Radiative Penguin Decays at Belle

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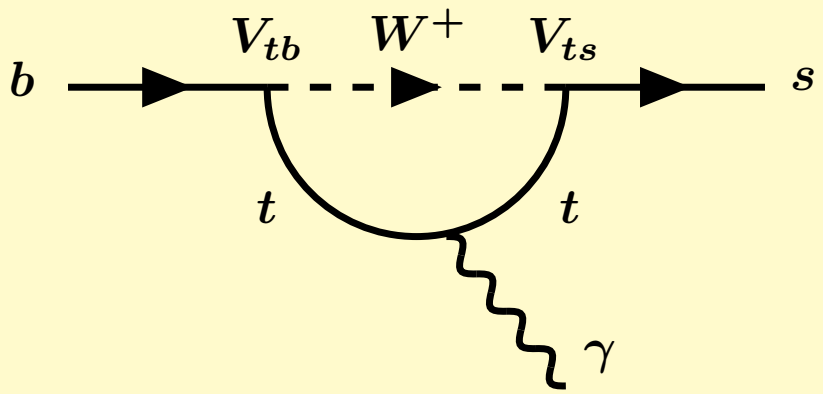
KEK — High Energy Accelerator Research Organization

EPS HEP2003 in Aachen

- $B \to K^* \gamma$, $B^+ \to \phi K^+ \gamma$
- $B \to K^{(*)} \ell\ell$, $B \to X_s \ell\ell$
- $B \to \ell\ell$

Introduction



$b \longrightarrow \gamma s$

First observation of penguin decays 10 years ago by CLEO

- Used to be a hot candidate for New Physics ($|C_7|$)
- $\mathrm{BR} \simeq 3.5 \cdot 10^{-4}$ (not that rare...)
- Today we enter the era of precision measurements
  - Photon energy spectrum (handle for V_{ub}, V_{cb})
  - Many final states are visible

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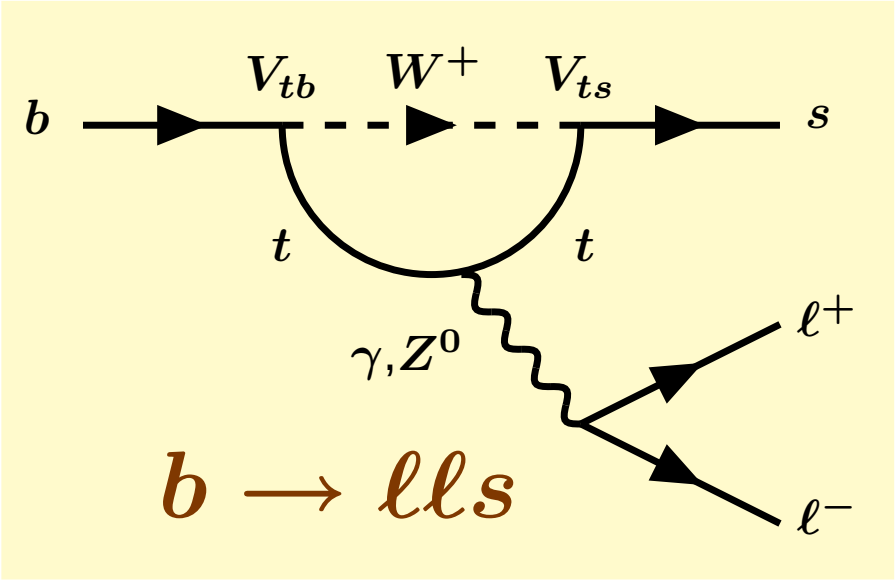

- Suppressed by α_{em}
- First seen by Belle in 2001

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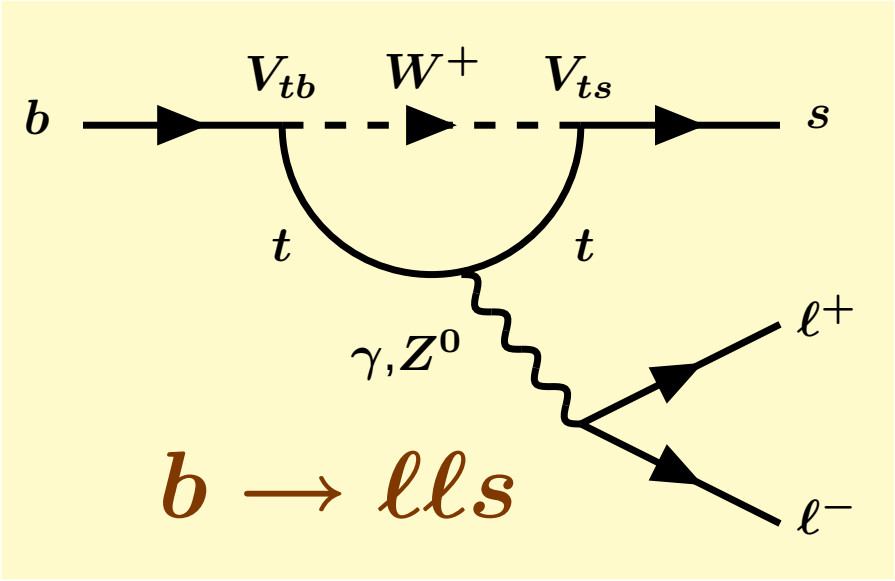
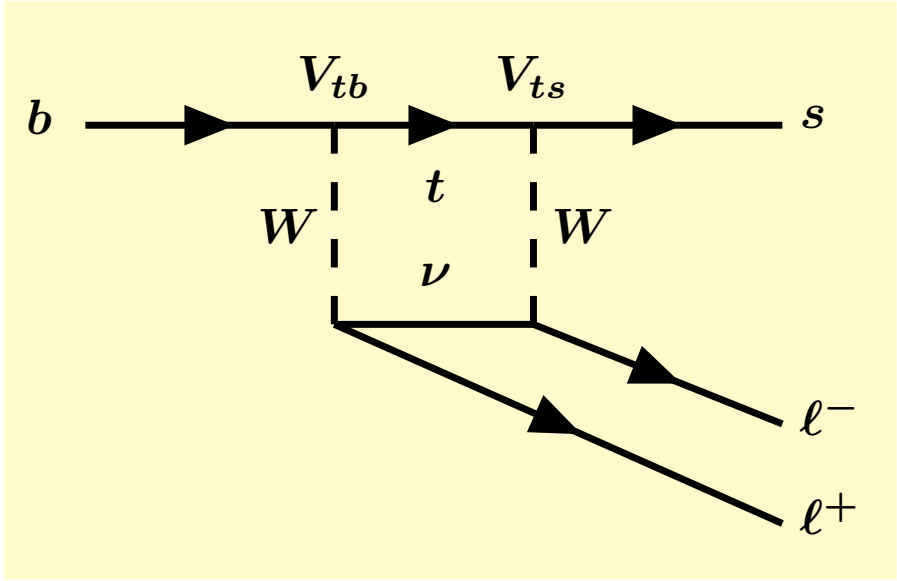
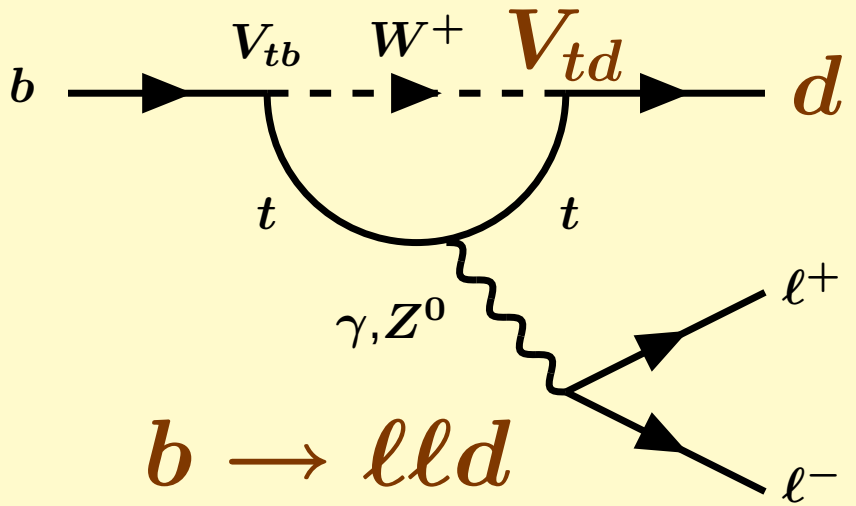


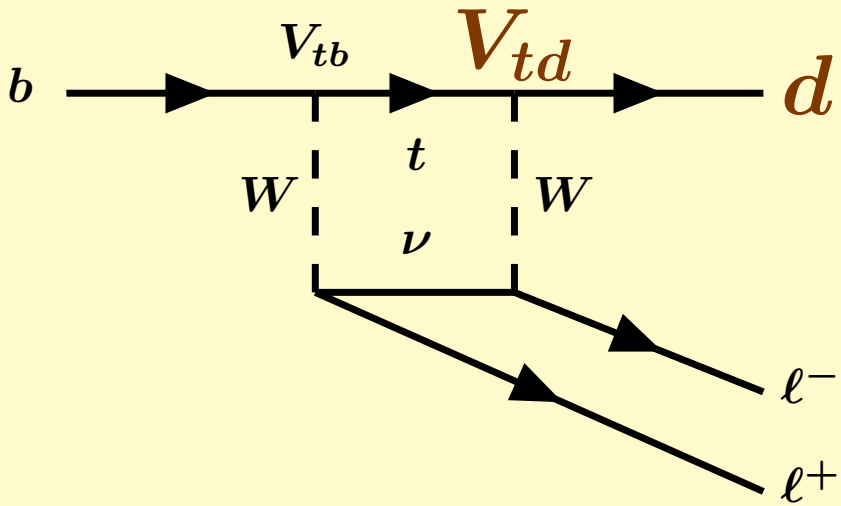


- Suppressed by α_{em}
- First seen by Belle in 2001
- Additional Z penguin and W box diagram contributions at leading order, additional Wilson coefficients C_9, C_{10}
- More dimensions to explore (q^2, A_{FB})

Introduction

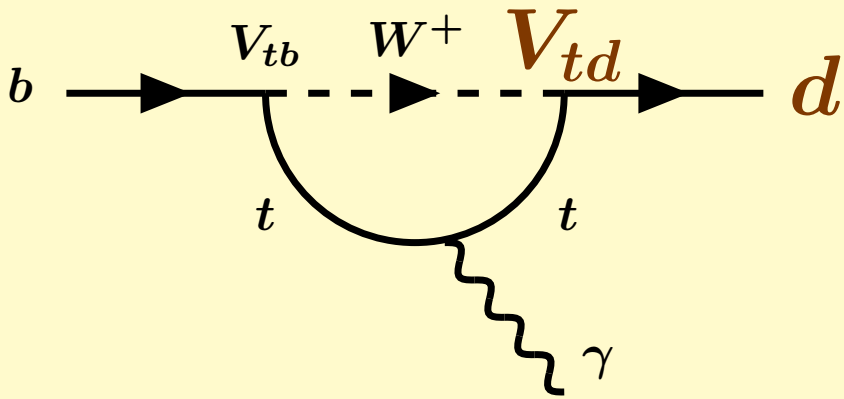


$b \to \ell\ell d$



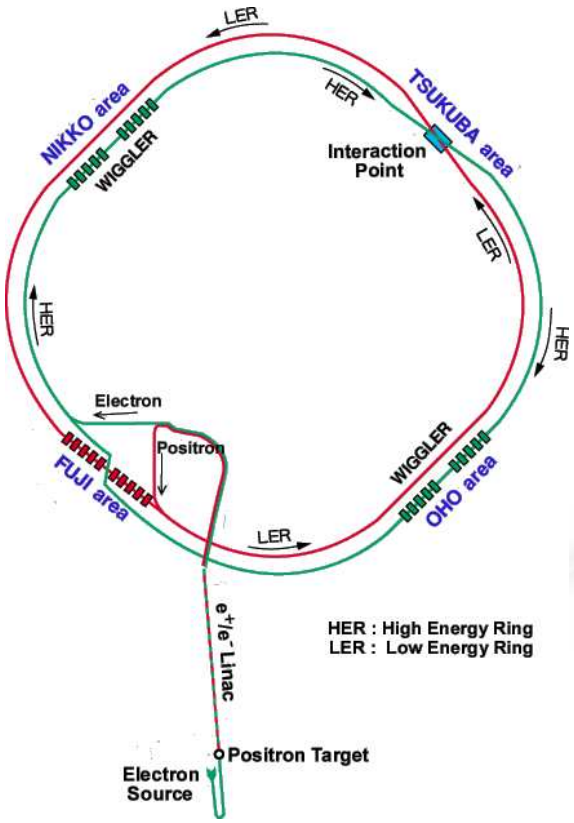
$s \to d$

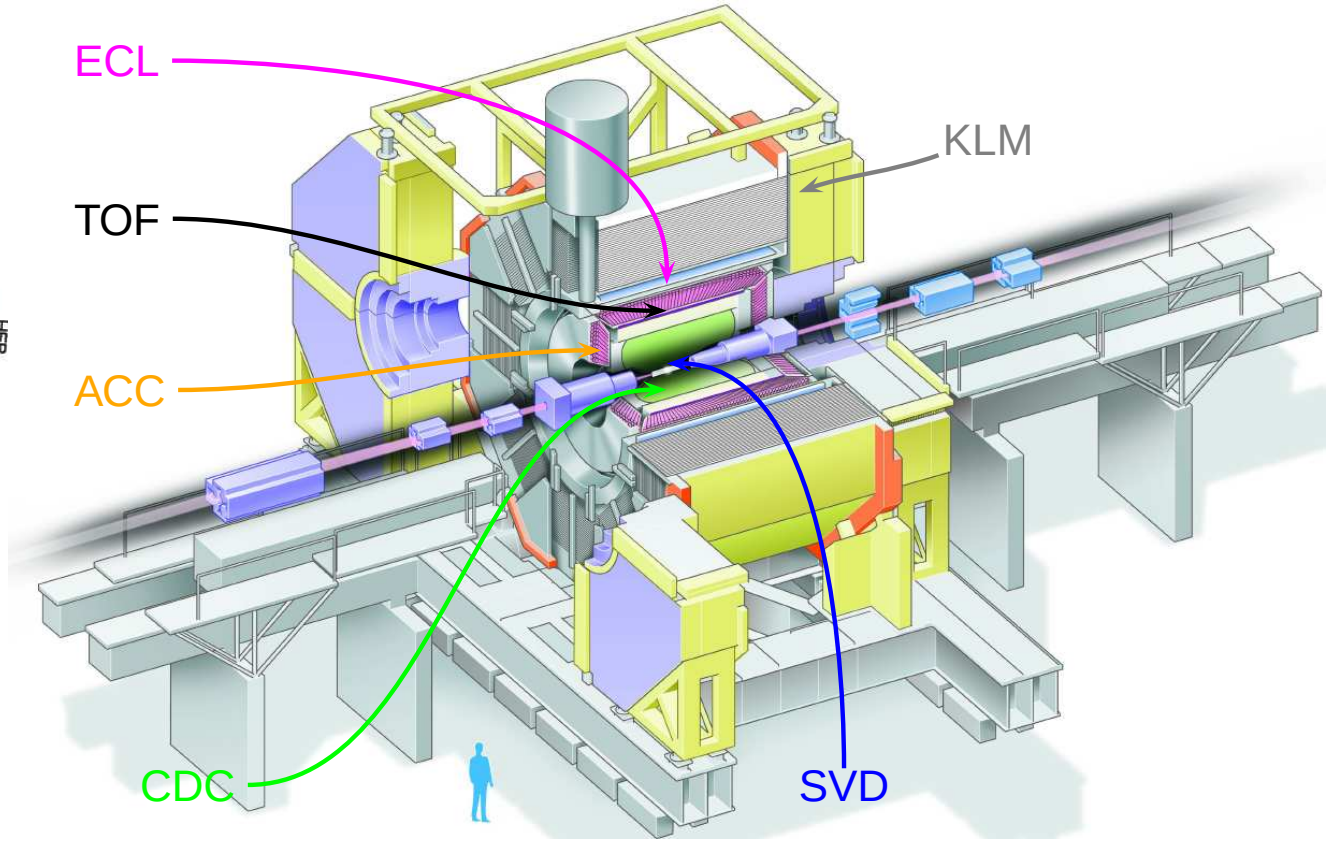
- Handle on $|V_{td}|^2/|V_{ts}|^2$
- Very rare. Not seen yet.



$b \to \gamma d$

The Belle Experiment

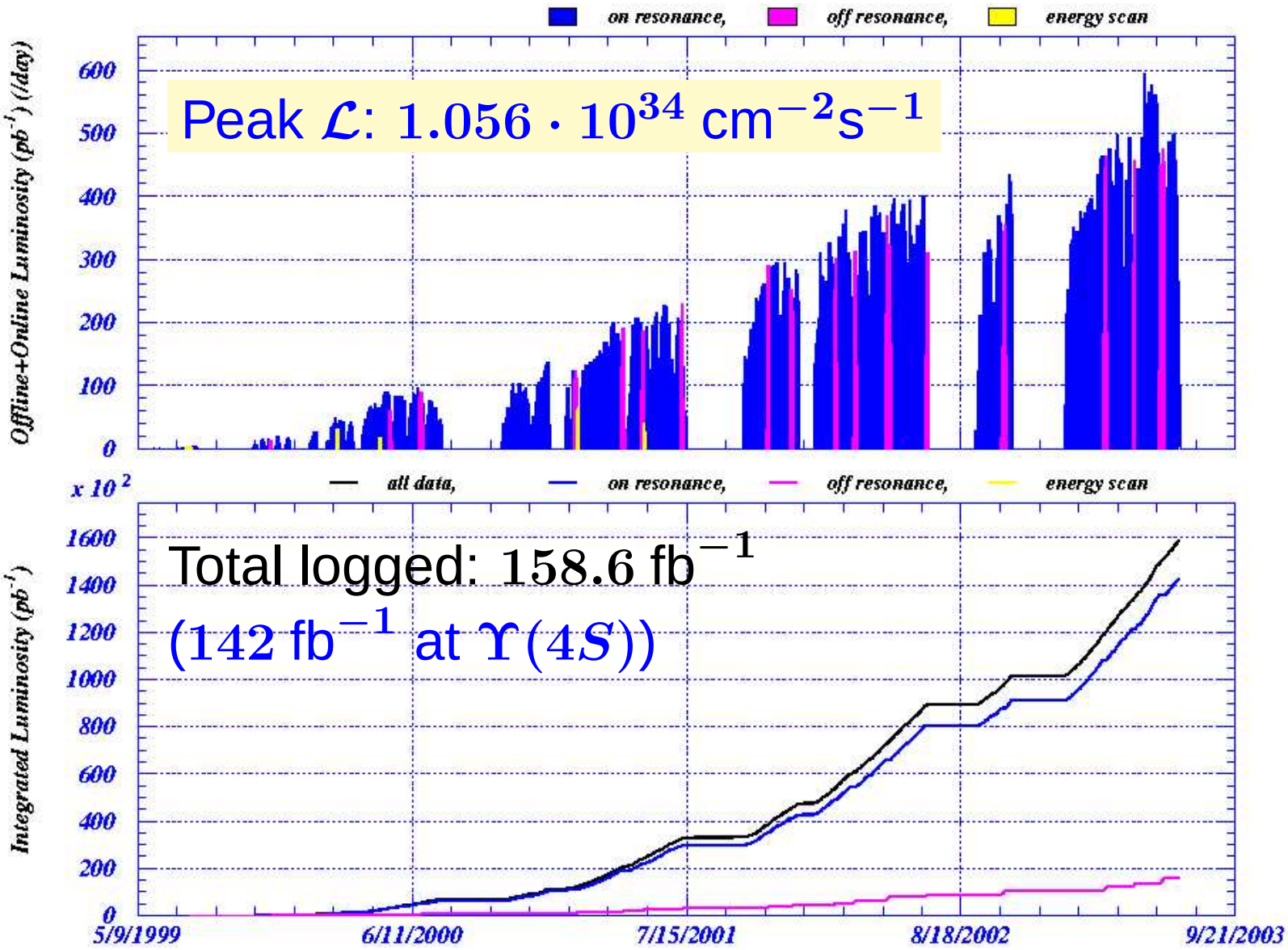




Asymmetric e^+e^- collider at $\Upsilon(4S)$

PID:
- γ: $16X_0$ CsI(Tl) (ECL)
- e: ECL, Cherenkov (ACC), TOF, dE/dx in CDC
- μ: KLM

The Belle Experiment



BELLE

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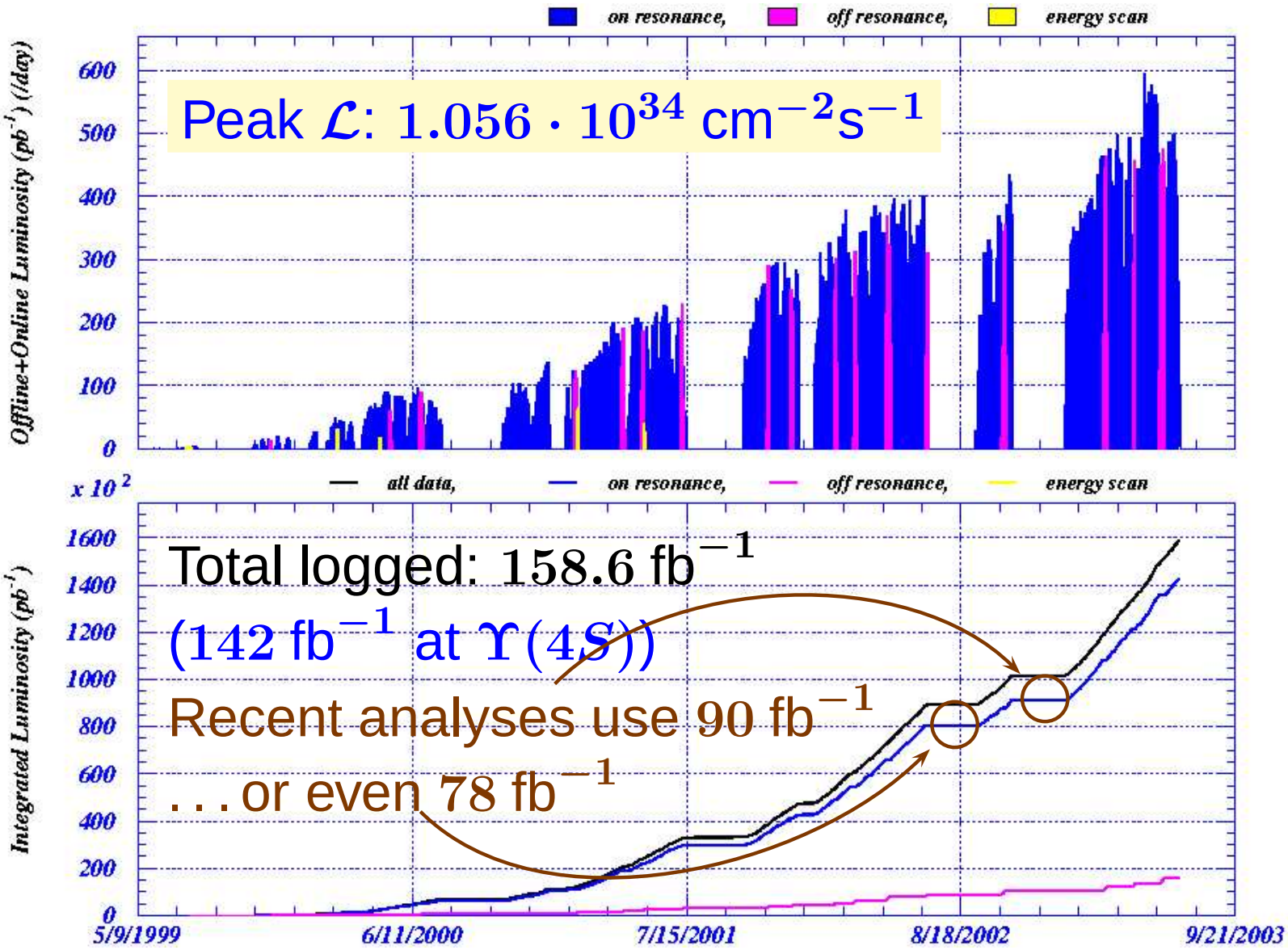
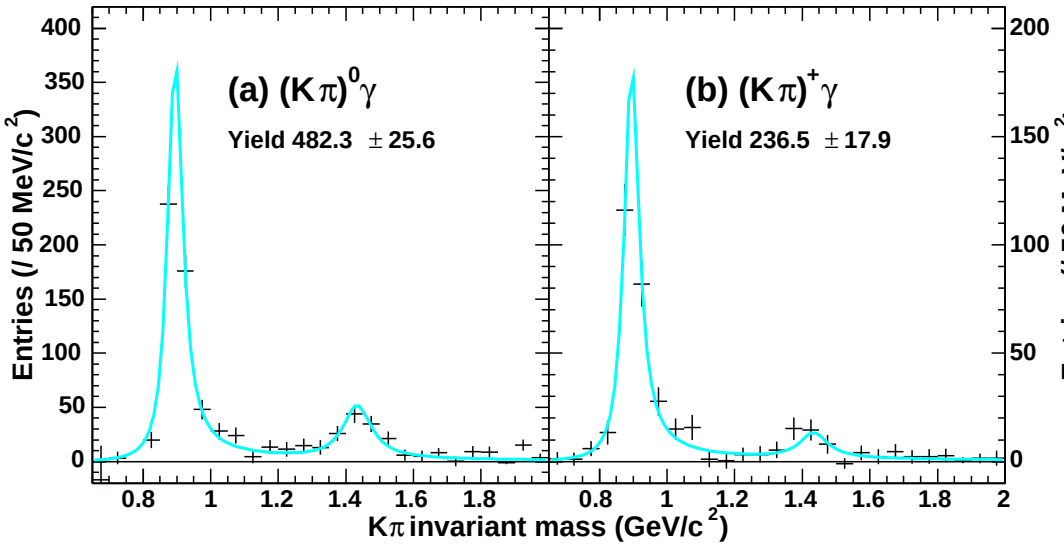


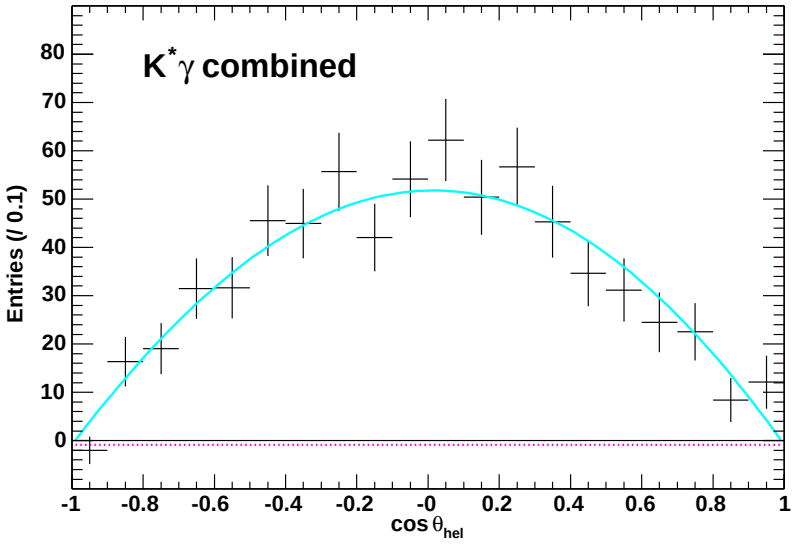
$B \to K^*\gamma$ [Abs.537, BELLE-CONF-0319]

- Photon with $1.8 < E^*_\gamma < 3.4\,\mathrm{GeV}$, not from π^0, η
- K^* reconstructed as $K^+\pi^-$, $K^0_S\pi^0$, $K^+\pi^0$, $K^0_S\pi^+$ with
  - $|m_{K\pi} - m_{K^*}| < 75\,\mathrm{MeV}/c^2$

$K\pi$ mass (without $m_{K\pi}$ cut)



$K\pi$ cos(helicity)



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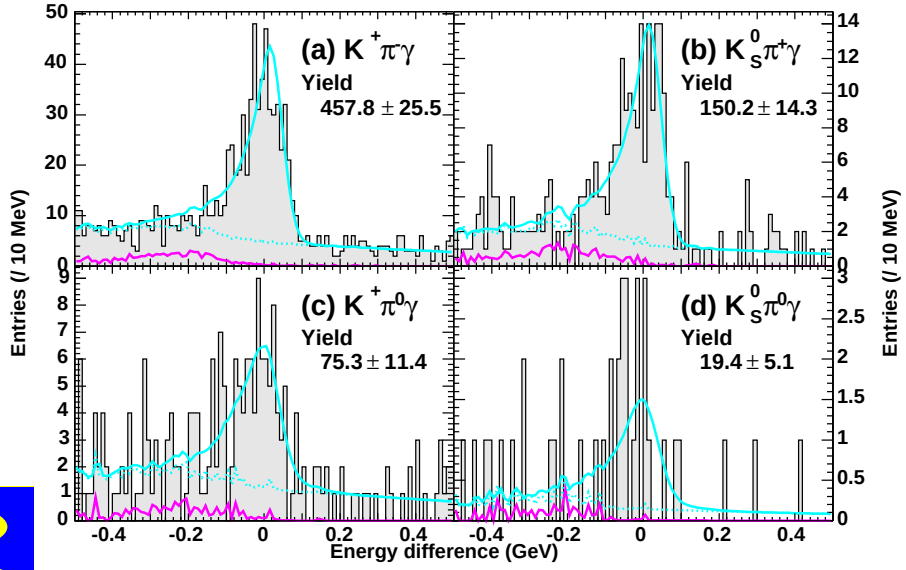
- $-200 < \Delta E < 100\,\mathrm{MeV}$

$$\Delta E = E^*_B - E^*_{\mathrm{beam}}$$



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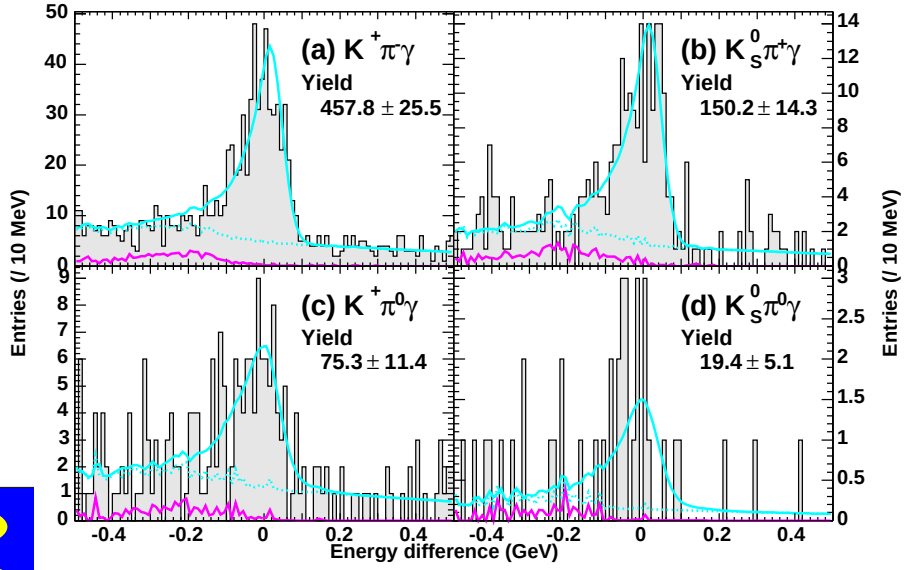
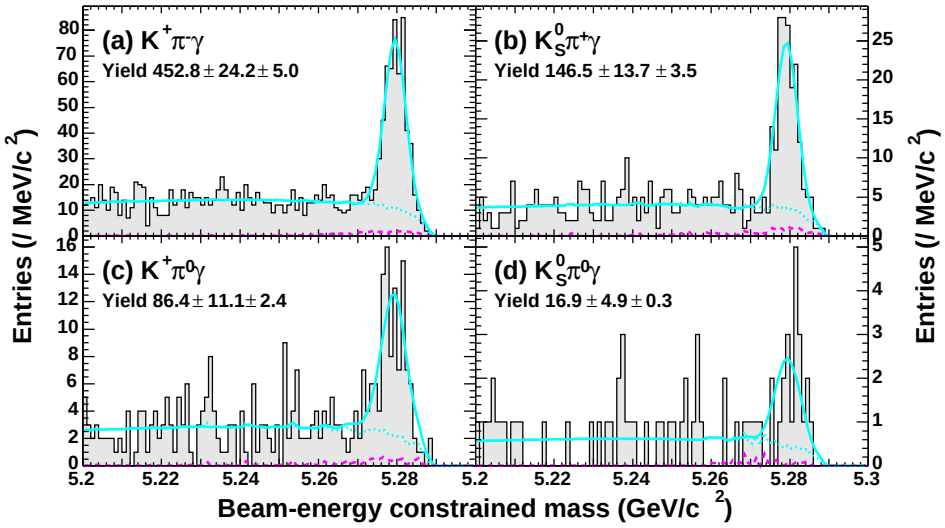


$$M_{\mathrm{bc}} = \sqrt{E^{*2}_{\mathrm{beam}} - |p^*_B|^2}$$



$B \to K^*\gamma$ Branching Ratios

Using 78 fb^{-1} ($85 \cdot 10^6$ $B\overline{B}$ pairs):

$$\begin{aligned} \text{BR}\left(B^0 \to K^{*0}\gamma\right) &= (40.9 \pm 2.1 \pm 1.9) \cdot 10^{-6} \\ \text{BR}\left(B^+ \to K^{*+}\gamma\right) &= (44.0 \pm 3.3 \pm 2.4) \cdot 10^{-6} \end{aligned}$$

Preliminary

This is becoming a precision measurement

But there is no such precise theoretical prediction. . .

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Isospin asymmetry between B^0 and B^+:

$$\Delta_{0+} = \frac{\Gamma\left(B^0 \to K^{*0}\gamma\right) - \Gamma\left(B^+ \to K^{*+}\gamma\right)}{\Gamma\left(B^0 \to K^{*0}\gamma\right) + \Gamma\left(B^+ \to K^{*+}\gamma\right)}$$

$\Rightarrow$ sign (C_6/C_7) [Kagan & Neubert, PLB539:227-234,2002]

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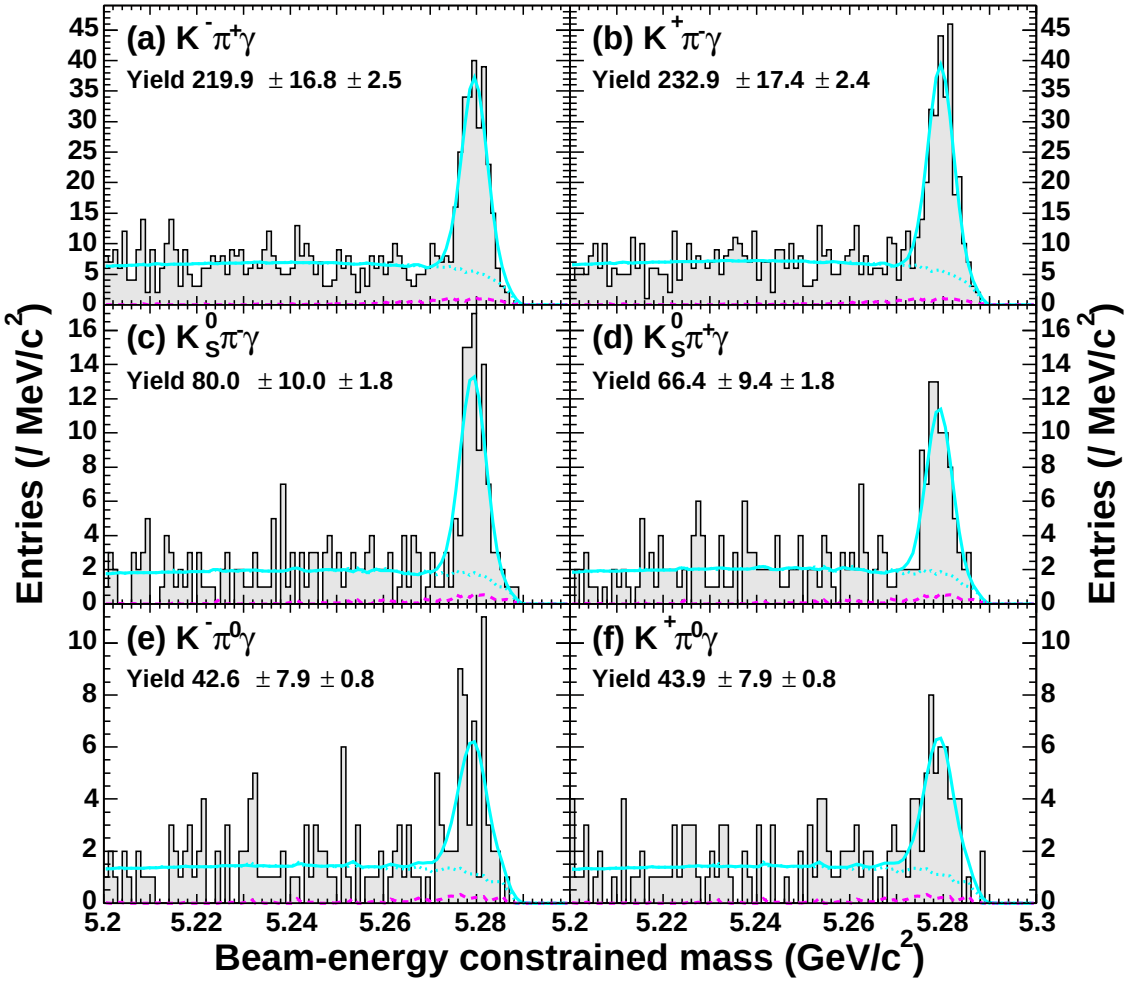
Preliminary

A_{CP} in $B \to K^*\gamma$



A_{CP} expected to be very small ($< 1\%$) in the SM

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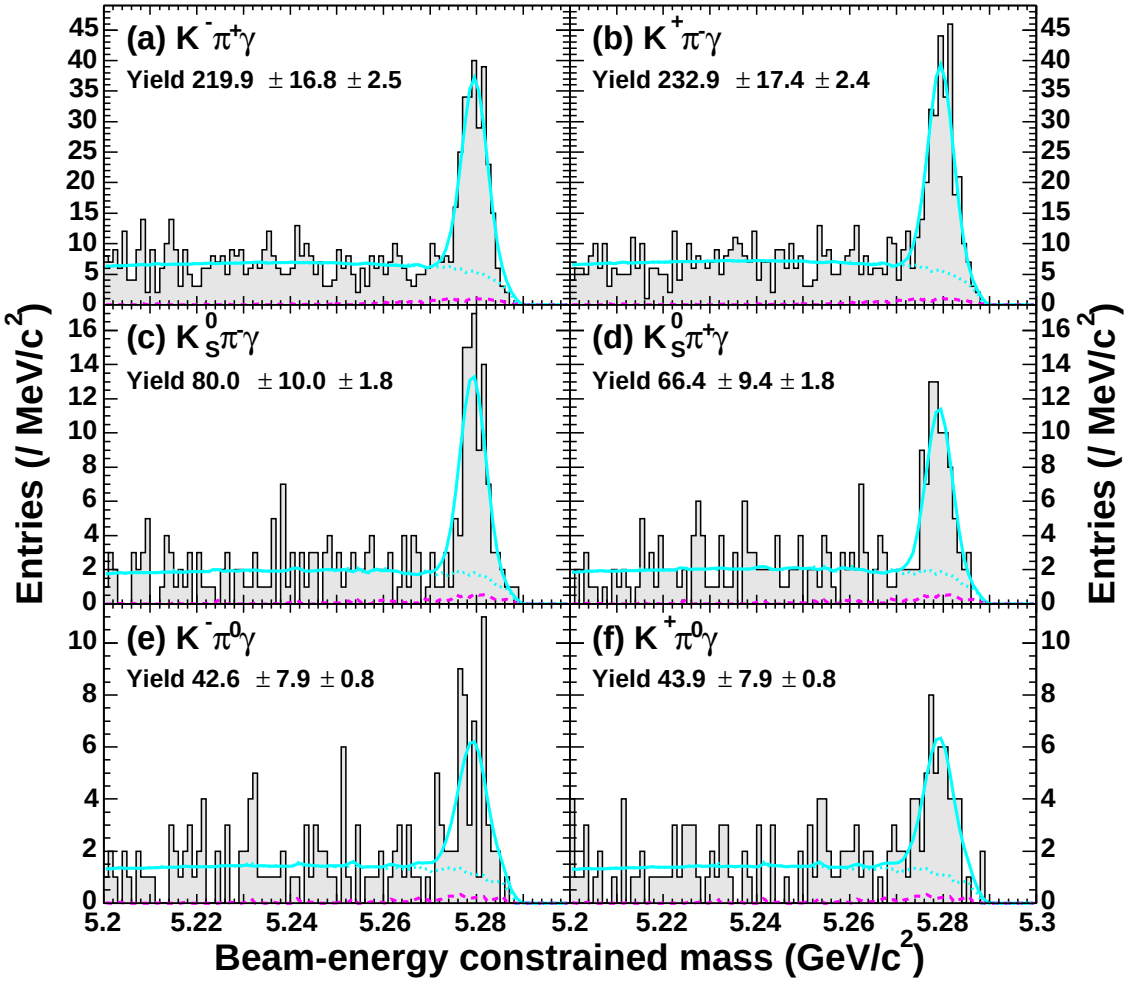


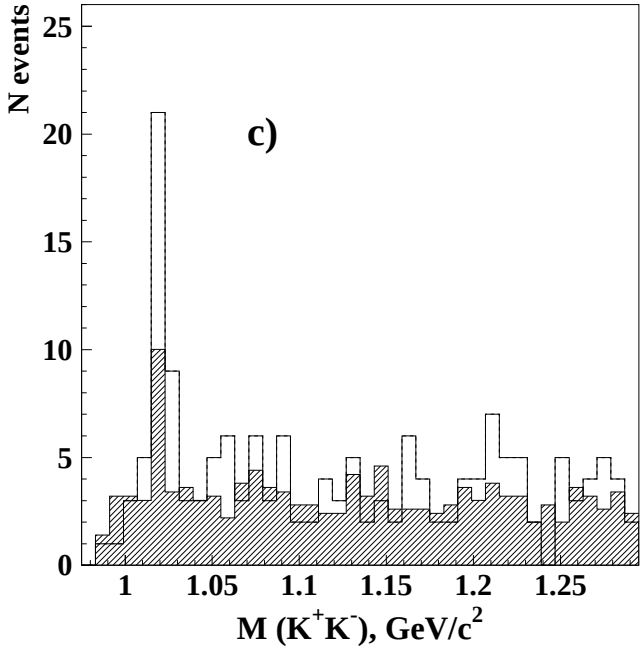
A_{CP} expected to be very small ($< 1\%$) in the SM

$$A_{CP} = (-0.1 \pm 4.4 \pm 0.8)\,\%$$

Most systematic errors cancel. Error is still statistics-dominated.

$B^+ \to \phi K^+ \gamma$ [Abs.542, BELLE-CONF-0322]

- Photon with $2.0 < E^*_\gamma < 2.7$ GeV not from π^0, η
- 3 charged K
- $|m_{KK} - m_\phi| < 10\ \mathrm{MeV}/c^2$



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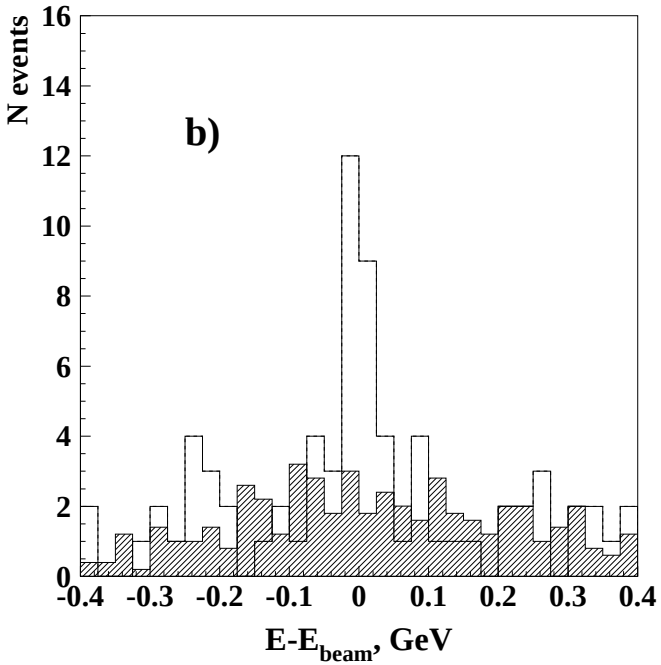

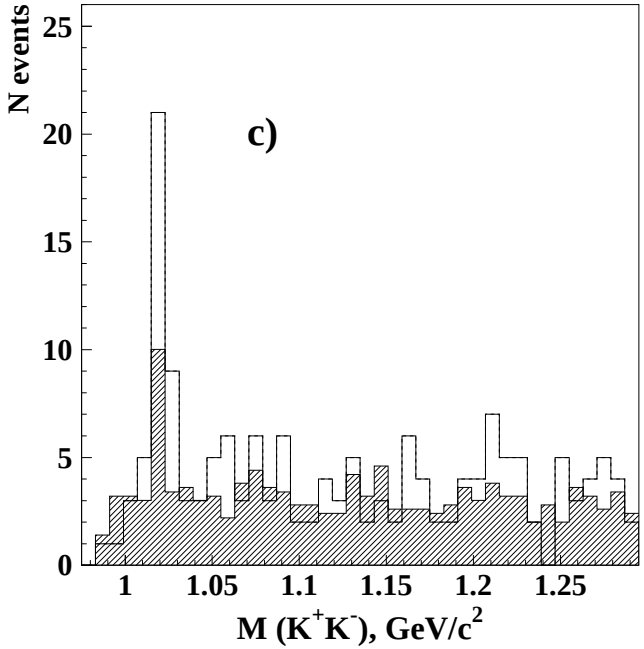

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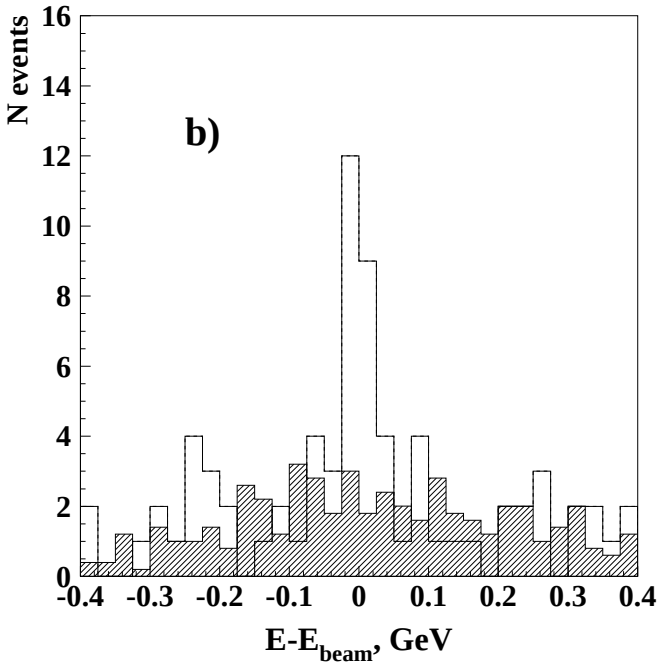
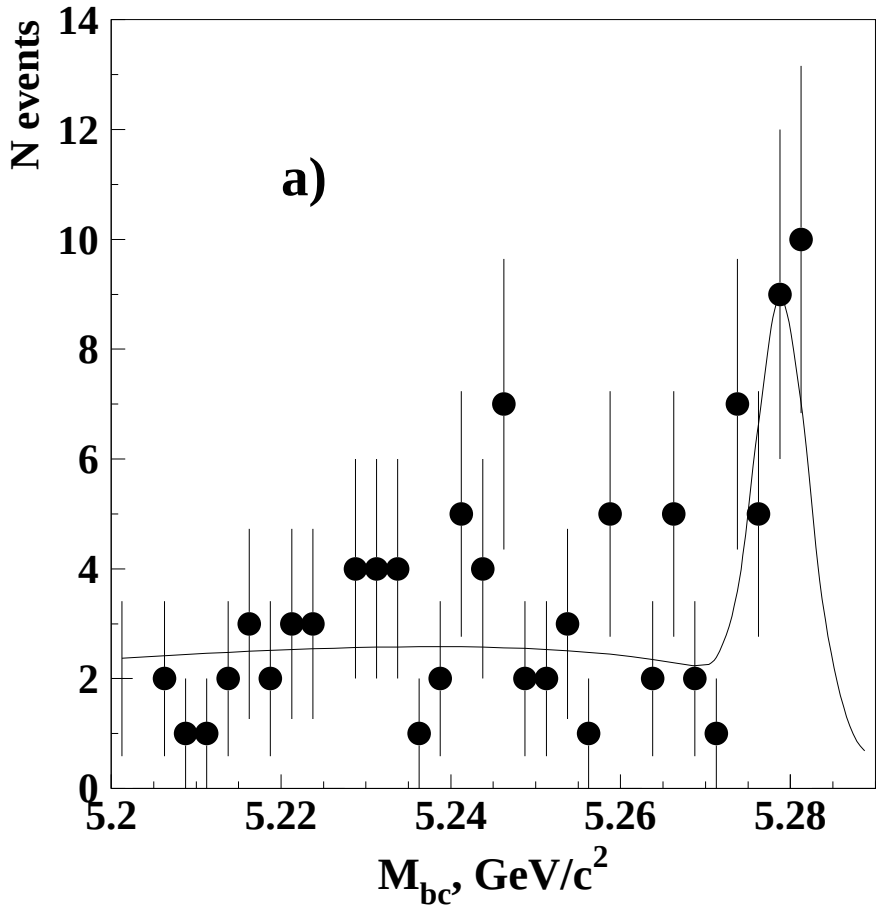




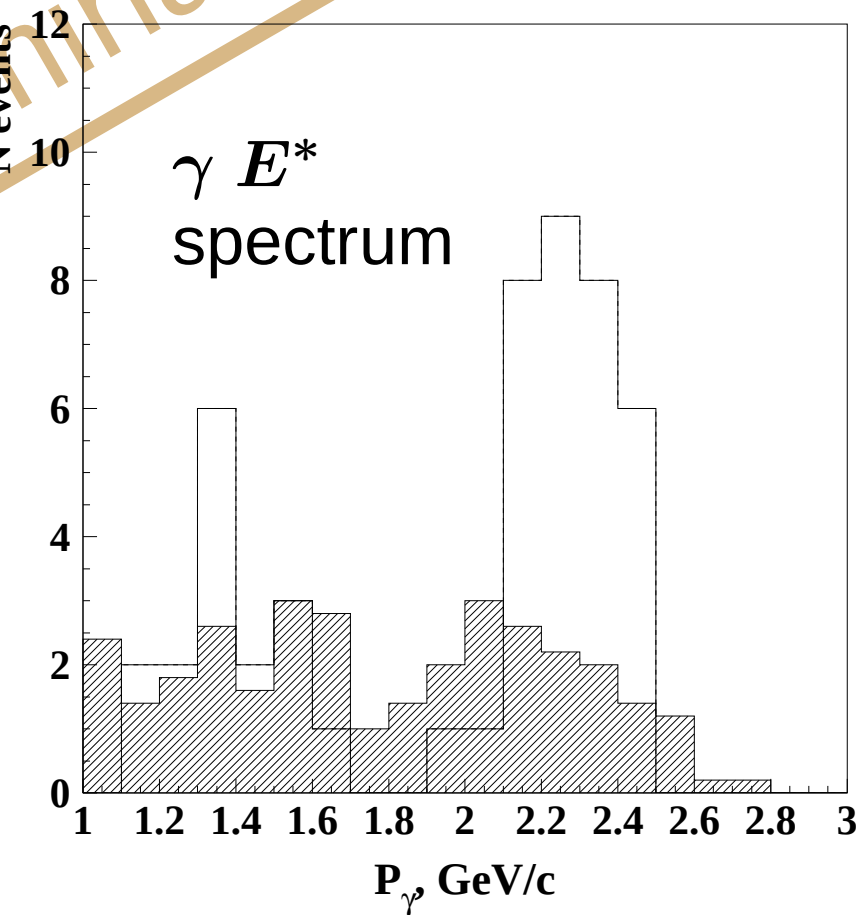
$B^+ \to \phi K^+ \gamma$ [Abs.542, BELLE-CONF-0322]

$$\mathrm{BR}\left(B^+ \to \phi K^+ \gamma\right) = (3.4 \pm 0.9 \pm 0.4) \cdot 10^{-6}$$ ($90\ \mathrm{fb}^{-1}$)

(5.5σ significance)

First observation!

[Abs.542, BELLE-CONF-0322]



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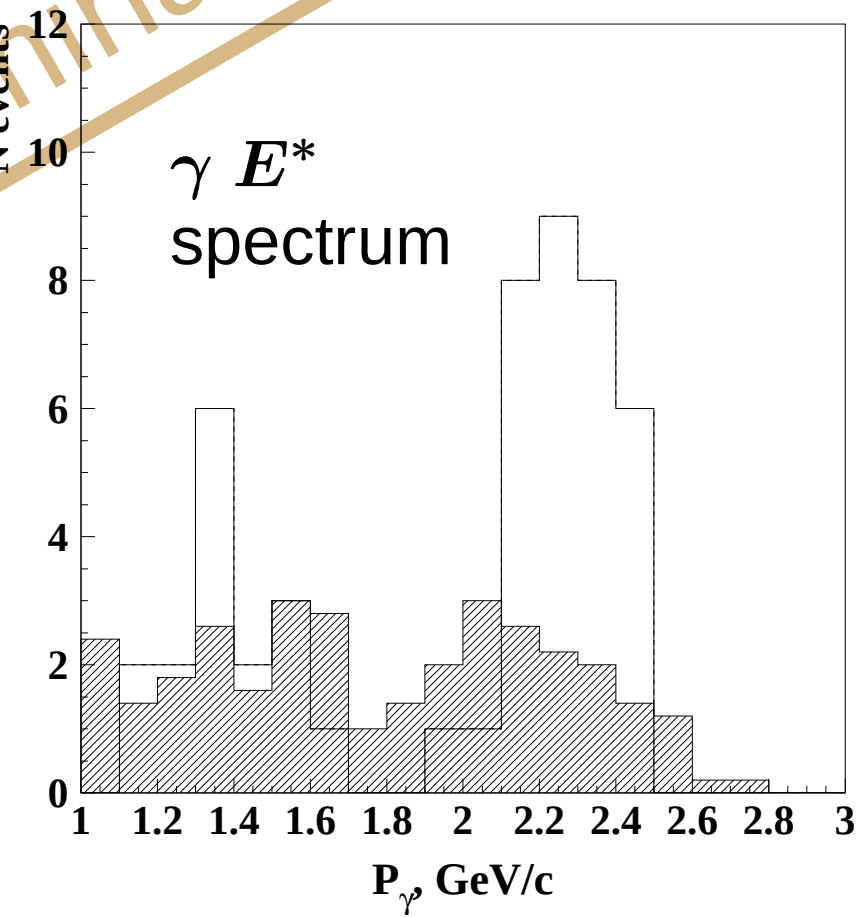

$B^0 \to \phi K^0_S \gamma$ is promising for time-dependent CP violation searches (Δt in $K^*(K^0_S \pi^0)\gamma$ is too difficult to measure).

All radiative results

Channel	BR ($\cdot 10^{-6}$)	$\int \mathcal{L}$	Ref.
$B \to X_s \gamma$	$340 \pm 50 \pm 40 \pm 50$	6 fb^{-1}	[1]
$B^0 \to K^{*0} \gamma$	$40.9 \pm 2.1 \pm 1.9$	78 fb^{-1}	[2]
$B^+ \to K^{*+} \gamma$	$44.0 \pm 3.3 \pm 2.4$	78 fb^{-1}	[2]
$B^+ \to K^+ \pi^+ \pi^- \gamma$	$24 \pm 5 \, ^{+4}_{-2}$	29 fb^{-1}	[3]
$B^0 \to K_2^*(1430) \gamma$	$13 \pm 5 \pm 1$	29 fb^{-1}	[3]
$B^+ \to \phi K^+ \gamma$	$3.4 \pm 0.9 \pm 0.4$	90 fb^{-1}	[4]

[1] [Phys.Lett.B 511, 151 (2001)]

[2] [Abs.537, BELLE-CONF-0319] —Preliminary

[3] [Phys. Rev. Lett. 89, 231801 (2002)]

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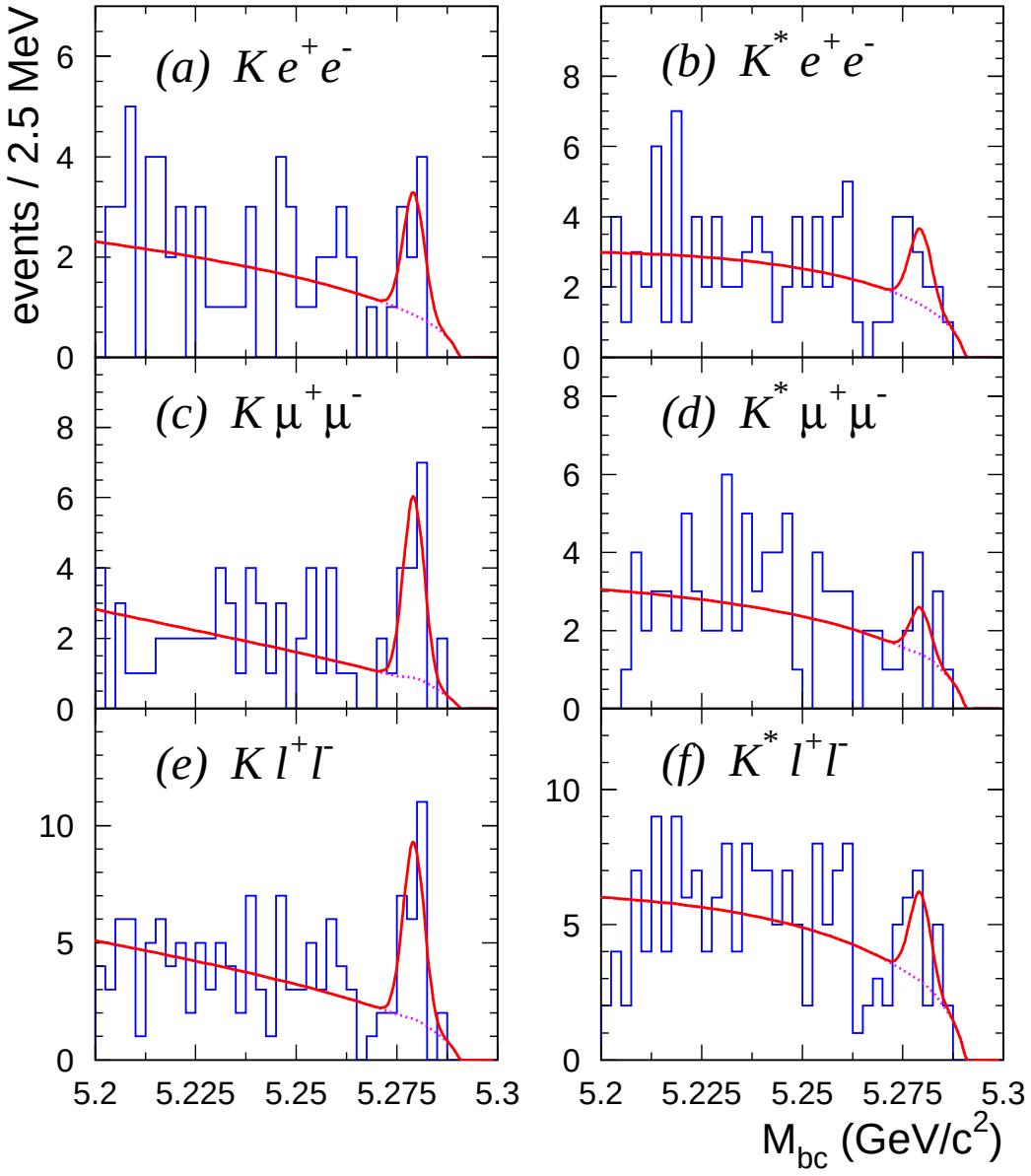
$B^0 \to K_2^*(1430)\gamma$	$13 \pm 5 \pm 1$	29 fb^{-1}	[3]
$B^+ \to \phi K^+\gamma$	$3.4 \pm 0.9 \pm 0.4$	90 fb^{-1}	[4]
$B^+ \to \rho^+\gamma$	< 2.7 (90% C.L.)	78 fb^{-1}	[5]
$B^0 \to \rho^0\gamma$	< 2.6 (90% C.L.)	78 fb^{-1}	[5]
$B^0 \to \omega(783)\gamma$	< 4.4 (90% C.L.)	78 fb^{-1}	[5]

[5] Moriond 2003 —Preliminary

$B \to K\ell\ell$ and $B \to K^*\ell\ell$

- K: $K^\pm$ or K^0_S
- K^*: $K^+\pi^-$, $K^0_S\pi^+$, $K^+\pi^0$ with $|m_{K\pi} - m_{K^*}| < 75\ \mathrm{MeV}/c^2$
- a pair of e or μ
  $p(e) > 0.5\ \mathrm{GeV}/c$
  $p(\mu) > 1.0\ \mathrm{GeV}/c$
  $m_{\ell\ell} > 0.2\ \mathrm{GeV}/c^2$
- Veto J/ψ, $\psi(2S)$



$B \to K\ell\ell$ and $B \to K^*\ell\ell$

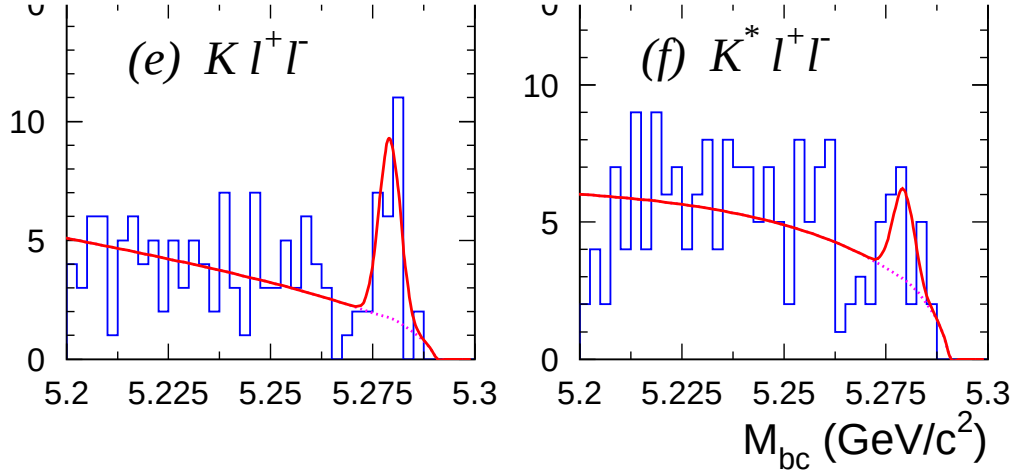
	Branching ratio at $60\ \text{fb}^{-1}$	
$B \to K\ell\ell$	$\left(0.58\ ^{+\,0.17}_{-\,0.15} \pm 0.06\right) \cdot 10^{-6}$	Clear signal
$B \to K^*\ell\ell$	$< 1.4 \cdot 10^{-6}$	Vague hint

Preliminary

[ICHEP 2002, update of PRL88,021801(2002)]

Precision on $B \to K\ell\ell$ is as good as theory

$B \to K^*\ell\ell$ is around the corner



BELLE

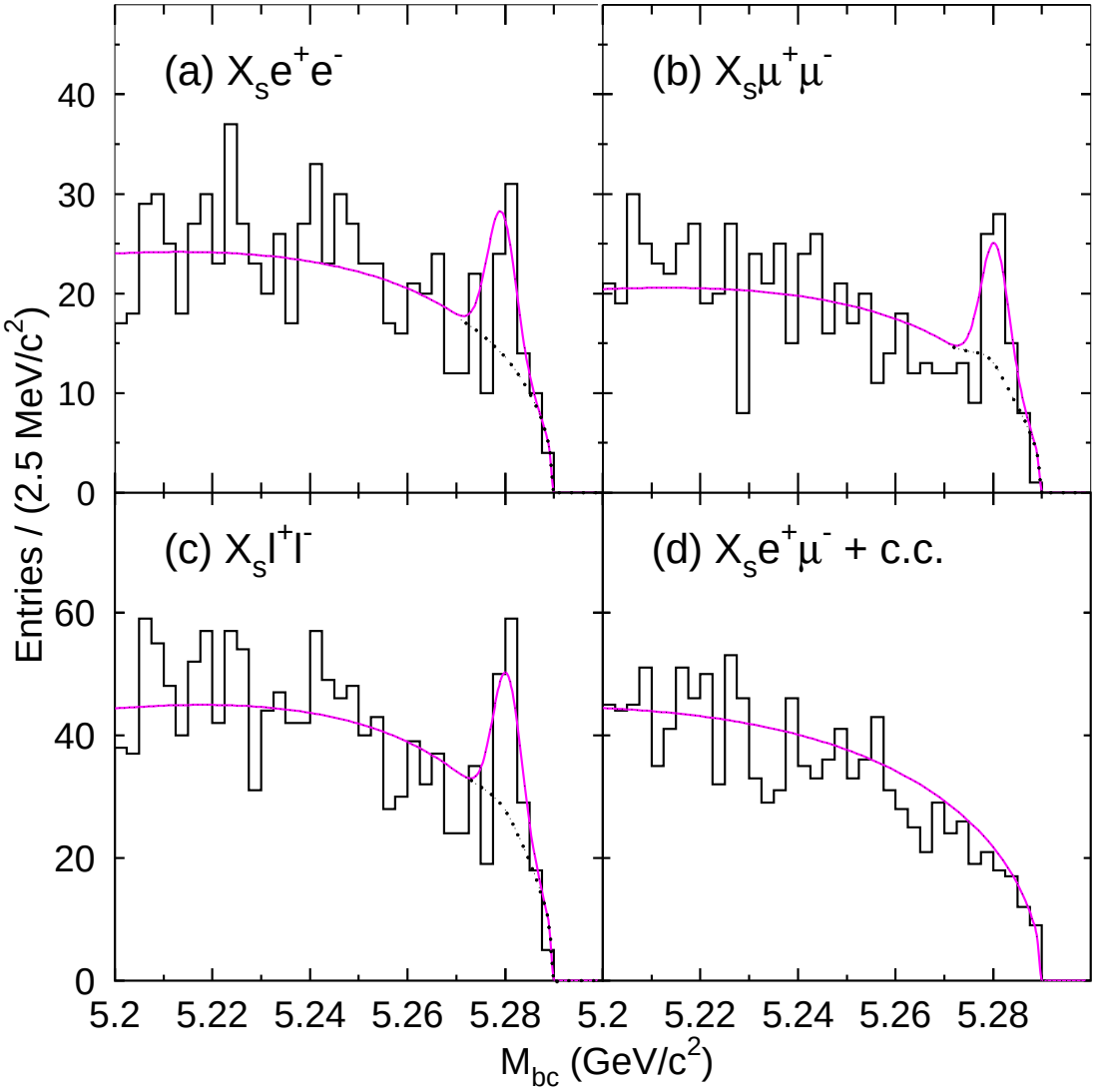
Semi-Inclusive $B \to X_s \ell\ell$

- X_s:
  - 1 $K^\pm$ or K^0_S
  - 0–4 π ($\leq 1\ \pi^0$)
  - $m_{X_s} < 2.1\ \mathrm{GeV}/c^2$
- a pair of e or μ

  $p(e) > 0.5\ \mathrm{GeV}/c$

  $p(\mu) > 1.0\ \mathrm{GeV}/c$

  $m_{\ell\ell} > 0.2\ \mathrm{GeV}/c^2$
- J/ψ, $\psi(2S)$ are vetoed



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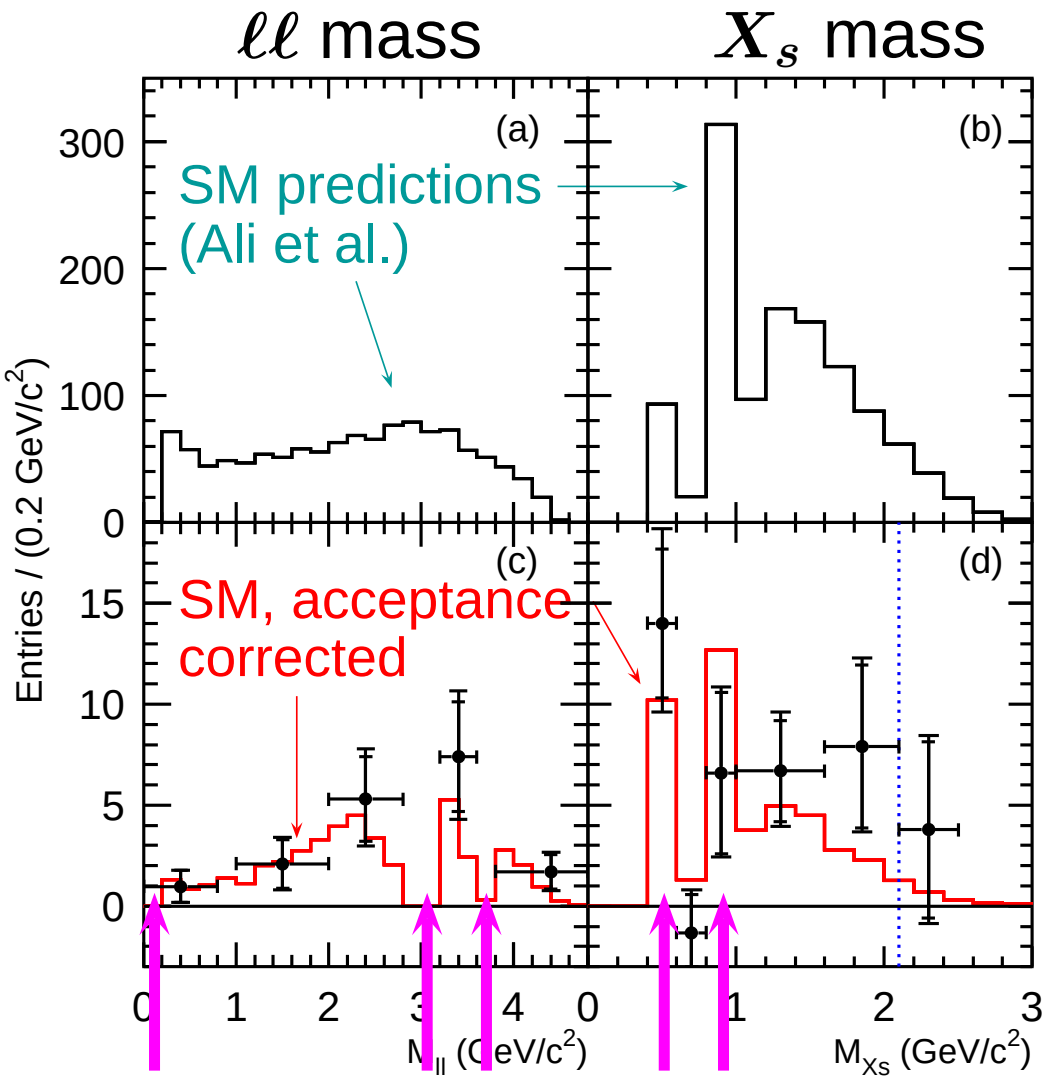

First measurement, using 60 fb^{-1}

	BR in 10^{-6}
$\mu\mu$	$7.9 \pm 2.1 \,^{+2.1}_{-1.5}$
ee	$5.0 \pm 2.3 \,^{+1.3}_{-1.1}$
$\ell\ell$	$6.1 \pm 1.4 \,^{+1.4}_{-1.1}$

[Phys.Rev.Lett.90,021801(2003)]

K and K^* yields are compatible with exclusive analysis

Search for leptonic B^0 decays

Predicted BR in SM:

- $B \to \mu\mu$: $8 \cdot 10^{-11}$
- $B \to ee$: $2 \cdot 10^{-15}$

They could be larger by two orders of magnitude in two-Higgs-doublet models and Z-mediated FCNC models.

$B \to e\mu$ decays are forbidden in SM,
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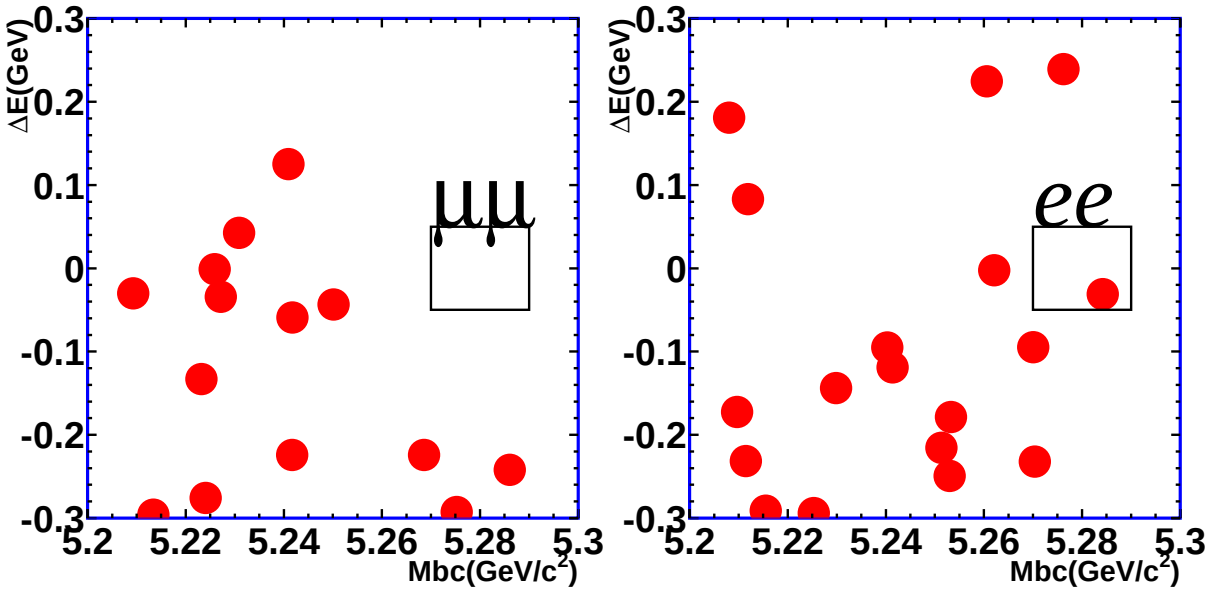
Reconstruction:

- Two leptons with tight ID ($\mathcal{L} > 0.9$)
- $5.27 < M_{\mathrm{bc}} < 5.29\ \mathrm{GeV}/c^2$
- $|\Delta E| < 0.05\ \mathrm{GeV}$

Main background from light-quark continuum
$\Rightarrow$ Topology, missing energy, number of tracks...

Search for leptonic B^0 decays



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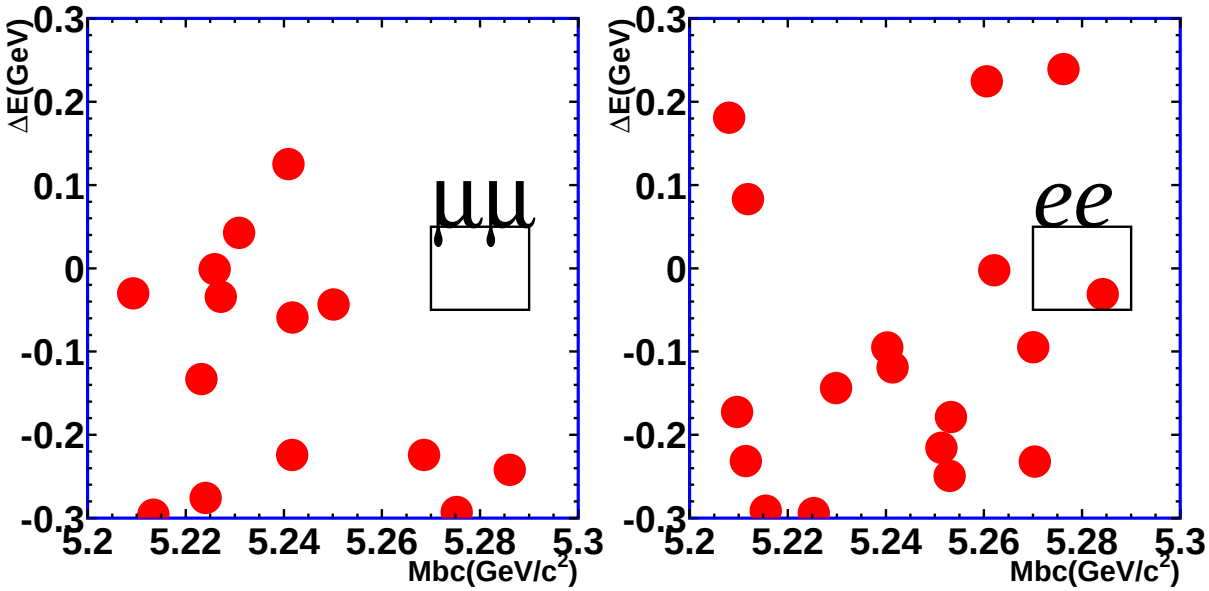


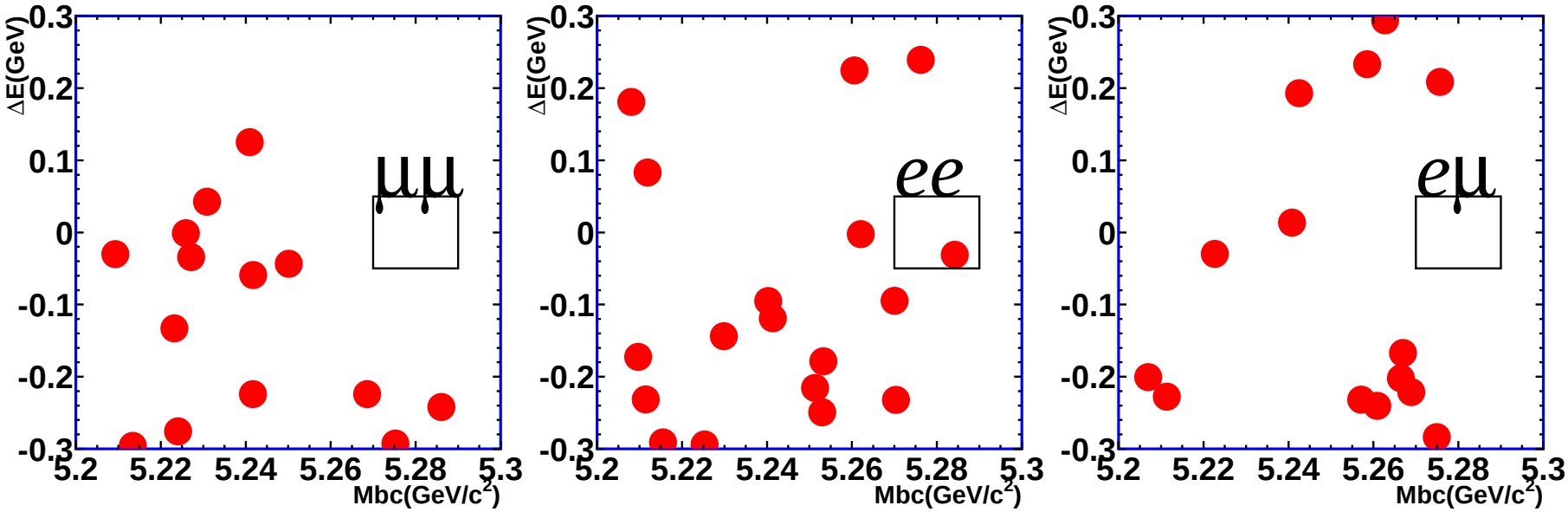
	Branching ratio
$B \to \mu\mu$	$< 0.9 \cdot 10^{-7}$ (90% C.L.)
$B \to ee$	$< 2.0 \cdot 10^{-7}$ (90% C.L.)

Preliminary

This improves the previous best limits by a factor 2

[Belle Preliminary, FPCP'03]

Search for leptonic B^0 decays



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Preliminary

$B \to e\mu$ allows to set the limit $M_{LQ} > 54$ TeV (90% C.L.) for the Pati-Salam leptoquark

Conclusion

$B \to X_s\gamma$:

- Precise measurements of $B \to K^*\gamma$, but no deviation from SM is seen in A_{CP} or Δ_{0+}
- Rare decays become visible: First observation of $B^+ \to \phi K^+\gamma$
- . . . but most of $B \to X_s\gamma$ is yet to explore

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$B \to X_s\ell\ell$:

- Clear $B \to K\ell\ell$ signal. No $B \to K^*\ell\ell$ yet
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$B \to \ell\ell$: New upper limits at 10^{-7}!

Conclusion

$B \to X_s\gamma$:

- Precise measurements of B … deviation from SM is seen in A …
- Rare decays … of B^+ …

These are results using up to 90 fb^{-1}.

We have 142 fb^{-1} now…

and we'll have much more by next summer

… $B \to K^*\ell\ell$ yet

- … of semi-inclusive $B \to X_s\ell\ell$
- … more data to measure asymmetries

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