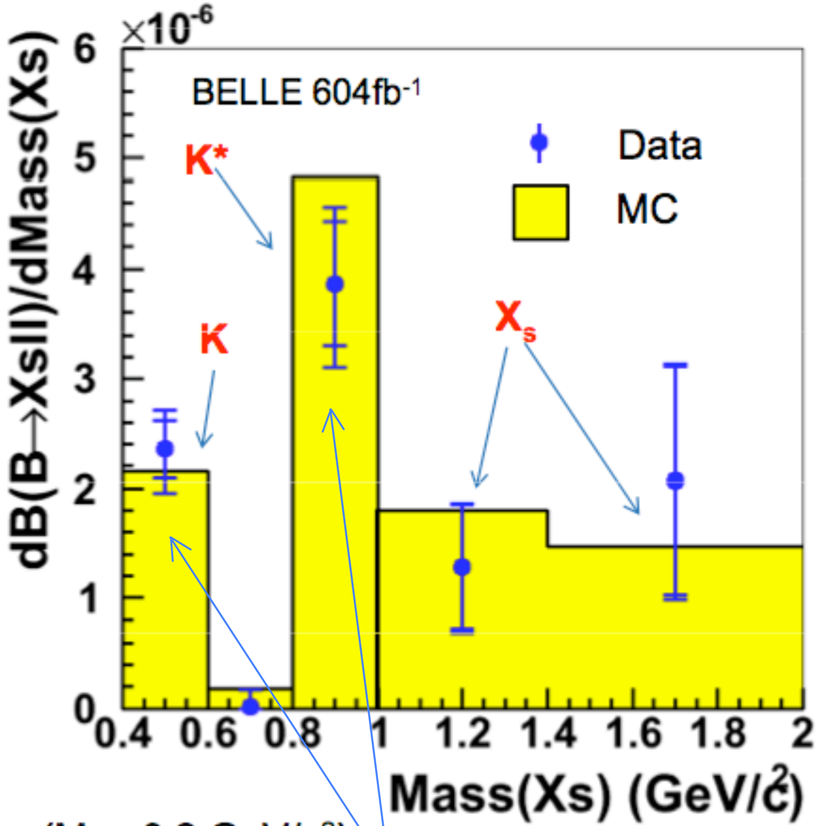
(For $M_{X_s} < 2.0$ GeV/c^2 and $M_{l+l-} > 0.2$ GeV/c^2)



Mode	Yield	BF (x 10^{-6})	Σ
$B \to X_s e^+ e^-$	121.6 ± 19.3(stat.) ± 2.0(syst.)	4.56 ± 1.15(stat.) $^{+0.33}_{-0.40}$(syst.)	7.0
$B \to X_s \mu^+ \mu^-$	118.5 ± 17.3(stat.) ± 1.5(syst.)	1.91 ± 1.02(stat.) $^{+0.16}_{-0.18}$(syst.)	7.9
$B \to X_s l^+ l^-$	238.3 ± 26.4(stat.) ± 2.3(syst.)	3.33 ± 0.80(stat.) $^{+0.19}_{-0.24}$(syst.)	10.1

ps: BF($X_s e^+ e^-$) / BF($X_s \mu^+ \mu^-$) = 2.39 ± 1.41

dBF($X_s l^+ l^-$) / dM_{Xs}



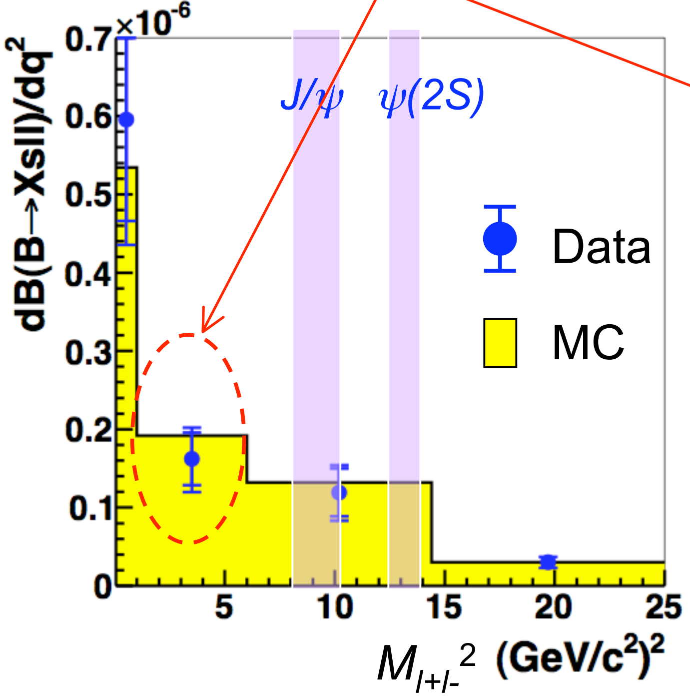
(M_{ll} > 0.2 GeV/c^2)

Our MC fragmentation model is consistent with data

B → K^{(*)}l^+l^- MC normalization is based on HFAG (ICHEP08):
http://www.slac.stanford.edu/xorg/hfag/rare/index.html

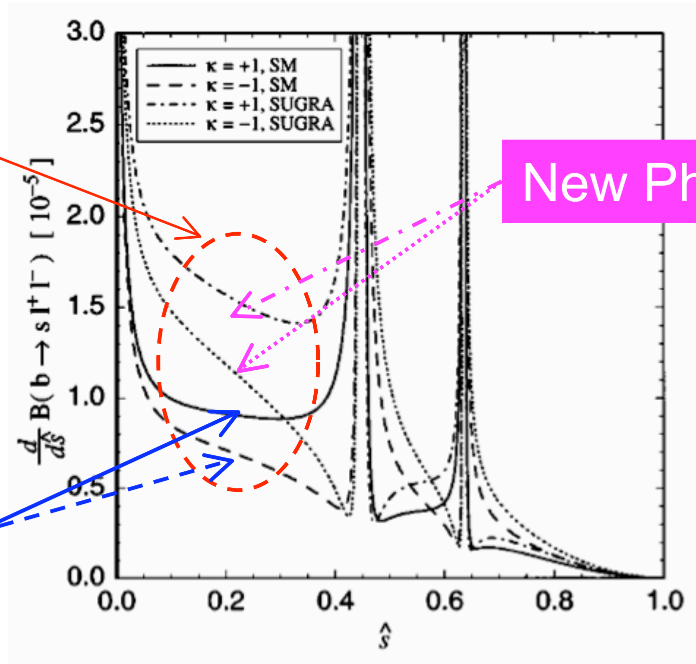
$dBF(X_s l^+ l^-) / dM_{l+l-}^2$

This region is sensitive to New Physics



Our M_{l+l-}^2 distribution is consistent with SM

T.Goto *et al.*, PRD **55** 4273 (1997)



New Physics

SM

$\hat{s} = M_{l+l-}^2 / m_b^2$

Systematic Errors

- Peaking backgrounds (fit PDF systematics):
  - $B \to J/\psi X_s$, $\psi(2S) X_s$
  - $B \to \psi(3770) X_s$, $\psi(4040) X_s$, $\psi(4160) X_s$
  - $B \to X_s \pi\pi$, $B \to X_s \pi l \nu$

  …
- Detector systemaitcs:
  - Tracking efficiency
  - Lepton identification efficiency
  - Kaon/pion efficiency

  …
- MC modeling systematics:
  - BF($B \to K^* l^+ l^-$) and BF($B \to K l^+ l^-$) assumptions
  - Transitions between $K^* l^+ l^-$ and $X_s l^+ l^-$
  - X_s decay fractions
  - X_s decay with two or more kaons

  …

Summary

- We have measured the branching fraction of $B \rightarrow X_s l^+ l^-$ to be $(3.33 \pm 0.80\ ^{+0.19}_{-0.24})$x 10^{-6} with 10.1σ significance, the $B\bar{B}$ data sample used is 657M.

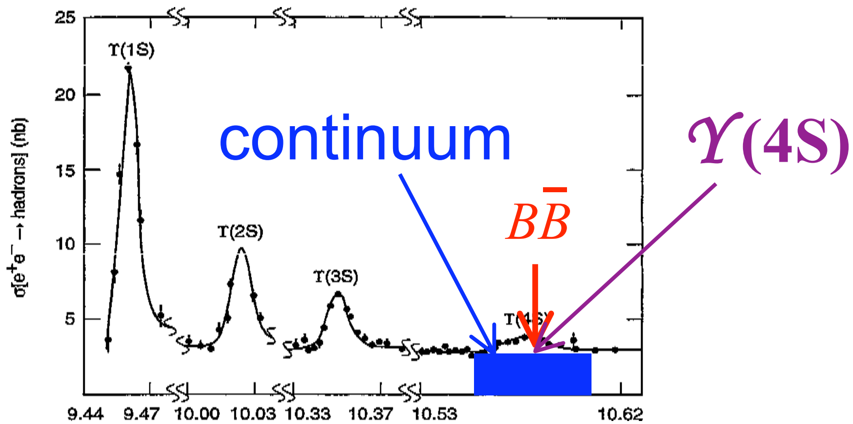
- The distributions of $dBF(X_s l^+ l^-) / dM_{Xs}$ and $dBF(X_s l^+ l^-) / dM_{l+l-}^2$ are consistent with SM prediction.

- The ratio $BF(X_s e^+ e^-) / BF(X_s \mu^+ \mu^-) = 2.39 \pm 1.41$ is within our assumption $BF(X_s e^+ e^-) / BF(X_s \mu^+ \mu^-) = 1.0$. The systematic uncertainty for $X_s l^+ l^-$ efficiency with this assumed value is about 1.5%. This ratio can be checked in future with more $B\bar{B}$ data sample.

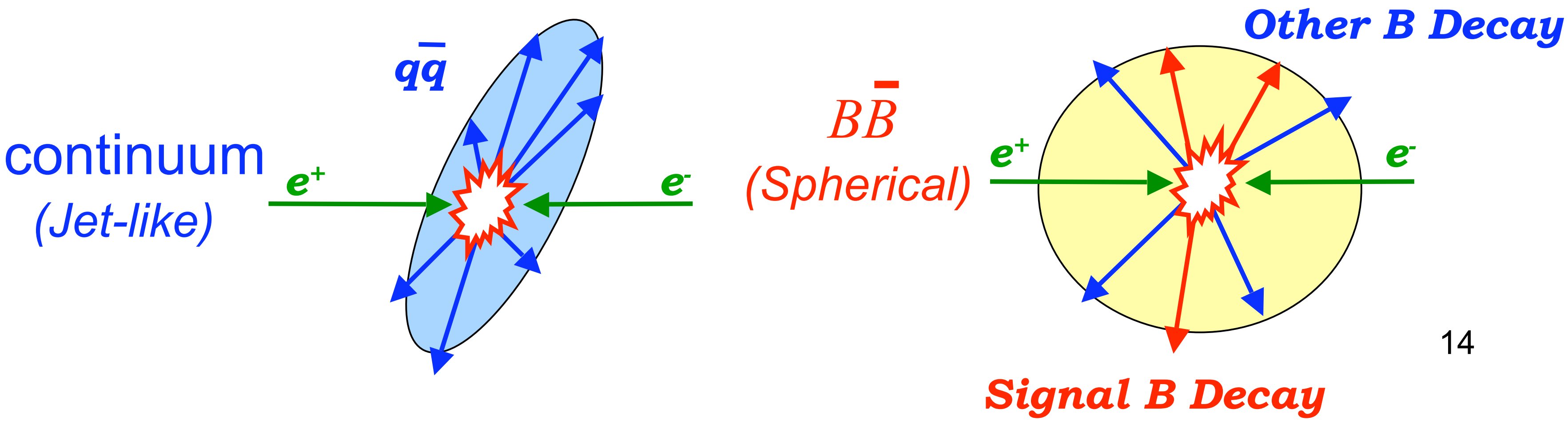
Backup

$e^+e^- \to q\bar{q}$ (q=u,d,s,c) Background Suppression

- The dominant background in *B* analysis is $e^+e^- \to q\bar{q}$ *(q=u,d,s,c)*, we called "continuum" (~ 3x $B\bar{B}$).



- To suppress continuum background, we use <u>event shape variables (Fox-Wolfram momentum)</u> and <u>flavor tagging information</u>.



Systematic Errors

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 total	±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	$^{-4.9}_{+1.3}$	$^{-2.0}_{+0.6}$
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	$^{+6.6}_{-10.3}$	$^{+6.4}_{-9.4}$
Monte Carlo statistics	< 0.1	< 0.1
$B\bar{B}$ counting	±1.4	±1.4
Total	$^{+10.2}_{-12.9}$	$^{+8.9}_{-11.2}$

(In %)

Fit PDF systematics

- $B \to J/\psi X_s$, $\psi(2S) X_s$
- $B \to \psi(3770) X_s$, $\psi(4040) X_s$, $\psi(4160) X_s$
- $B \to X_s \pi\pi$, $B \to X_s \pi l \nu$

Detector systematics

MC modeling systemaics

- Transitions between $K^* l^+ l^-$ and $X_s l^+ l^-$
- X_s decay fractions
- X_s decay with two or more kaons