Recent Results on

Electroweak Penguins at Belle

— $b \to s\gamma$ and $b \to s\, l^+ l^-$ decays —

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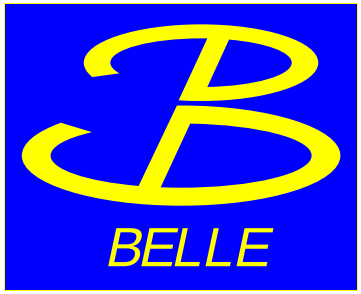
For the Belle collaboration



BEAUTY2002

Jun. 17, 2002

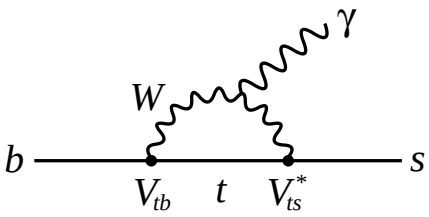
Introduction

- **Flavor-Changing Neutral Current** (FCNC)
  - Forbidden at tree level in the SM, but occurs via loop or box diagrams
  - Sensitive to heavy particles in new physics models

- Presented are studies on

$b \to s\gamma$

<< Penguin diagram >>



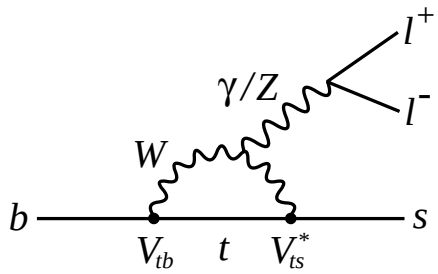
- Rare decays
- The most stringent limit on $M_{H^\pm}$

Results on

$B \to K^*(892)\gamma,\ K\pi\gamma,\ K\pi\pi\gamma$

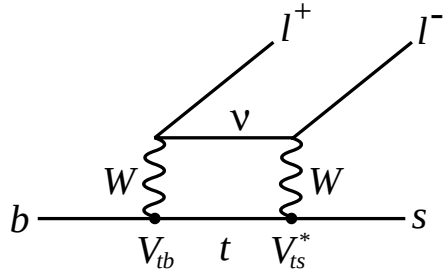
$b \to s l^+ l^-$

<< Penguin >>



+

<< Box >>



- Rarer decays
- *Power to distinguish different models using* $M_{l^+l^-}$, A_{FB}

Results on $B \to K^{(*)} l^+ l^-,\ X_s l^+ l^-$

Analysis in General

✏ Signal-yield extraction

1. Reconstruction of $(E_B, \vec{p}_B)$ in the CM frame
2. Two kinematic variables to identify B decays:
   - $M_{bc} \stackrel{\text{def}}{\equiv} \sqrt{E_{beam}^2 - \vec{p}_B{}^2}$ (beam-constrained mass)
   - $\Delta E \stackrel{\text{def}}{\equiv} E_B - E_{beam}$ (energy difference)
3. Fit of M_{bc}

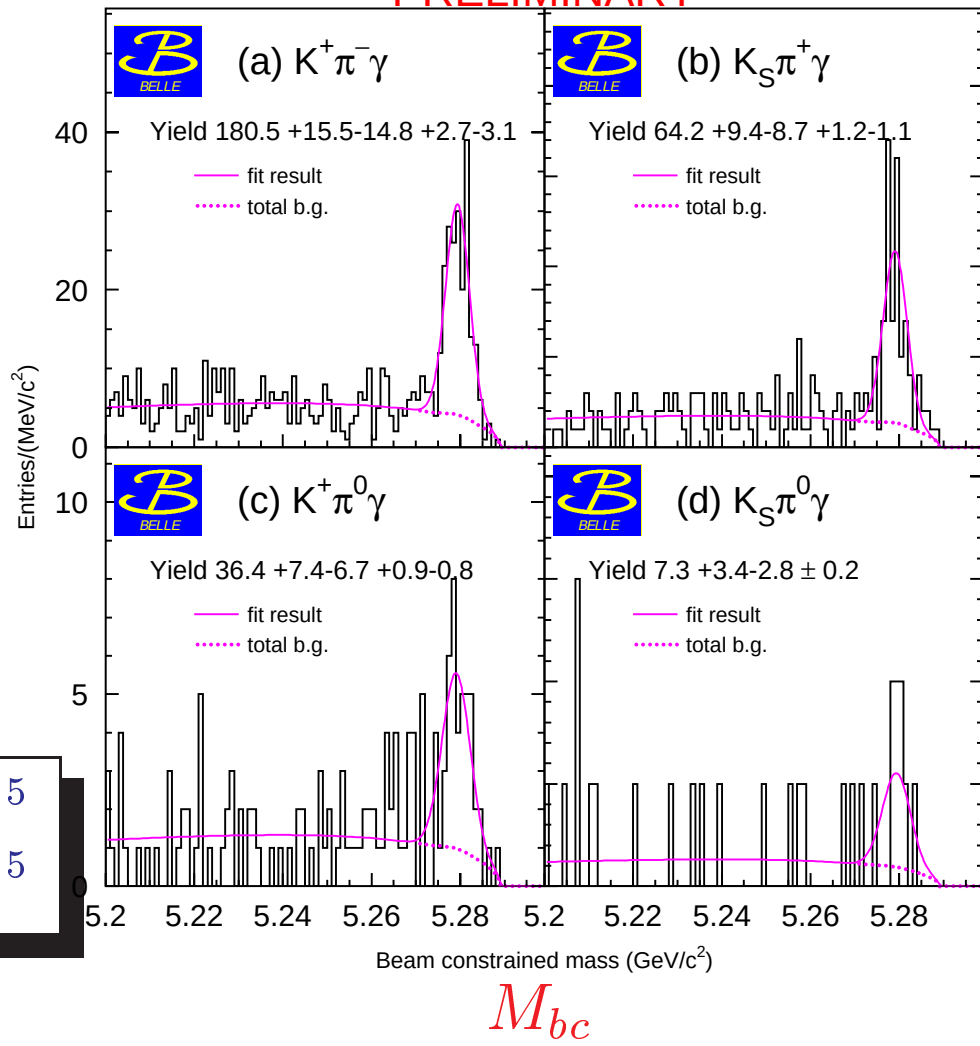
✏ Continuum: $e^+e^- \to q\bar{q}$ suppression using

- ➠ Event shape variables: (modified) Fox-Wolfram moments, etc.
- ➠ B flight direction
- ➠ ΔE cut
- ➠ etc.

$B \to K^*(892)\gamma$ Analysis

- Reconstructed modes:
  - $B^0 \to K^*(892)^0\,\gamma$
    $\hookrightarrow K^+\pi^-,\ K_S\pi^0$
  - $B^+ \to K^*(892)^+\,\gamma$
    $\hookrightarrow K^+\pi^0,\ K_S\pi^+$
- Dataset: 29.4 fb^{-1}
- $B\bar{B}$ background
  - A small contribution from $B \to K^*\pi\gamma$

PRELIMINARY



M_{bc}

Preliminary

$$\mathcal{B}(B^0 \to K^{*0}\gamma) = (4.08\,^{+0.35}_{-0.33} \pm 0.26) \times 10^{-5}$$
$$\mathcal{B}(B^+ \to K^{*+}\gamma) = (4.92\,^{+0.59\,+0.38}_{-0.54\,-0.37}) \times 10^{-5}$$

$B \to K^*(892)\gamma$ Asymmetry

$$A_{CP} \stackrel{\text{def}}{\equiv} \frac{1}{1-2\omega}\frac{N(\bar{B})-N(B)}{N(\bar{B})+N(B)}$$

(ω: wrong tag fraction = 0.9 %)

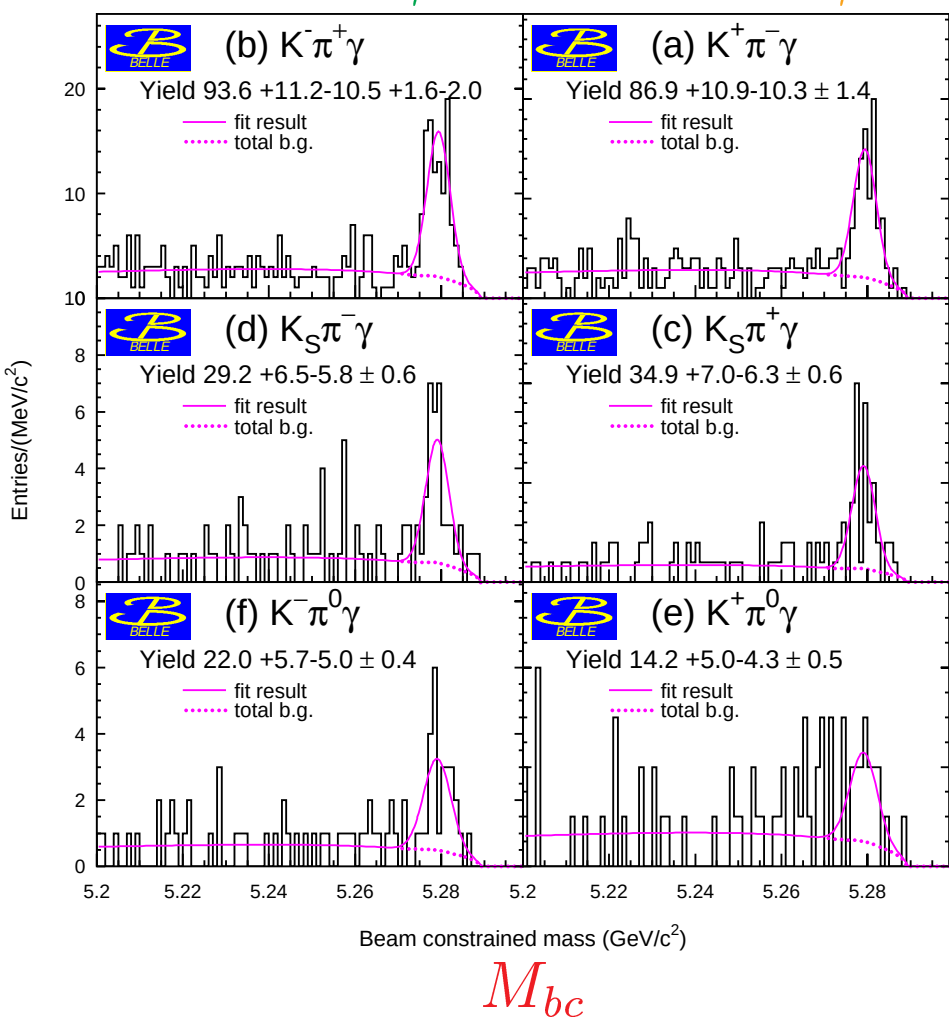
- $A_{CP} \sim 0.5\,\%$ in the SM
  $\sim 20\,\%$ in some new physics models
- From the self-tagged modes:
  $K^+\pi^-, K_S\pi^+, K^+\pi^0$

Preliminary

$$A_{CP}(K^*\gamma) = (+3.2\,^{+6.9}_{-6.8} \pm 2.0)\,\%$$

$-8.5\,\% < A_{CP}(K^*\gamma) < +14.9\,\%$ (90 % CL)

PRELIMINARY



$B \to K\pi\gamma$ Analysis with $M_{K\pi} > M_{K^*(892)}$

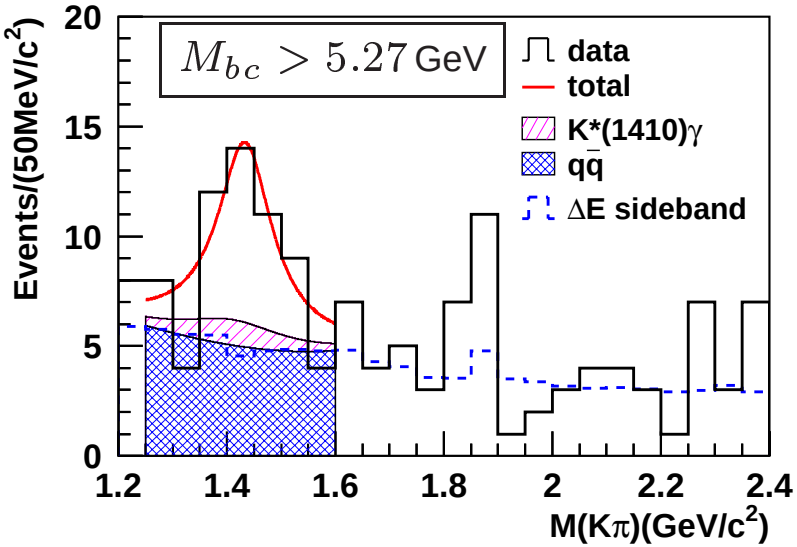
- Some resonant structure is expected:
  $K^*(1410)$, $K_2^*(1430)$, $K^*(1680)$, etc.
- Dataset: 29.4 fb^{-1}
- A clear excess around $M_{K\pi} = 1.4$ GeV
- Fitting M_{bc} in $1.25 < M_{K\pi} < 1.6$ GeV,
  $\to$ Signal yield: $27\,^{+8}_{-7}\,^{+1}_{-3}$ evts (5.0σ signif.)

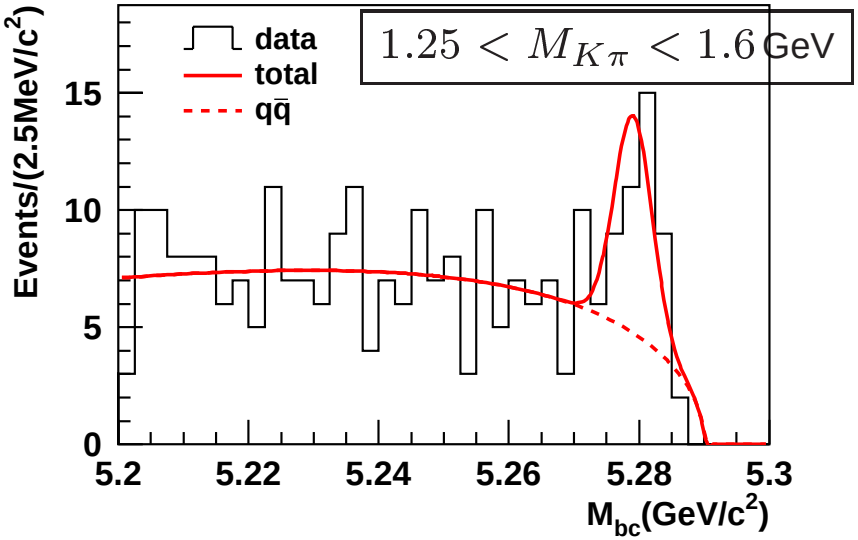
Assuming

$K^*(1410)^0\gamma$ + $K_2^*(1430)^0\gamma$

+ non-resonant $K^+\pi^-\gamma$ (N.R.)

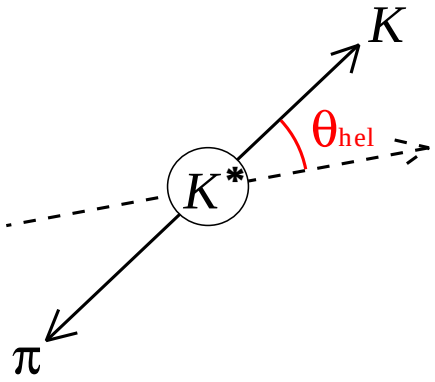
$\to$ Extract the resonant components.



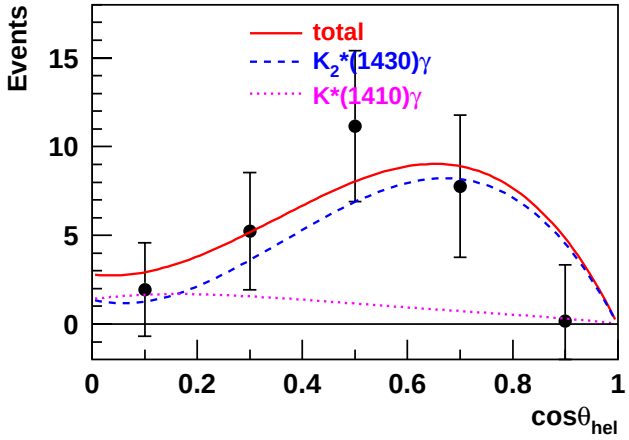


Multi-dimensional Unbinned Maximum Likelihood Fit

to $\cos\theta_{\rm hel}$, $M_{K\pi}$, M_{bc}



	Spin state	Helicity-angle distribution
$K_2^*(1430)$	$\|2,\pm1>$	$\cos^2\theta_{\rm hel} - \cos^4\theta_{\rm hel}$
$K^*(1410)$	$\|1,\pm1>$	$1 - \cos^2\theta_{\rm hel}$
N.R.	—	$\sim$ flat



	Signal yield	Signif.
$K_2^*(1430)\gamma$	$24 \pm 9 \pm 1$	3.1
$K^*(1410)\gamma$	$5.4^{+8.3}_{-5.4}$	—
N.R.	$0.0^{+4.3}_{-0.0}$	—

$$\mathcal{B}(B^0 \to K_2^*(1430)^0\gamma) = (1.5\,^{+0.6}_{-0.5} \pm 0.1) \times 10^{-5}$$

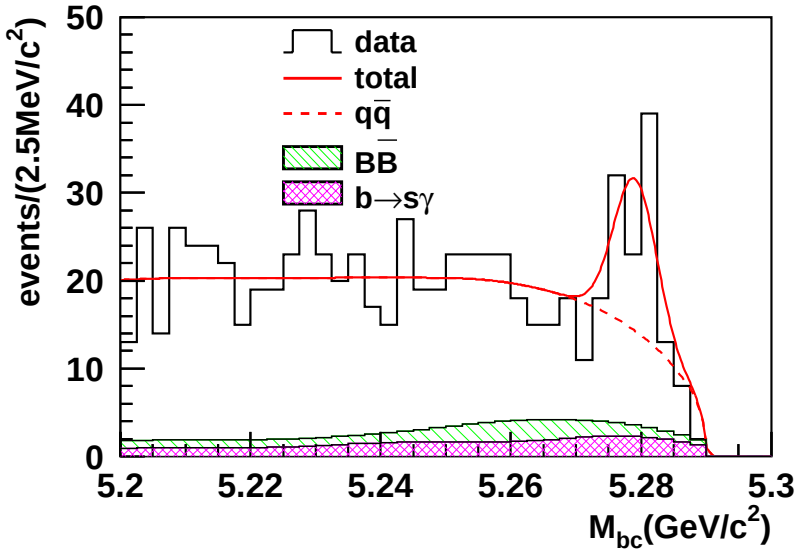
hep-ex/0205025; submitted to Phys. Rev. Lett.

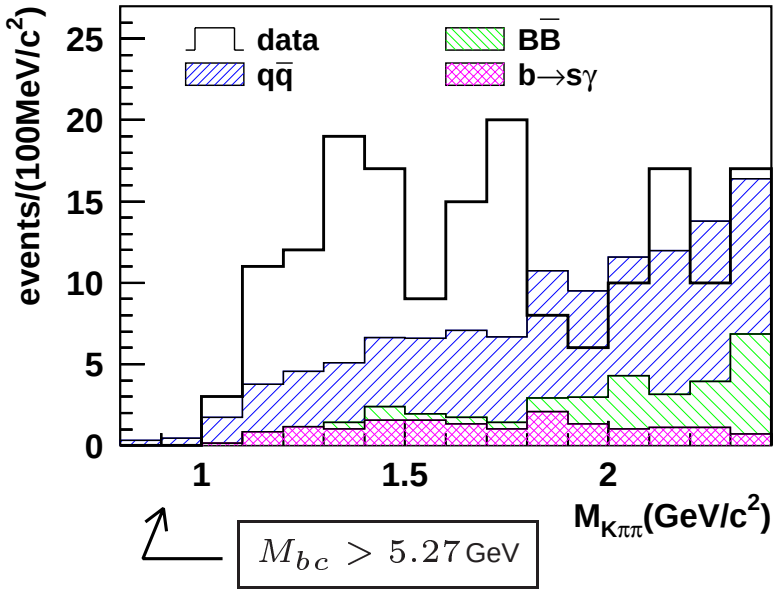
$B^+ \to K^+\pi^-\pi^+\gamma$ Analysis

- Photon-polarization measurement
  using $K_1(1400) \to K\pi\pi$
  $\to$ could be a tool to search for new physics
  (M. Gronau *et al.*, PRL **88** (2002) 051802)
- Dataset: 29.4 fb^{-1}
- Fitting M_{bc} in $M_{K\pi\pi} < 2.4$ GeV,
  $\to$ Signal yield: $57\,^{+12}_{-11}\,^{+6}_{-2}$ evts (5.9σ signif.)

Assuming
$K^{*0}\pi^+\gamma$ + $K^+\rho^0\gamma$
+ non-resonant $K^+\pi^-\pi^+\gamma$ (N.R.)

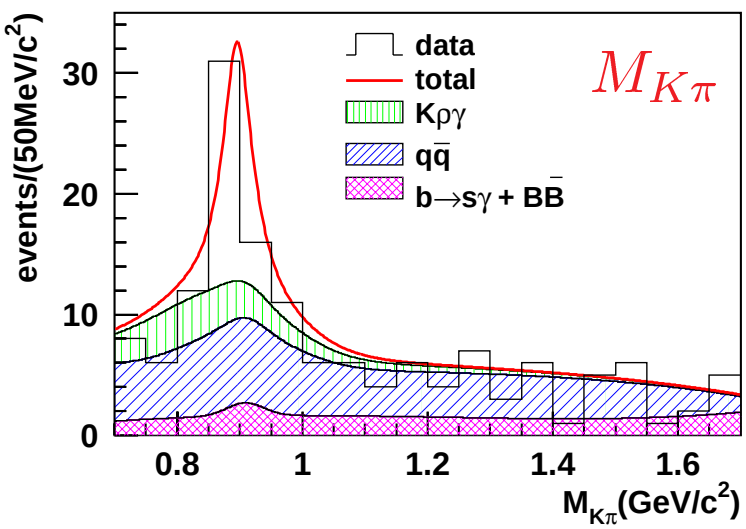
$\to$ Extract these 3 components.

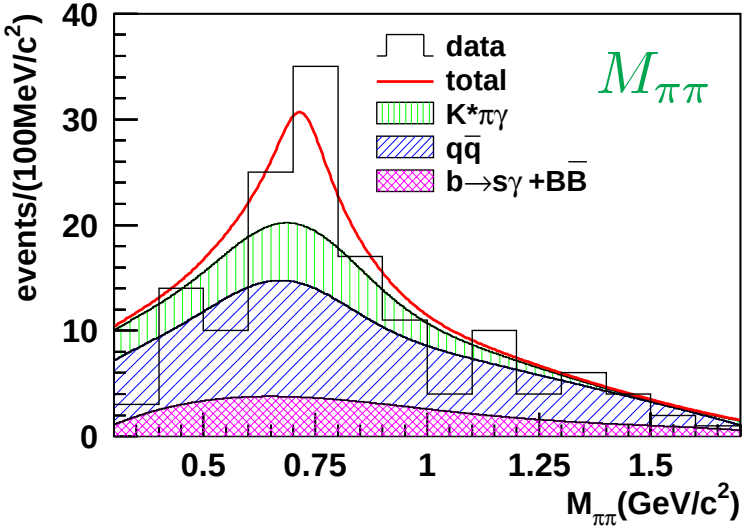




Multi-dimensional Unbinned Maximum Likelihood Fit

to $M_{K\pi}$, $M_{\pi\pi}$, M_{bc}





	Signal yield	Significance	$\mathcal{B}\,(\times 10^{-5})$
$K^{*0}\pi^+\gamma$	$33\,^{+11}_{-10} \pm 2$	3.7	$2.0\,^{+0.7}_{-0.6} \pm 0.2$
$K^+\rho^0\gamma$	$24 \pm 12\,^{+4}_{-7}$	2.2	$1.0 \pm 0.5\,^{+0.2}_{-0.3}$
N.R.	$0.0\,^{+11}_{-0}$	—	—

hep-ex/0205025; submitted to Phys. Rev. Lett.

Summary of $b \to s\gamma$ Measurements

(using isospin symmetry)

	Mode	$\mathcal{B}\,(\times 10^{-5})$	
Exclusive	$K^*\gamma$	4.2 ± 0.4	← Belle, BaBar, CLEO
	$K_2^*(1430)\gamma$	1.0 ± 0.4	excluding $K_2^* \to K\pi\pi$
	$K^*\pi\gamma$	3.1 ± 1.0	
	$K\rho\gamma$	3.0 ± 1.6	
	Sum	11.3 ± 2.1	
Inclusive →	$X_s\gamma$	32.2 ± 4.0	← Belle, CLEO, ALEPH

$$\frac{\textbf{Exclusive}(K^*\gamma, K_2^*\gamma, K\pi\pi\gamma)}{\textbf{Inclusive}} = 35 \pm 8\,\%$$

Next step: >3-body kaonic system

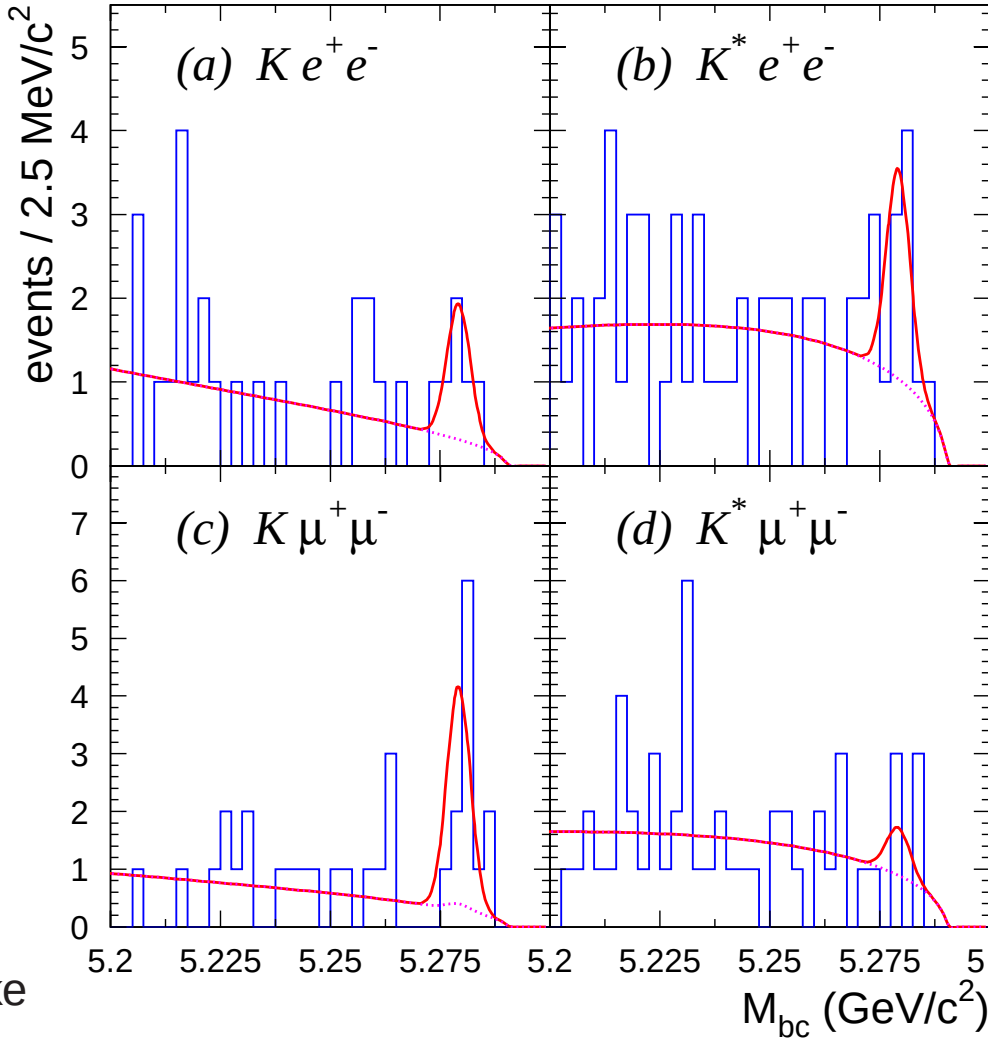
for a better understanding on $b \to s\gamma$ measurements

$b \to s\, l^+ l^-$ Measurements

- **Exclusive Analysis**
  - $B \to K\, l^+ l^-,\ K^*(892)\, l^+ l^-$ $(l^+ l^- = e^+ e^-,\ \mu^+ \mu^-)$
  - Experimentally easy, but more theoretical uncertainty
- **Inclusive Analysis**
  - $B \to X_s\, l^+ l^-$
  - Experimentally difficult, but **less theoretical uncertainty**

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

- Reconstructed modes:
  - $B^0 \to K_S\, l^+ l^-,\ B^+ \to K^+\, l^+ l^-$
  - $B^0 \to K^*(892)^0\, l^+ l^-$
    $\hookrightarrow K^+\pi^-,\ K_S\pi^0$
  - $B^+ \to K^*(892)^+\, l^+ l^-$
    $\hookrightarrow K^+\pi^0,\ K_S\pi^+$
- Dataset: 29.1fb^{-1}
- $B\bar{B}$ backgrounds
  - $J/\psi(\psi')\, X_s$ eliminated by $J/\psi(\psi')$ veto
  - $l^+\nu X, l^-\nu Y$ suppressed using $E_{\rm miss}$
  - $K^{(*)}\, h^+ h^-$ estimated with
    - the reconstructed $K^{(*)}\, h^+ h^-$ data
    - the measured momentum-dependent fake rate



$B \to K^{(*)} l^+ l^-$ Results

Mode	Signal yield	$\mathcal{B}\,(\times 10^{-6})$	Significance
$K\,e^+e^-$	$4.1\,^{+2.7\,+0.6}_{-2.1\,-0.8}$	< 1.3	2.5
$K^*\,e^+e^-$	$6.3\,^{+3.7\,+1.0}_{-3.0\,-1.1}$	< 5.6	2.5
$K\,\mu^+\mu^-$	$9.5\,^{+3.8\,+0.8}_{-3.1\,-1.0}$	$0.99\,^{+0.40\,+0.13}_{-0.32\,-0.14}$	4.7
$K^*\,\mu^+\mu^-$	$2.1\,^{+2.9\,+0.9}_{-2.1\,-1.0}$	< 3.1	—

First Observation

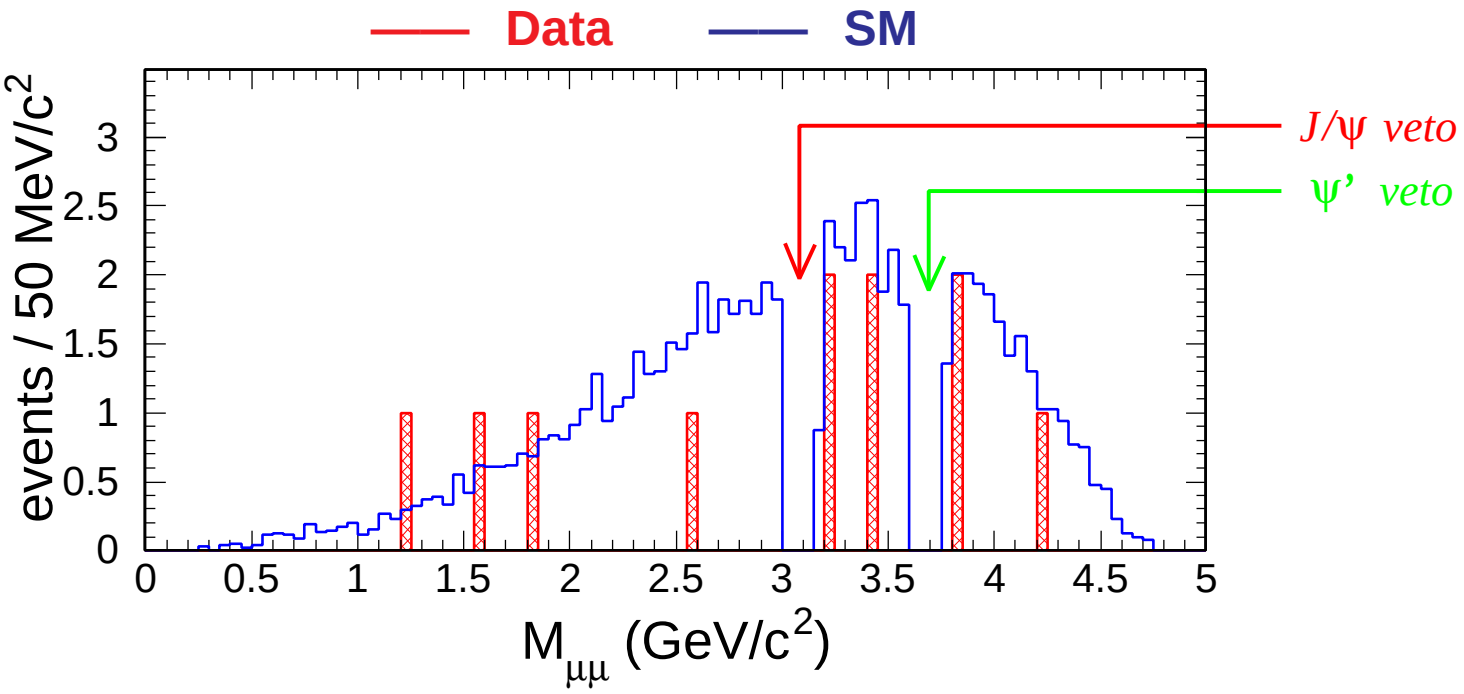
$$\mathcal{B}(B \to K\, l^+ l^-) = (0.75\,^{+0.25}_{-0.21} \pm 0.09) \times 10^{-6}$$

(significance: 5.3 σ)

Phys. Rev. Lett. **88** (2002) 021801

$B \to K^{(*)} l^+ l^-$ Results

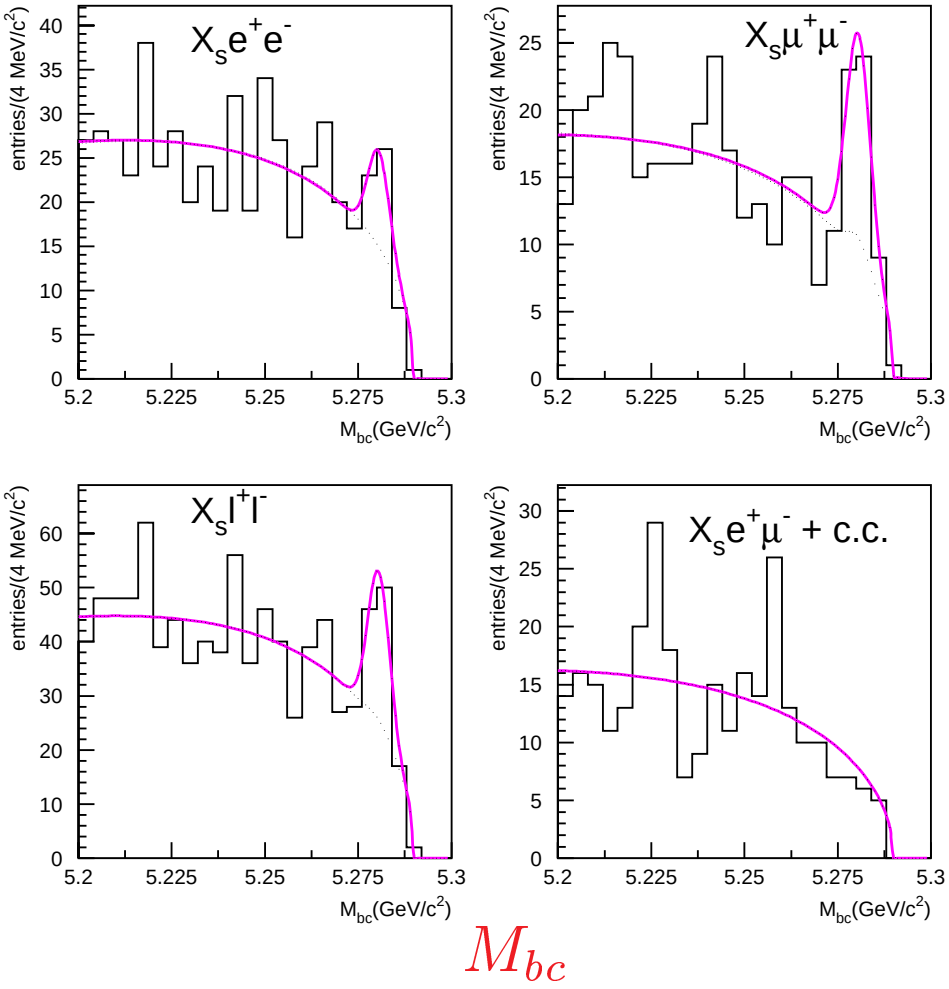
$(B \to K \mu^+ \mu^-)$



$\to$ Consistent with the SM prediction.

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

- **Pseudo-reconstruction**
  - $X_s = (K^+ \text{ or } K_S) + (0 \sim 4)\pi$
    (up to one π^0)
- Dataset: 43 fb^{-1}
- $B\bar{B}$ backgrounds
  - $J/\psi(\psi')\, X_s$ eliminated by $J/\psi(\psi')$ veto
  - $l^+\nu X, l^-\nu Y$ suppressed using $E_{\rm miss}$
  - $X_s\, h^+ h^-$ (misidentified as $X_s\, \mu^+\mu^-$) estimated with
    - the reconstructed $X_s\, h^+ h^-$ data
    - the measured momentum-dependent fake rate



$B \to X_s l^+ l^-$ Results NEW

PRELIMINARY

Mode	Signal yield	$\mathcal{B}\,(\times 10^{-6})$	Significance
$X_s\, e^+ e^-$	$16.6\ ^{+8.0\,+3.9}_{-7.3\,-3.8}$	$5.1\ ^{+2.6\,+1.3}_{-2.4\,-1.2}$	2.1
$X_s\, \mu^+ \mu^-$	$30.7\ ^{+7.9\,+5.4}_{-7.4\,-3.8}$	$8.9\ ^{+2.3\,+1.6}_{-2.1\,-1.7}$	4.4

First Evidence

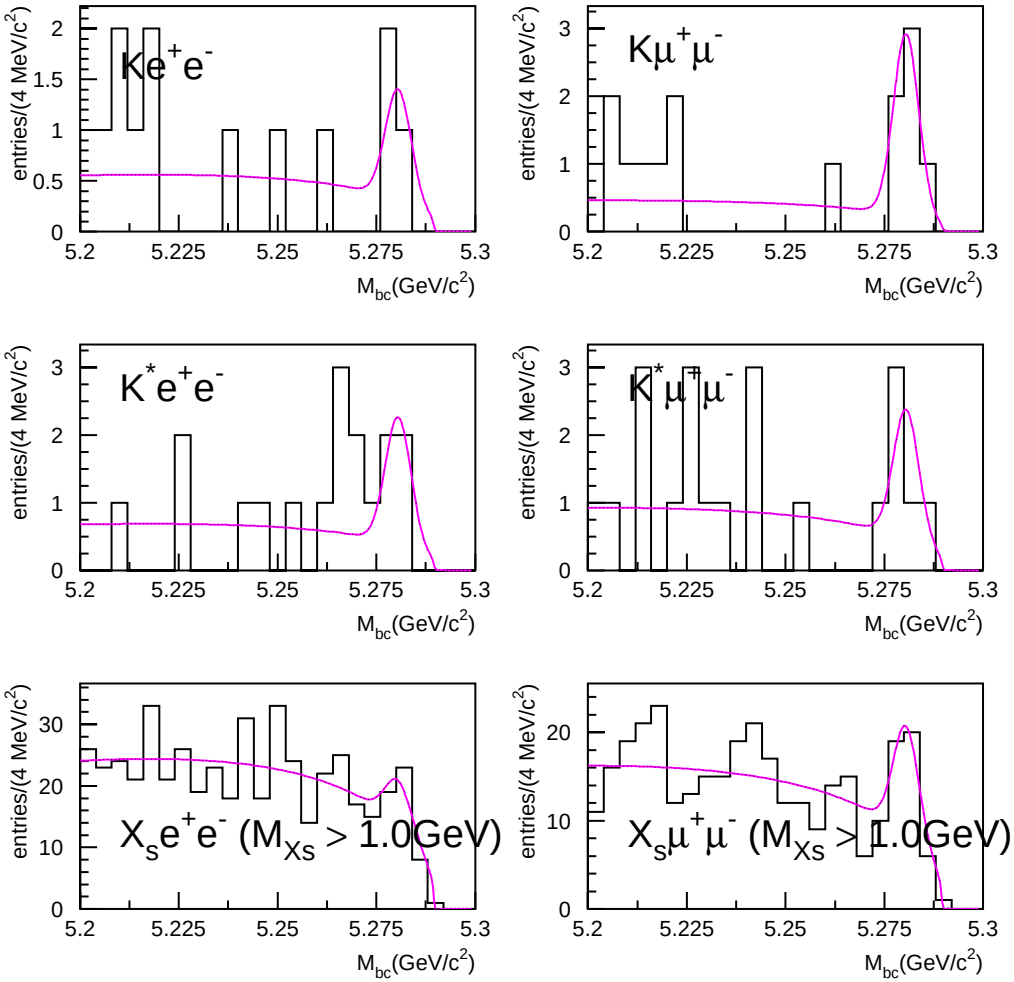
$$\mathcal{B}(B \to X_s\, l^+ l^-) = (7.1 \pm 1.6\ ^{+1.4}_{-1.2}) \times 10^{-6}$$

(significance: **4.8** σ)

Consistent with the SM prediction: $(3.5 \sim 7.9) \times 10^{-6}$ (Ali *et al.*, hep-ph/0112300)

Consistency with the Exclusive Analysis

$X_s e^+ e^-$ $X_s \mu^+ \mu -$



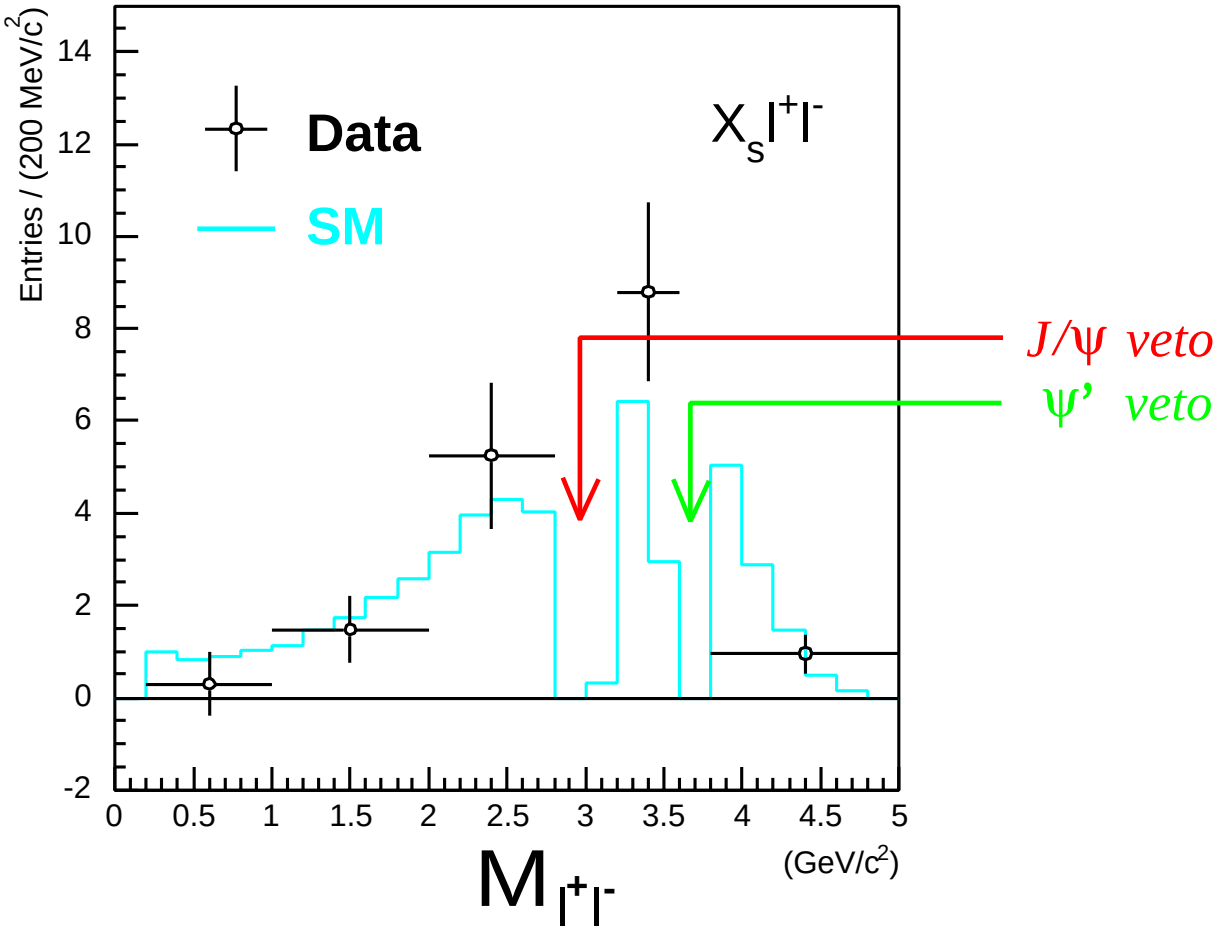
← K mass region

← K^* mass region

The inclusive analysis is consistent with the exclusive analysis.

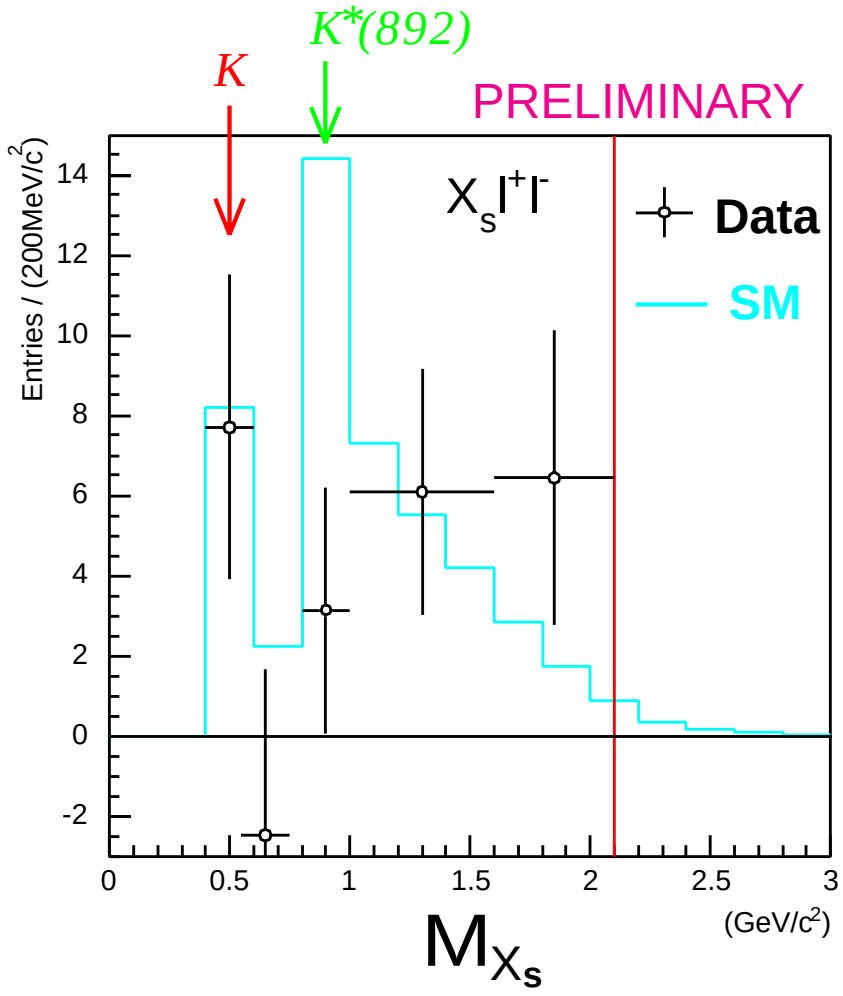
$B \to X_s l^+ l^-$ Results NEW

PRELIMINARY



→ Consistent with the SM prediction.

$B \to X_s l^+ l^-$ Results NEW



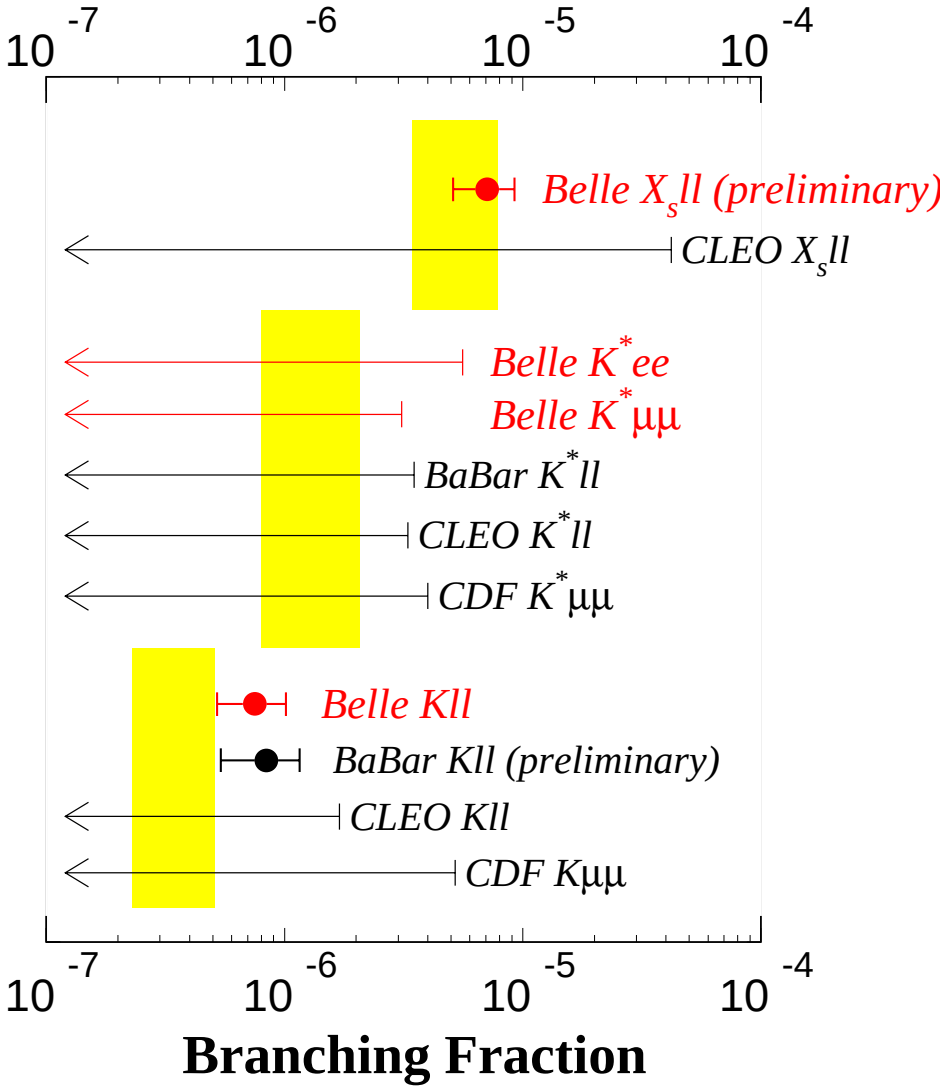
$\to$ Consistent with the SM prediction.

Systematic Uncertainties

for $\mathcal{B}(B \to X_s l^+ l^-)$

	$B \to X_s\, e^+ e^-$	$B \to X_s\, \mu^+ \mu^-$
Tracking	8.1 %	8.0 %
Kaon ID	1.9 %	2.0 %
Pion ID	0.8 %	0.8 %
Lepton ID	3.6 %	4.4 %
K_S detection	2.1 %	1.5 %
π^0 detection	2.0 %	1.6 %
MC statistics	3.9 %	4.1 %
Decay modeling	$^{+14}_{-9}$ %	$^{+16}_{-12}$ %
Total	$^{+18}_{-14}$ %	$^{+19}_{-16}$ %

Summary of $b \to s\, l^+ l^-$ Measurements



- The experimental results are consistent with the SM predictions.
- Just started testing the SM in $b \to s\, l^+ l^-$.

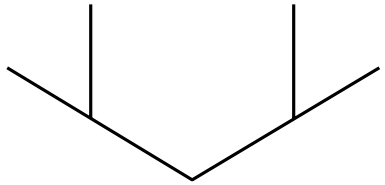
SM predictions from
Ali *et al.*, hep-ph/0112300;
Greub *et al.*, Phys. Lett. B **346** (1995) 149;
Melikhov *et al.*, Phys. Lett. B **410** (1997) 290

Conclusions

We have studied FCNC in $b \to s\gamma$ and $b \to s\,l^+l^-$.

- $b \to s\gamma$
  - Measurements of the $K\pi\gamma, K\pi\pi\gamma$ final states
  - Exclusive($K^*\gamma, K_2^*\gamma, K\pi\pi\gamma$) / Inclusive $= 35 \pm 8\,\%$
  - Extensive studies of exclusive $B \to K_X\gamma$
- $b \to s\,l^+l^-$
  - First observation: $\mathcal{B}(B \to K\,l^+l^-) = (0.75\,^{+0.25}_{-0.21} \pm 0.09) \times 10^{-6}$ (5.3 σ signif.)
  - First evidence: $\mathcal{B}(B \to X_s\,l^+l^-) = (7.1 \pm 1.6\,^{+1.4}_{-1.2}) \times 10^{-6}$ (4.8 σ signif.)
  - Both consistent with the SM predictions

- More data is coming: $\sim 90\,\mathrm{fb}^{-1}$ by this summer.
- KEKB is getting close to its design luminosity.
- SuperKEKB is being proposed.



$b \to s\gamma$ and $b \to s\, l^+ l^-$

Promising probe for

BEYOND SM PHYSICS

in next several years