Electroweak Penguins Decays of B Mesons

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For the Belle Collaboration

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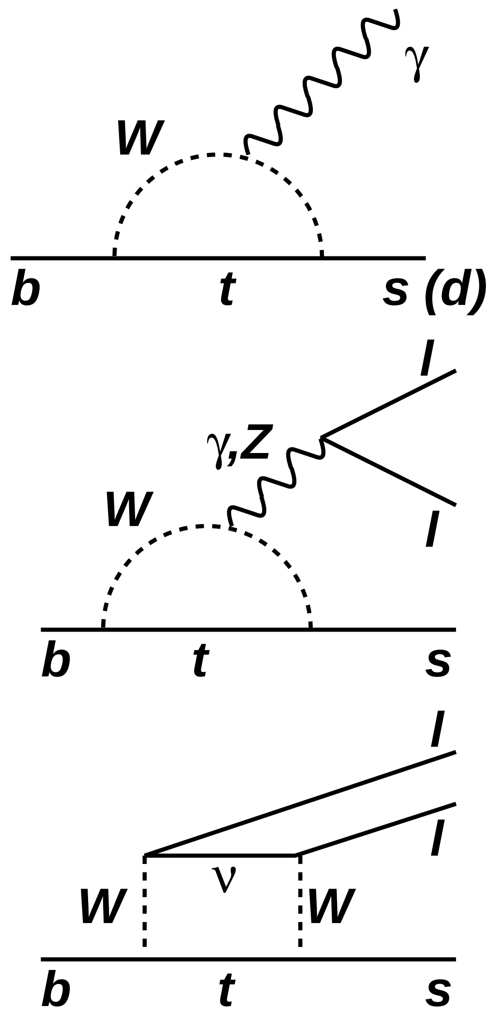
Results are based on $60\ \mathrm{fb}^{-1}$ $(65 \times 10^6\ B\bar{B})$ data (except 3. with $29\ \mathrm{fb}^{-1}$) taken by Belle.

Introduction

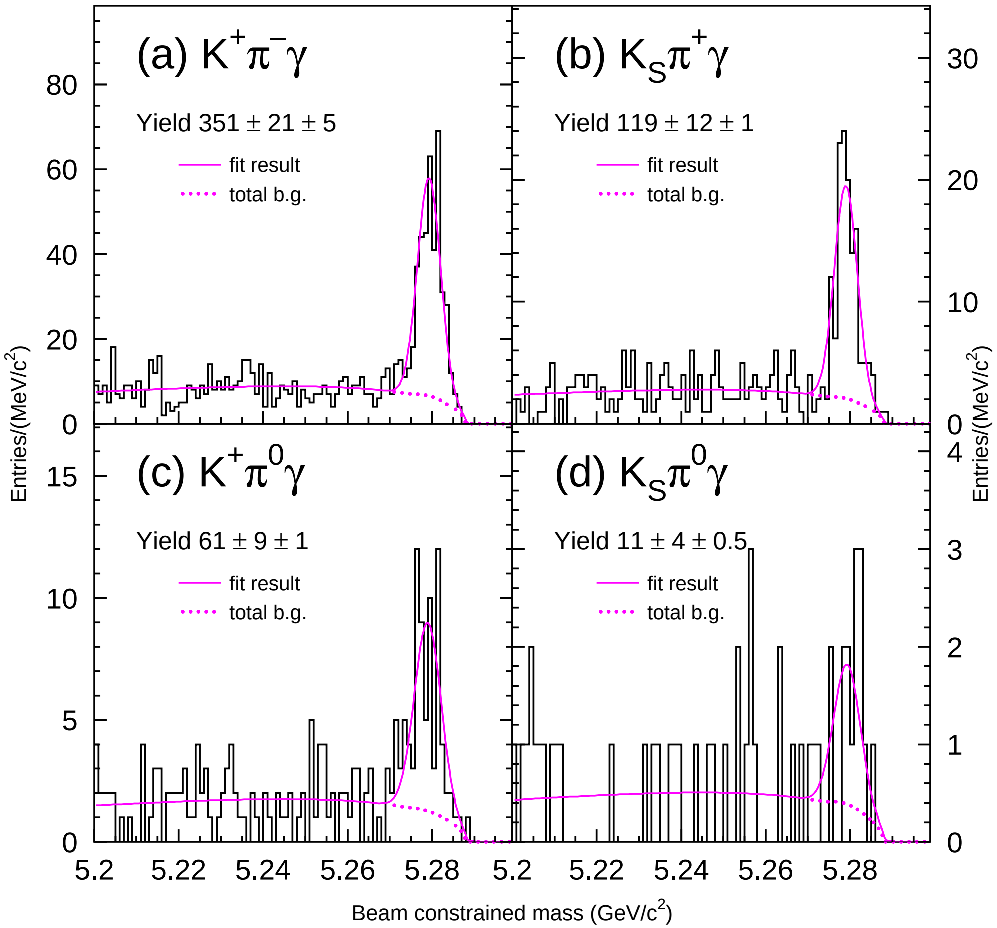
- $b \to s\gamma$ ($b \to d\gamma$) and $b \to s\ell\ell$: FCNC process
- lowest diagram: one loop penguin (or box) diagram
- sensitive to New Physics
  - $B \to K^*(892)\gamma$: rate difference between charged and neutral decay, charge asymmetry ($A_{\rm CP} > 1\%$ may be a sign of New Physics)
  - $B \to K\pi\pi\gamma$: photon helicity (M.Gronau *et al.* PRL **88**, 051802 (2002))
  - $B \to \rho\gamma$, $B \to \omega\gamma$: $b \to d\gamma$, $|V_{td}/V_{ts}|^2$
  - $B \to K^{(*)}\ell\ell$, $B \to X_s\ell\ell$: branching fractions, $M_{\ell\ell}$ spectrum, forward-backward asymmetry



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

Precision measurement of $B \to K^*\gamma$

- Reconstruct K^* from $K^+\pi^-$, $K_S\pi^+$, $K^+\pi^0$, $K_S\pi^0$ $(|M(K\pi)-M_{K^*}| < 75\ \mathrm{MeV}/c^2)$
- Main background : $q\bar{q}$
  LR from SFW (fisher discriminant of modified FW moments) and $\cos\theta_B$.
- Small BB background contamination:
  - rare B decay ($B \to K^*\pi^0$ etc)
  - $B \to K^*\pi\gamma$, $K\rho\gamma$
- Yield from beam constrained mass ($M_{\rm bc}$)

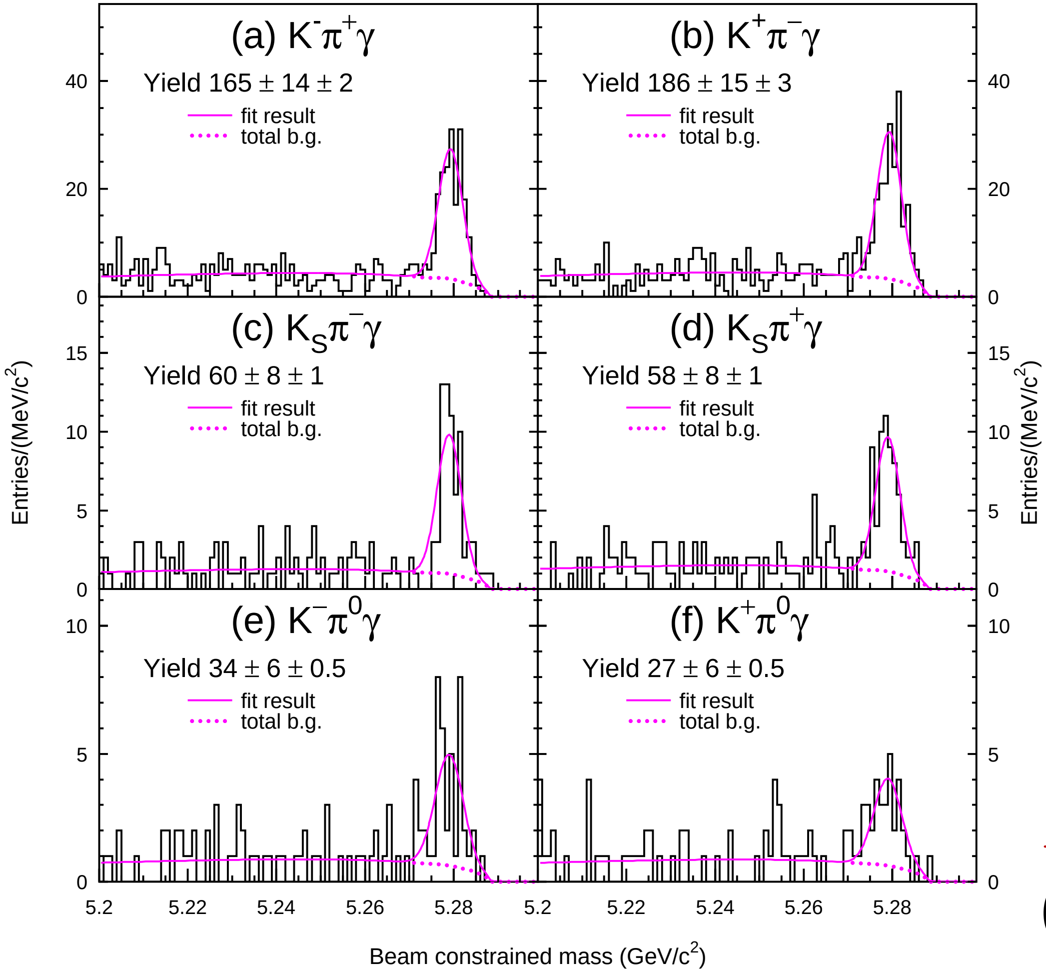


$$\mathcal{B}(B^0 \to K^*(892)^0\gamma) = (39.1 \pm 2.3 \pm 2.5) \times 10^{-6}$$
$$\mathcal{B}(B^+ \to K^*(892)^+\gamma) = (42.1 \pm 3.5 \pm 3.1) \times 10^{-6}$$

Preliminary

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

Charge asymmetry



$$A_{\rm CP} = \frac{1}{1-2w}\frac{N(\bar{B})-N(B)}{N(\bar{B})+N(B)}$$

- wrong tag fraction (w) is 0.9% for the neutral mode, and negligible for the charged mode.
- No asymmetry found in an inclusive K^* sample ($< 1.5\%$).

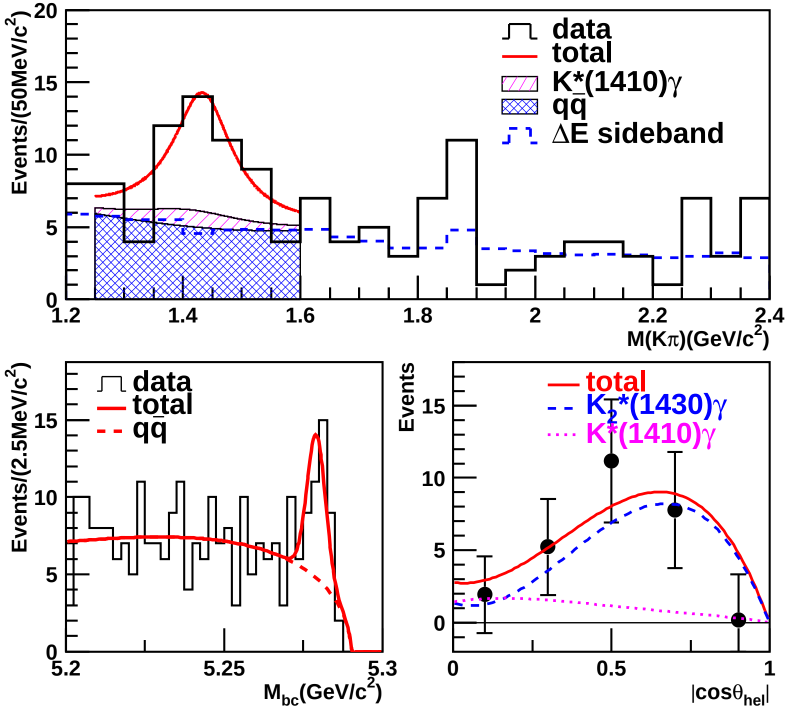
$$A_{\rm CP}(K^*\gamma) = (-2.2 \pm 4.8 \pm 1.7)\%$$
$$A_{\rm CP}(K^{*0}\gamma) = (-6.1 \pm 5.9 \pm 1.8)\%$$
$$A_{\rm CP}(K^{*\mp}\gamma) = (+5.3 \pm 8.3 \pm 1.6)\%$$

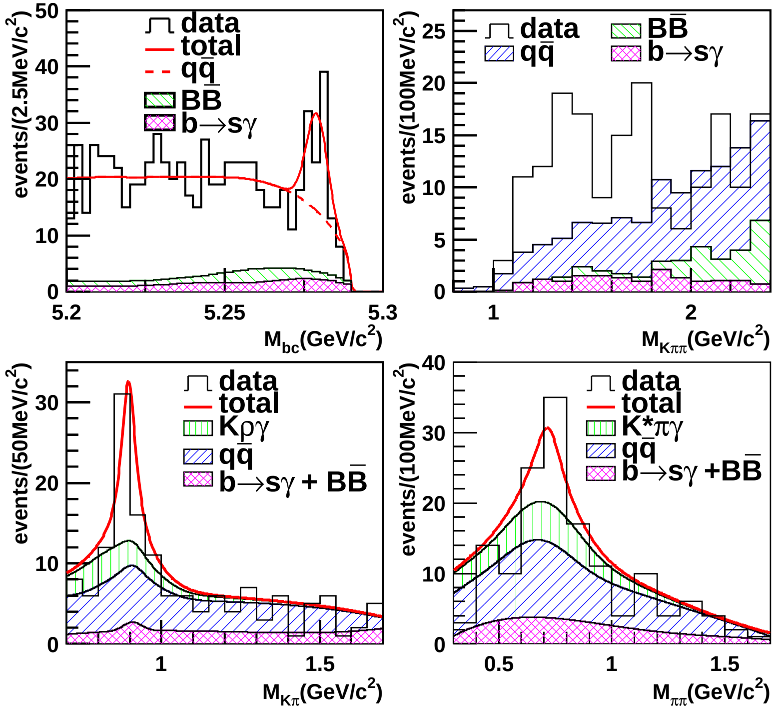
$-10.6\% < A_{\rm CP}(K^*\gamma) < 6.2\%$ (90% C.L.)

Preliminary

$B \to K_2^*(1430)\gamma$, $B \to K\pi\pi\gamma$

$B \to K_2^*(1430)\gamma$, $B \to K\pi\pi\gamma$ with 29fb^{-1}.
Submitted to PRL (BELLE-CONF 223).





$$\mathcal{B}(B^0 \to K_2^*(1430)^0\gamma) = (15\,^{+6}_{-5} \pm 1) \times 10^{-6}$$

$$\mathcal{B}(B^+ \to K^+\pi^-\pi^+\gamma) = (24 \pm 5\,^{+4}_{-2}) \times 10^{-6}$$

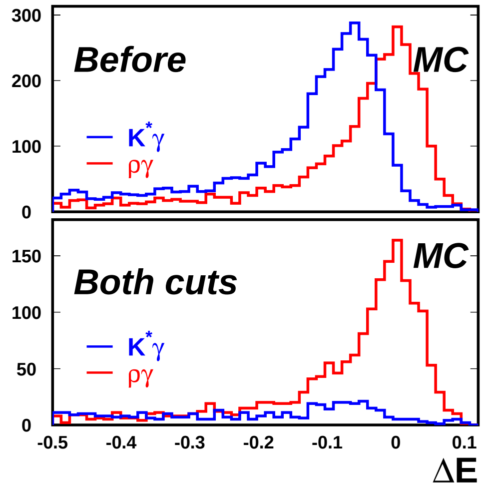
$K^*\pi\gamma$ and $K\rho\gamma$ are dominant.

$B \to \rho\gamma$, $B \to \omega\gamma$

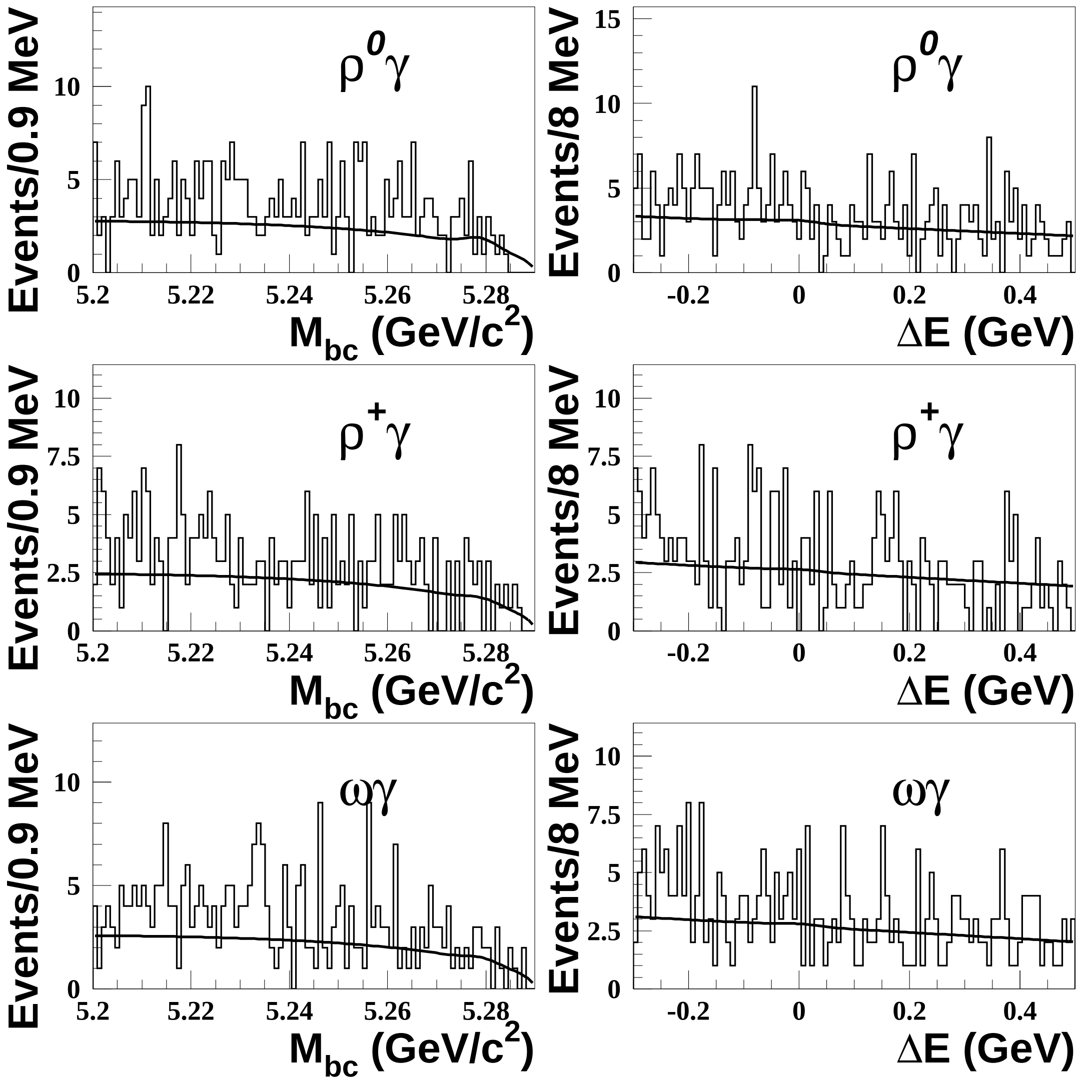
Analysis of $B \to \rho\gamma$, $B \to \omega\gamma$

- $|M(\pi\pi) - M_\rho| < 150$ MeV$/c^2$
- $|M(\pi^+\pi^-\pi^0) - M_\omega| < 15$ MeV$/c^2$
- $q\bar{q}$ background $\Longrightarrow$ LR cut
- K^* veto for $B \to \rho\gamma$
  (to suppress $B \to K^*\gamma$ background)
  - Tight kaon ID
  - Reject if $|M(K\pi) - M_{K^*}| < 50$ MeV$/c^2$ with a K mass hypothesis.

  $\Longrightarrow$ 0.9 ± 0.2 $K^*\gamma$ contribution for $\rho^0\gamma$
  negligible $K^*\gamma$ contribution for $\rho^+\gamma$
- Unbinned maximum likelihood fit for $M_{\rm bc}$ and ΔE



$B \to \rho\gamma$, $B \to \omega\gamma$



	yield	efficiency
$\rho^0\gamma$	2.1 ± 4.0	$(6.3 \pm 0.5)\%$
$\rho^+\gamma$	1.9 ± 2.7	$(3.3 \pm 0.3)\%$
$\omega\gamma$	1.5 ± 1.6	$(4.5 \pm 0.5)\%$

$$\mathcal{B}(B^0 \to \rho^0\gamma) < 2.6 \times 10^{-6}$$
$$\mathcal{B}(B^+ \to \rho^+\gamma) < 4.9 \times 10^{-6}$$
$$\mathcal{B}(B^0 \to \omega\gamma) < 3.1 \times 10^{-6}$$

(90%C.L.)

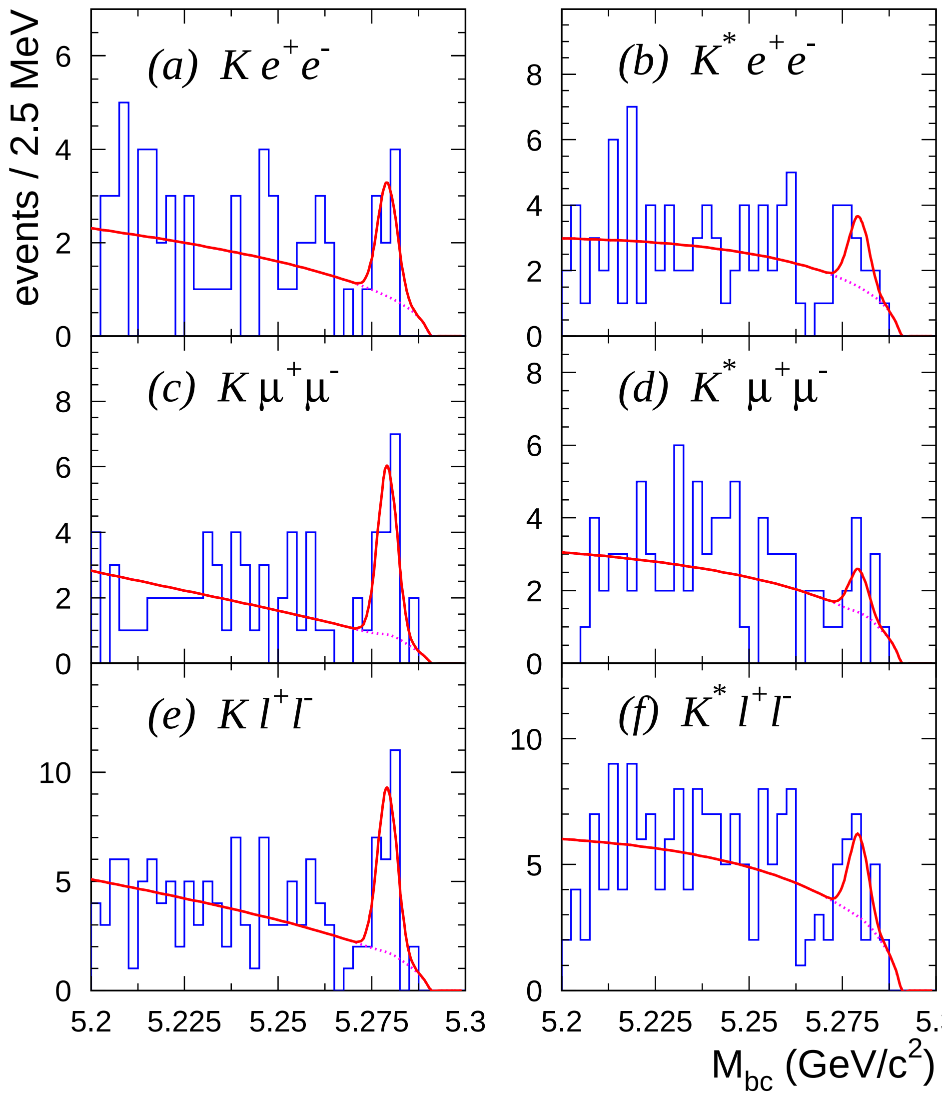
Preliminary

$B \to K^{(*)}\ell\ell$

Analysis of $B \to K^{(*)}\ell\ell$ ($\ell = e, \mu$)

- hadronic system: K^+, K_S, K^* (from $K^+\pi^-, K_S\pi^+, K^+\pi^0$)
- background suppression
  - LR from Virtual Calorimeter and $\cos\theta_B$ to suppress $q\bar{q}$ background.
  - LR from missing energy ($E_{\rm miss}$) and $\cos\theta_B$ to suppress $B\bar{B}$ background (semi-leptonic decay)
- $B \to K^{(*)}hh$ background (cf. $X_s\ell\ell$ analysis)
  expectation of 0.32 ± 0.03 (0.21 ± 0.02) events in $K\mu\mu$ ($K^*\mu\mu$)
- J/ψ, ψ' veto
- signal extraction from $M_{\rm bc}$ fit (signal shape is modeled by $B \to J/\psi K^{(*)}$)

$B \to K^{(*)}\ell\ell$

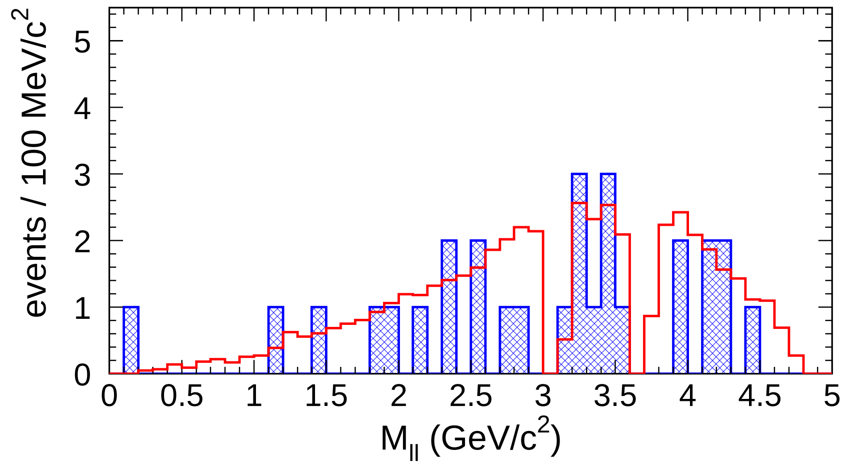


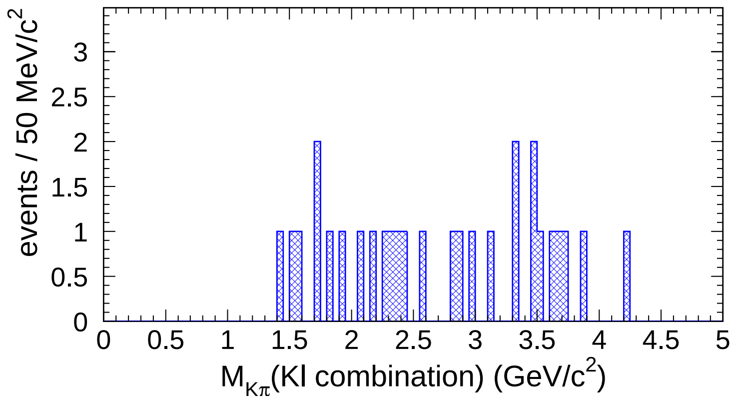
	(a) Ke^+e^-	(b) $K^*e^+e^-$
yield	$6.1\,^{+3.5}_{-2.8}\,^{+0.7}_{-0.8}$	$5.4\,^{+4.0}_{-3.3}\,^{+1.2}_{-1.3}$
eff.	$(12.5 \pm 1.0)\%$	$(4.6 \pm 0.5)\%$
$\mathcal{B}(10^{-7})$	$3.8\,^{+2.1}_{-1.7} \pm 0.6$	< 24
signif.	2.7	—
	(c) $K\mu^+\mu^-$	(d) $K^*\mu^+\mu^-$
yield	$13.0\,^{+4.5}_{-3.8}\,^{+0.8}_{-0.9}$	$3.0\,^{+3.3}_{-2.6}\,^{+1.0}_{-1.1}$
eff.	$(12.4 \pm 1.1)\%$	$(6.5 \pm 0.7)\%$
$\mathcal{B}(10^{-7})$	$8.0\,^{+2.8}_{-2.3} \pm 0.8$	< 12
signif.	4.9	—
	(e) $K\ell^+\ell^-$	(f) $K^*\ell^+\ell^-$
yield	$19.0\,^{+5.5}_{-4.8}\,^{+1.0}_{-1.2}$	$8.3\,^{+5.0}_{-4.3}\,^{+1.6}_{-1.7}$
eff.	$(12.5 \pm 1.1)\%$	$(5.3 \pm 0.5)\%$
$\mathcal{B}(10^{-7})$	$5.8\,^{+1.7}_{-1.5} \pm 0.6$	< 14
signif.	5.4	—

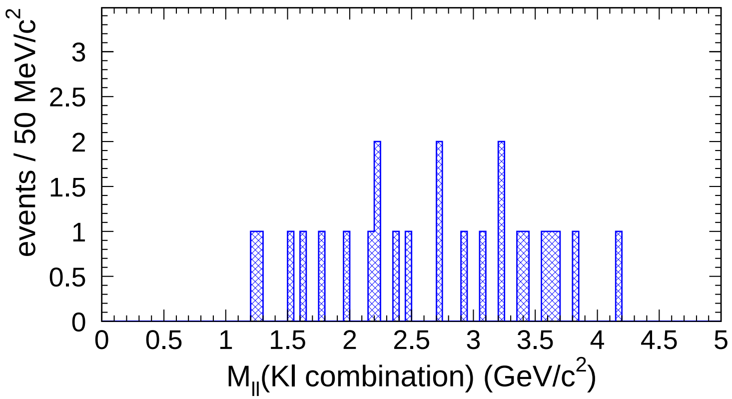
Preliminary

$B \to K^{(*)}\ell\ell$

Di-lepton mass distribution is consistent with SM expectation.







From invariant mass of $K\ell$ combination, neither D nor J/ψ is seen.

$B \to X_s \ell\ell$

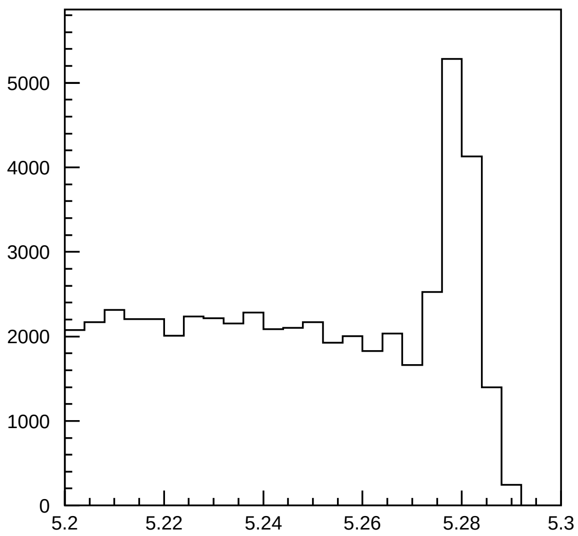
Analysis of inclusive $B \to X_s \ell\ell$ ($\ell = e, \mu$)

- Pseudo-reconstruction
- Hadronic system X_s : K (K^+ or K_S) + 0 to 4 π (up to 1 π^0)
- backgrounds : $q\bar{q}$, $B\bar{B}$, $J/\psi(\psi')X$, $X_s hh$ ($K + n\pi$)
- Main background : $q\bar{q}$, $B\bar{B}$ (semi-leptonic)
  - SFW
  - Fisher discriminant of total visible energy and missing mass
  - Likelihood ratio from ΔE and $\cos\theta_B$
- Tight J/ψ, ψ' veto
- Best candidate selection using $LR(\Delta E, \cos\theta_B)$
- $M_{X_s} < 2.1\ \mathrm{GeV}/c^2$
- Signal yield from M_{bc} fit.

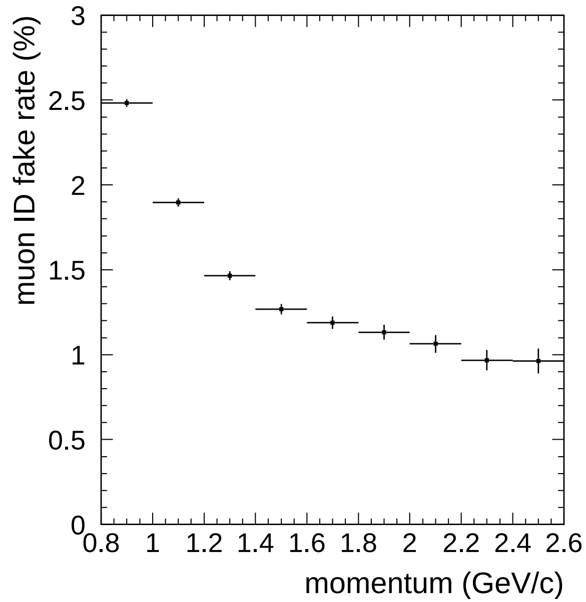
$B \to X_s \ell\ell$

$B \to X_s hh$ $(K + n\pi)$ background

- If we doubly mis-identify π as μ, decays like $B \to K + n\pi + \pi^+\pi^-$ contaminate $X_s\mu\mu$ mode.
- To estimate this contribution:
  - Reconstruct $B \to X_s\pi^+\pi^-$ without lepton ID requirement.
  - Multiply (momentum-dependent) muon fake rate $(1.4\%$ in average).



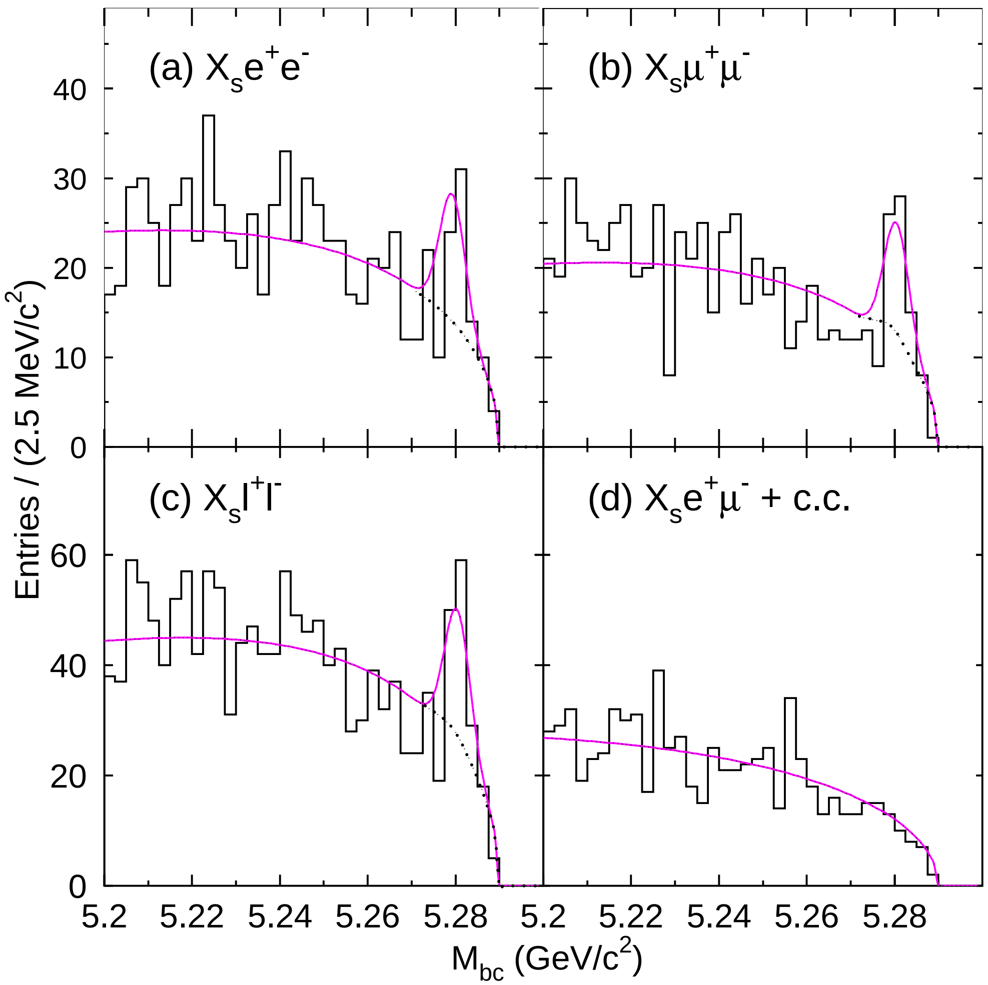
data $B \to X_s\pi^+\pi^-$



μ fake rate

2.6 ± 0.2 of $B \to X_s hh$ background

$B \to X_s \ell\ell$



First measurement of $B \to X_s \ell\ell$!

	(a) $X_s e^+ e^-$
yield	$26 \pm 11\,^{+5}_{-4}$
eff.	$(3.9 \pm 0.4 \pm 0.5)\%$
$\mathcal{B}(10^{-7})$	$50 \pm 23\,^{+12}_{-11}$
signif.	3.4

	(b) $X_s \mu^+ \mu^-$
yield	$37 \pm 10\,^{+7}_{-4}$
eff.	$(3.6 \pm 0.4 \pm 0.4)\%$
$\mathcal{B}(10^{-7})$	$79 \pm 21\,^{+20}_{-15}$
signif.	4.7

	(c) $X_s \ell^+ \ell^-$
yield	$60 \pm 14\,^{+9}_{-5}$
eff.	$(3.7 \pm 0.4 \pm 0.5)\%$
$\mathcal{B}(10^{-7})$	$61 \pm 14\,^{+13}_{-11}$
signif.	5.4

Preliminary

$B \to X_s \ell\ell$

Model

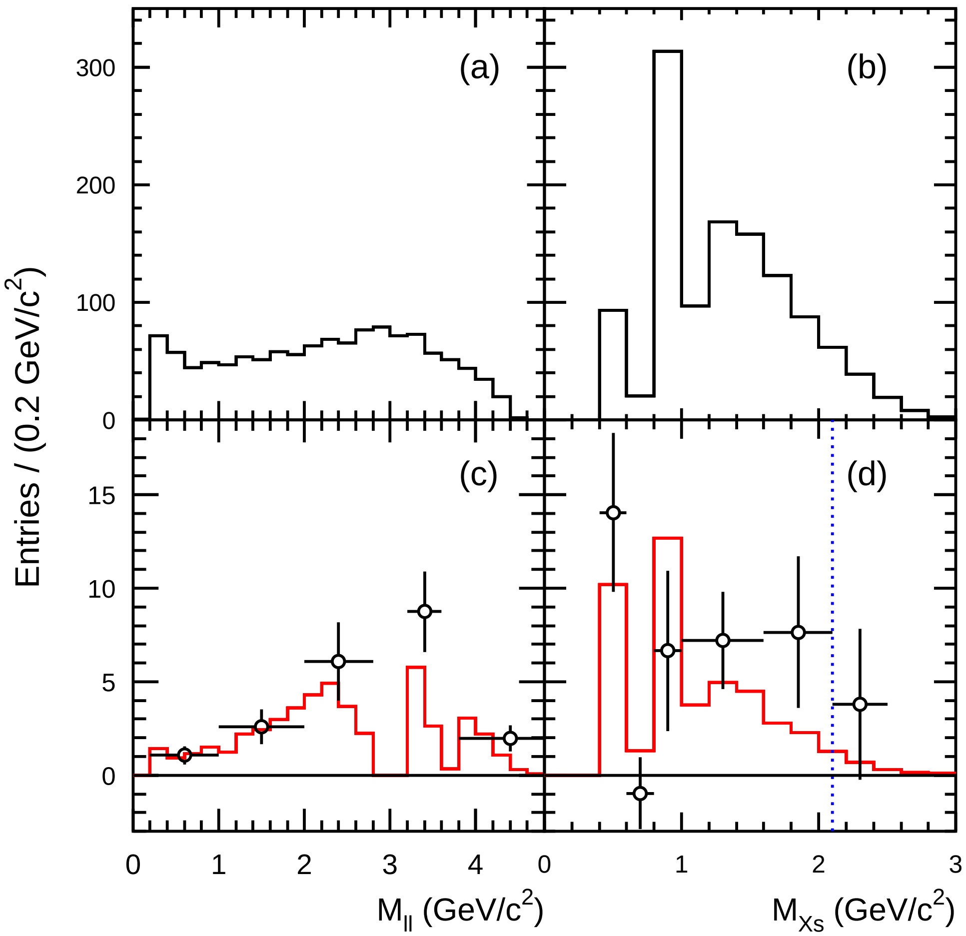
- Separate models for $K^{(*)}\ell\ell$ and $X_s\ell\ell$ ($M_{X_s} > 1.1\ \mathrm{GeV}/c^2$)
- For $K^{(*)}\ell\ell$,
  - Ali *et al.* PR**D61**, 074024 (2000) for $M_{\ell\ell}$ spectrum (NNLO)
- For $X_s\ell\ell$,
  - $M_{\ell\ell}$ and M_{X_s} spectra are taken from a series of work by Ali *et al.* based on NNLO and Fermi motion model (hep-ph/0112300, PR**D61**, 074024 and PR**D55**, 4105)
- $M_{\ell\ell} > 0.2\ \mathrm{GeV}/c^2$ to remove virtual photon contribution and $\pi^0 \to ee\gamma$, photon conversion backgrounds

Model uncertainties

- Fraction of $K^{(*)}\ell\ell$ components
  - taken from SM predictions
- p_F (Fermi momentum) and m_q (spectator quark mass)
  - to match the CLEO's λ_1 and $\overline{\Lambda}$

$B \to X_s \ell\ell$

Di-lepton mass ($M_{\ell\ell}$) and recoil mass (M_{X_s}) spectrum



- Agreement with the SM expectation.
- Consistent with the exclusive analysis.
- $B \to K\ell\ell$ is clearly seen.
- $B \to K^*\ell\ell$ is not significant.
- Signal for $M_{X_s} > M_{K^*}$ is seen!

Summary

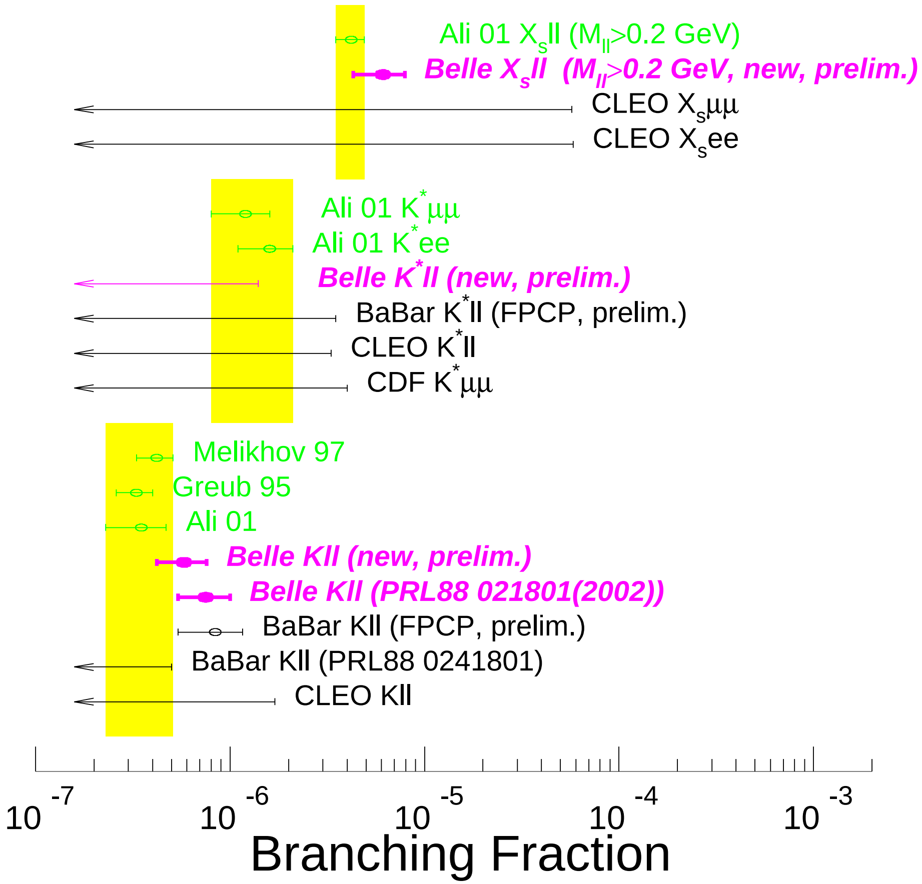
Radiative B decays

$$\mathcal{B}(B^0 \to K^*(892)^0\gamma) = (39.1 \pm 2.3 \pm 2.5) \times 10^{-6}$$
$$\mathcal{B}(B^+ \to K^*(892)^+\gamma) = (42.1 \pm 3.5 \pm 3.1) \times 10^{-6}$$
$$A_{\rm CP}(K^*\gamma) = (-2.2 \pm 4.8 \pm 1.7)\%$$
$$\mathcal{B}(B^0 \to \rho^0\gamma) < 2.6 \times 10^{-6} \quad (90\%\text{C.L.})$$
$$\mathcal{B}(B^+ \to \rho^+\gamma) < 4.9 \times 10^{-6} \quad (90\%\text{C.L.})$$
$$\mathcal{B}(B^0 \to \omega\gamma) < 3.1 \times 10^{-6} \quad (90\%\text{C.L.})$$

- New precision measurements on $B \to K^*\gamma$
  No significant difference between charged and neutral decay rates.
- No charge asymmetry in $B \to K^*\gamma$.
- $B^0 \to K_2^*(1430)^0\gamma$, $B^+ \to K^+\pi^-\pi^+\gamma$ are measured.
- Upper limit on $B \to \rho\gamma$, $\omega\gamma$ decays.

Summary

$b \to s\ell\ell$ decays



	$\mathcal{B}\ (\times 10^{-7})$	signif.
$X_s ee$	$50 \pm 23\,^{+12}_{-11}$	3.4
$X_s \mu\mu$	$79 \pm 21\,^{+20}_{-15}$	4.7
$X_s \ell\ell$	$61 \pm 14\,^{+13}_{-11}$	5.4
$K^* ee$	< 24	—
$K^* \mu\mu$	< 12	—
$K^* \ell\ell$	< 14	—
$K ee$	$3.8\,^{+2.1}_{-1.7} \pm 0.6$	2.7
$K \mu\mu$	$8.0\,^{+2.8}_{-2.3} \pm 0.8$	4.9
$K \ell\ell$	$5.8\,^{+1.7}_{-1.5} \pm 0.6$	5.4

- First measurement of $B \to X_s \ell\ell$
- Agree with SM expectation
  To be used to constrain New Physics.
- Experiments finally reached to the level of SM expectation.