

Radiative Penguin Decays at Belle

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KEK — High Energy Accelerator Research Organization



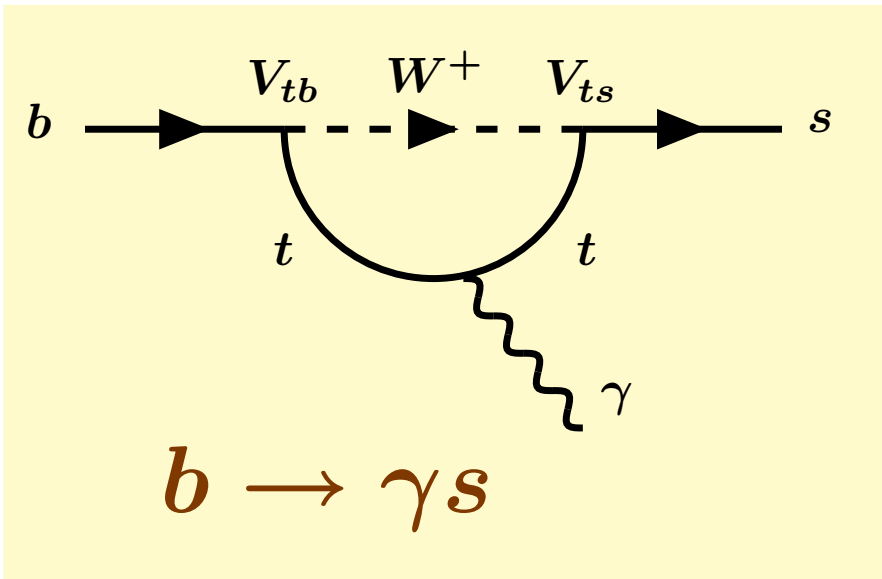
EPS HEP2003 in Aachen

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



P.Koppenburg

Introduction

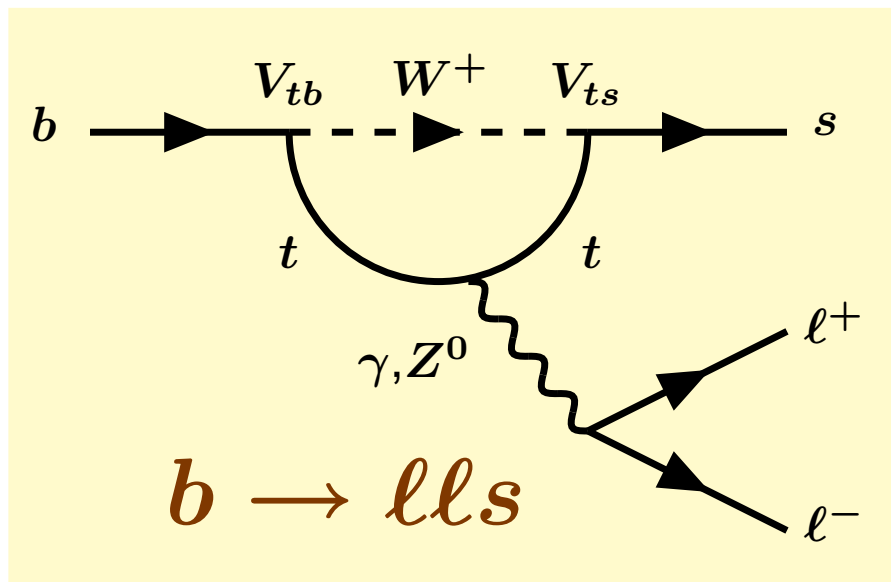


First observation of penguin decays 10 years ago by CLEO

- Used to be a hot candidate for New Physics ($|C_7|$)
- $\text{BR} \simeq 3.5 \cdot 10^{-4}$ (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

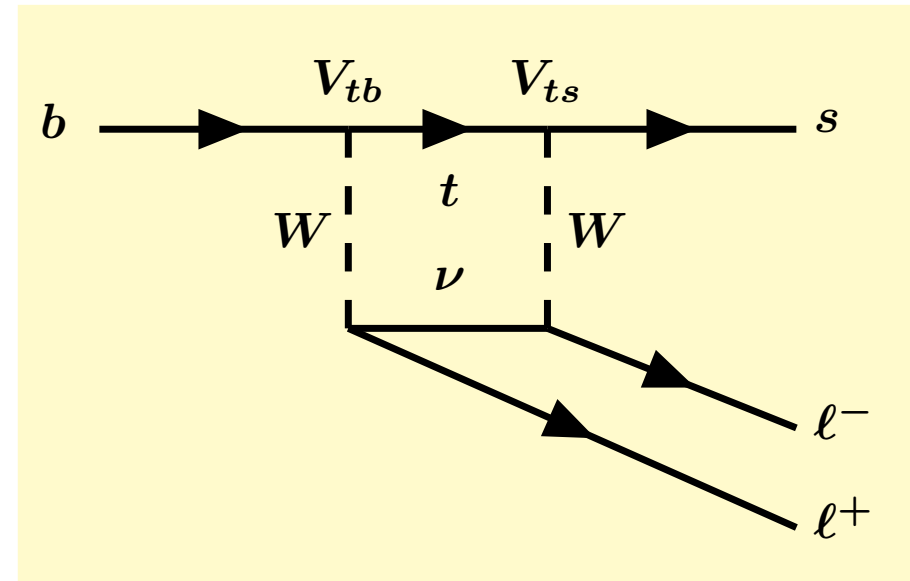
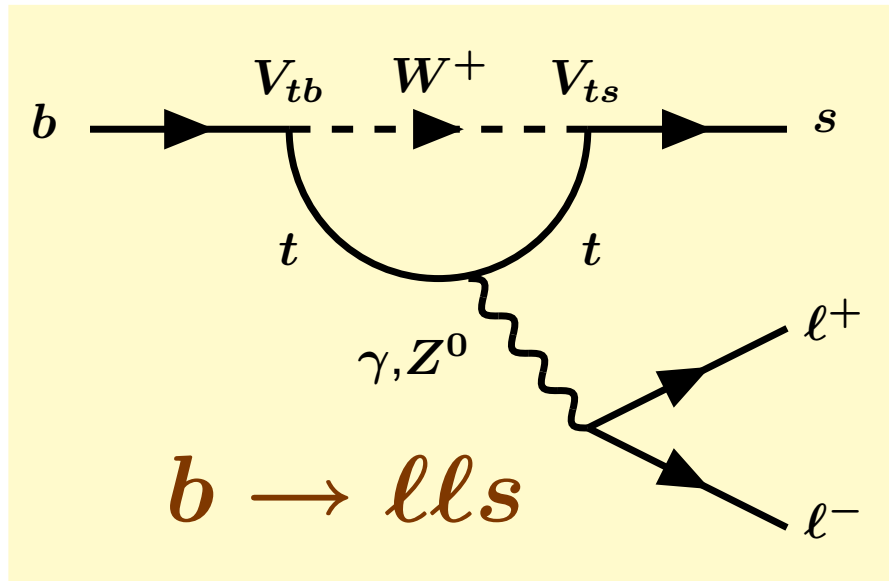


Introduction



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

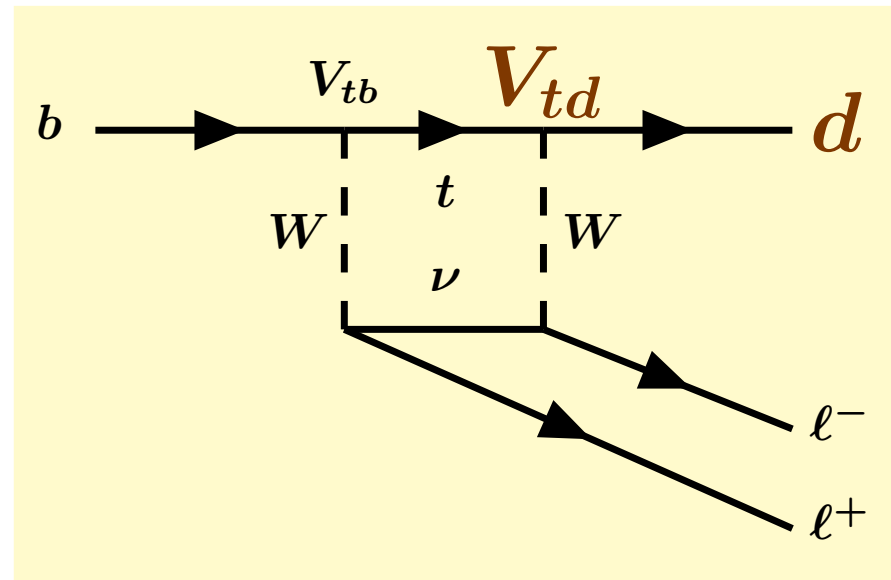
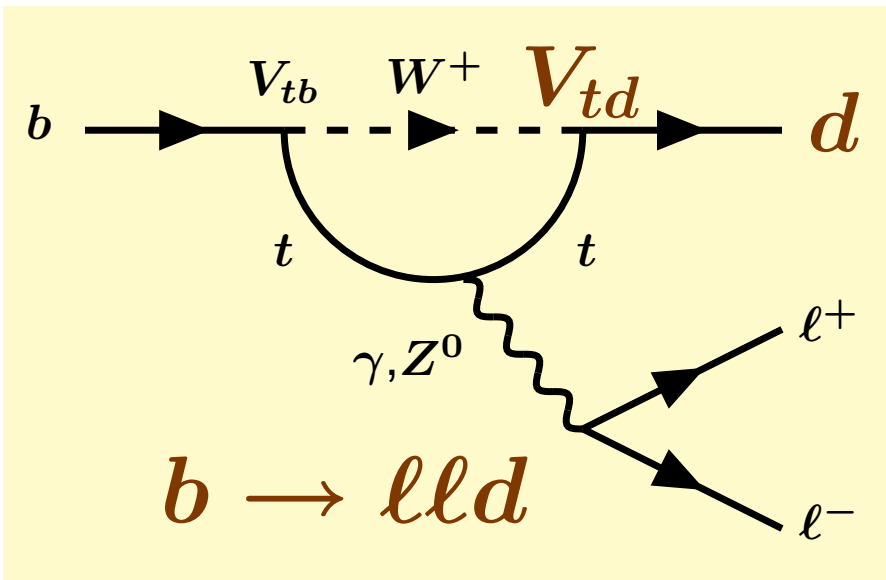
Introduction



- 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})

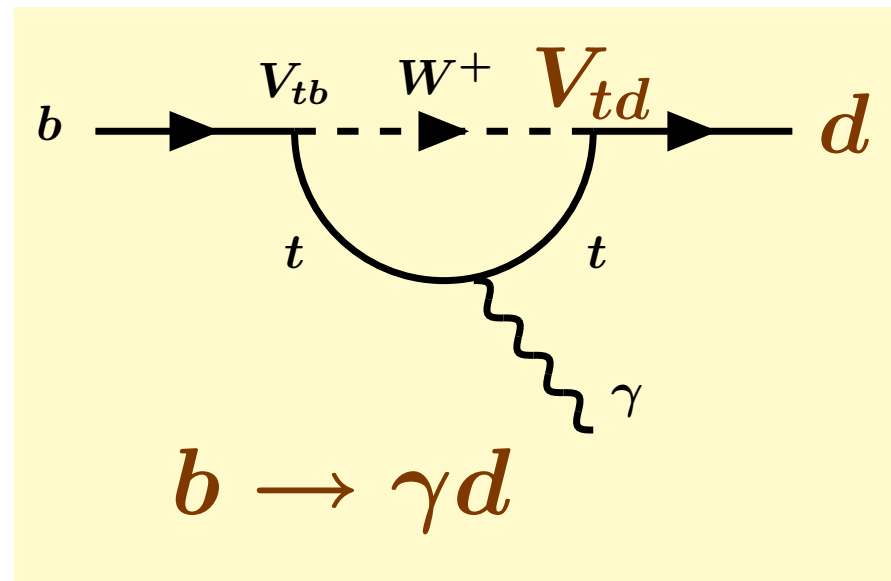


Introduction

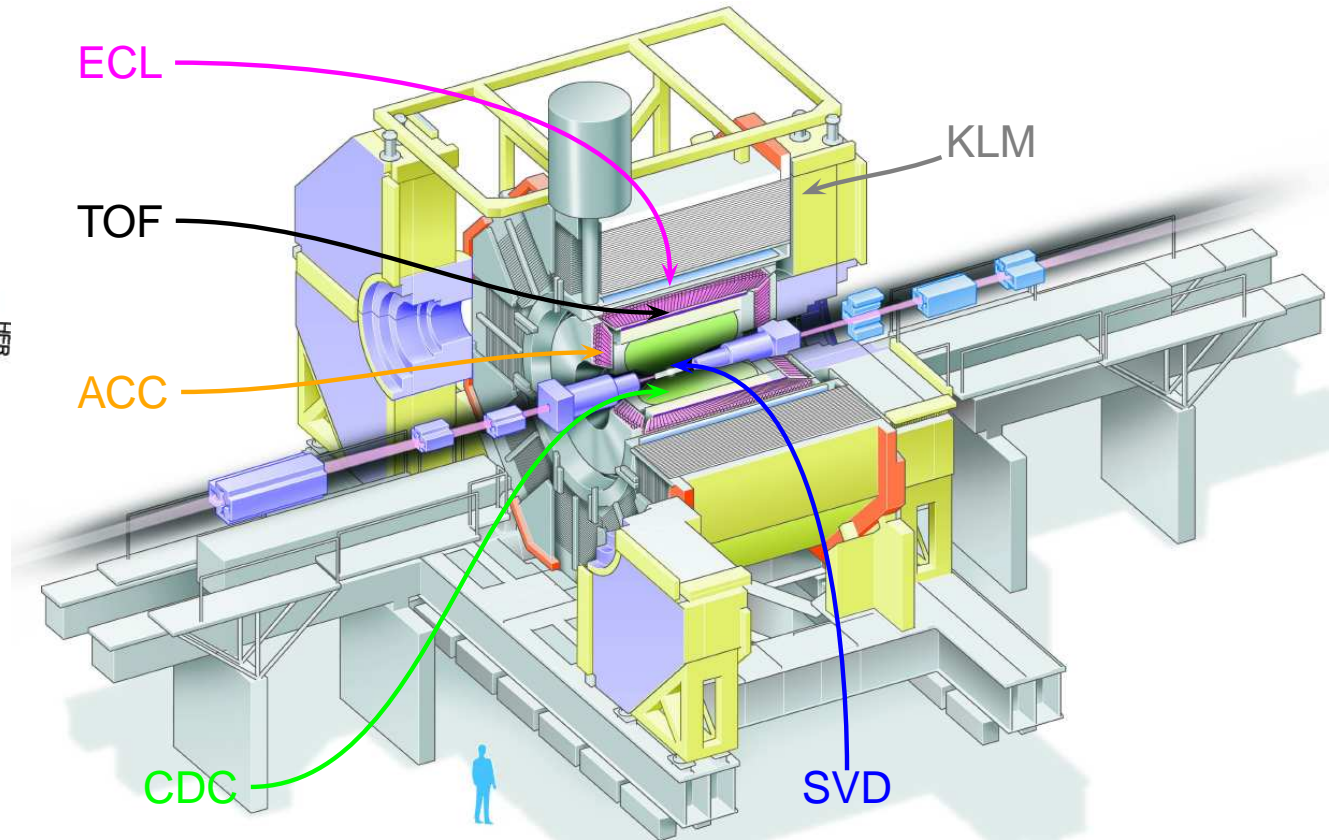
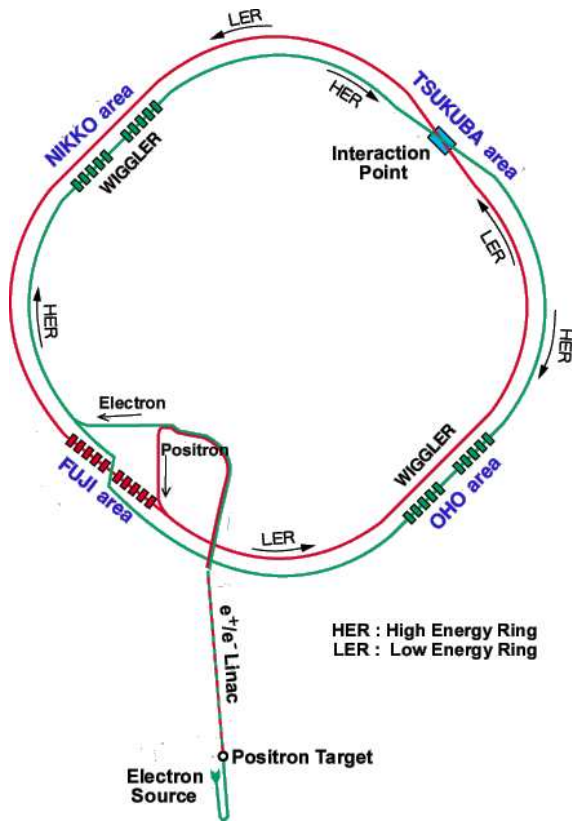


$s \rightarrow d$

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



The Belle Experiment



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

γ : $16X_0$ CsI(Tl) (ECL)

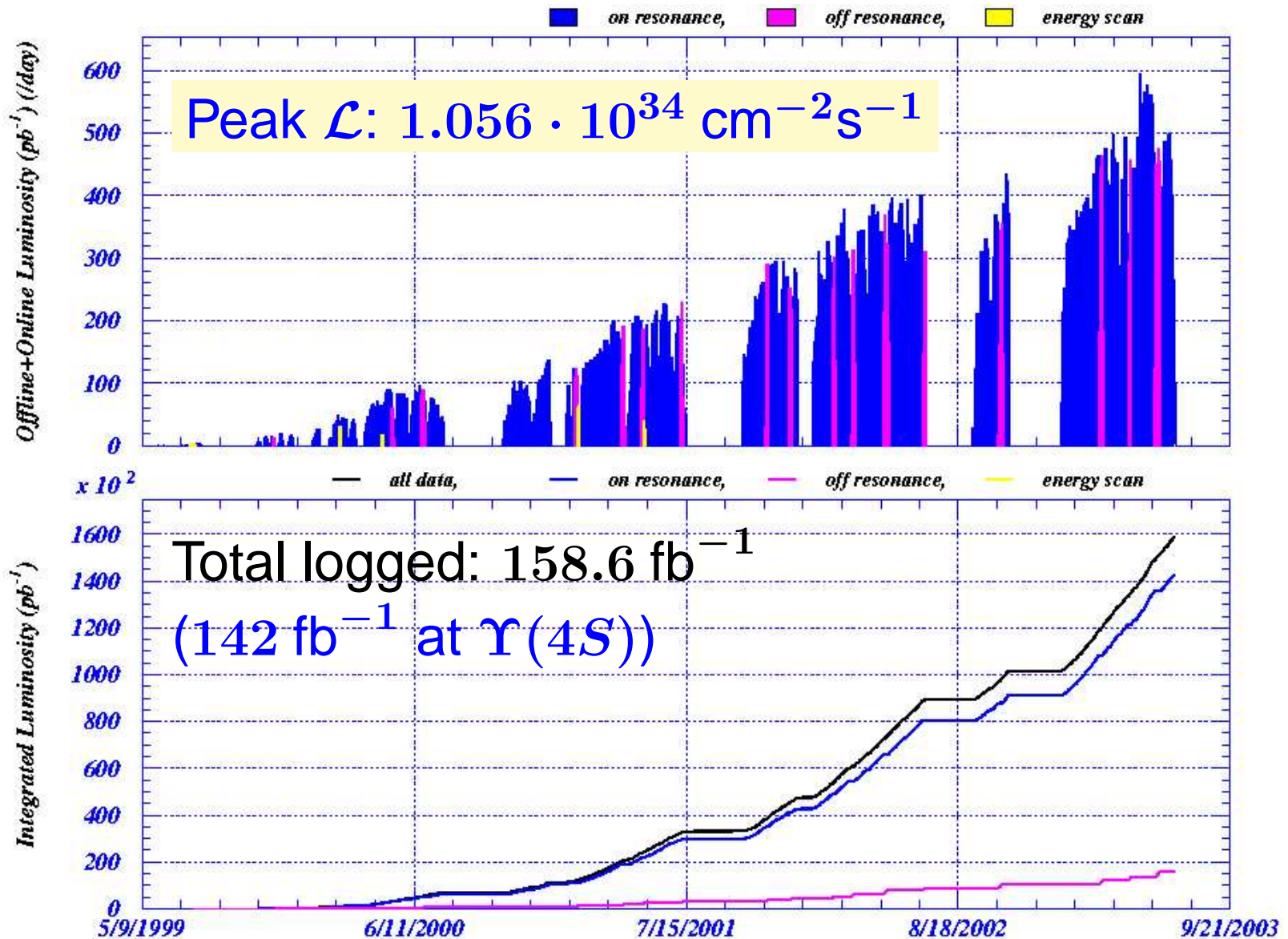
PID: e : ECL, Cherenkov (ACC), TOF, dE/dx in CDC

μ : KLM

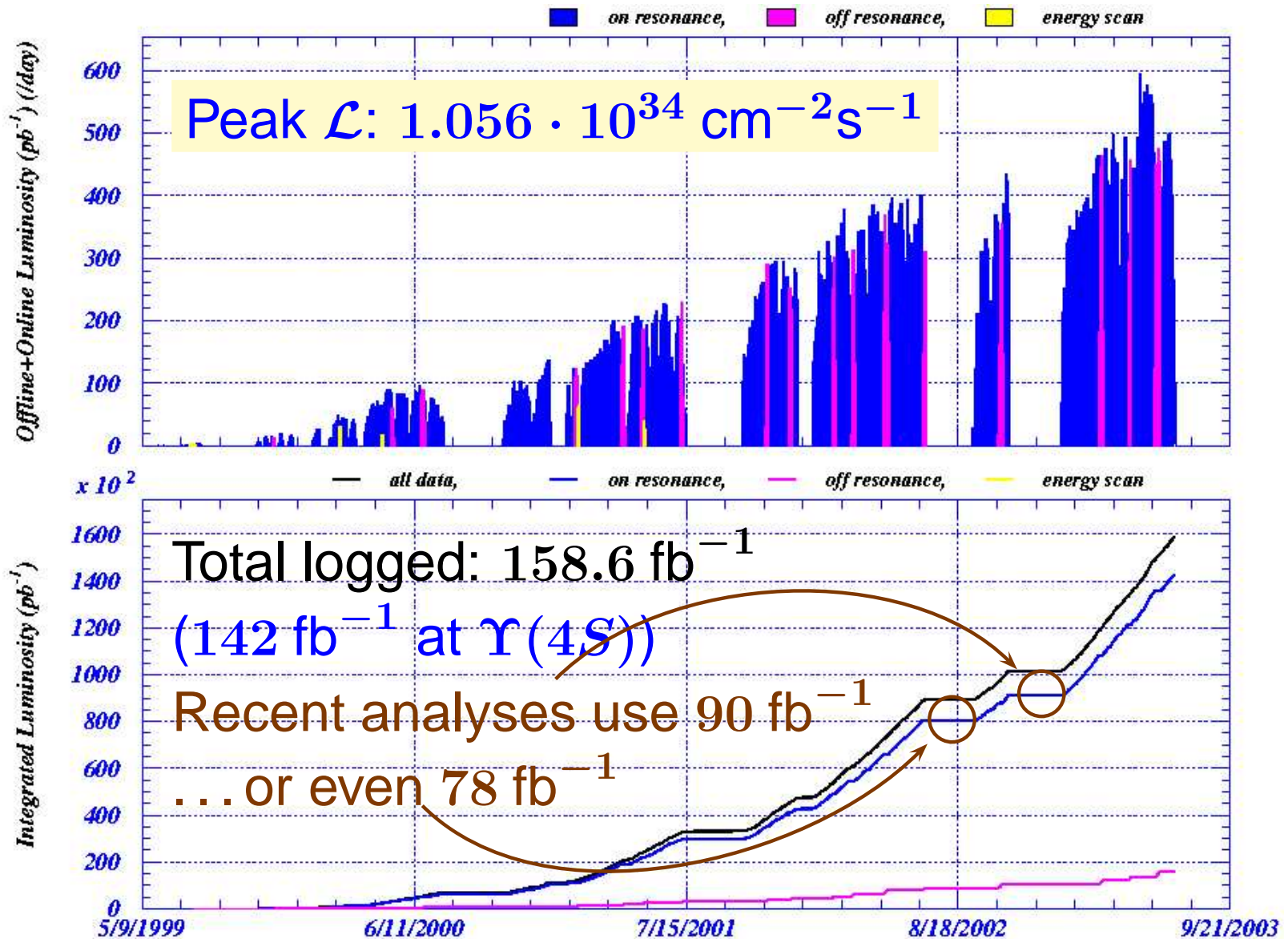


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The Belle Experiment



The Belle Experiment

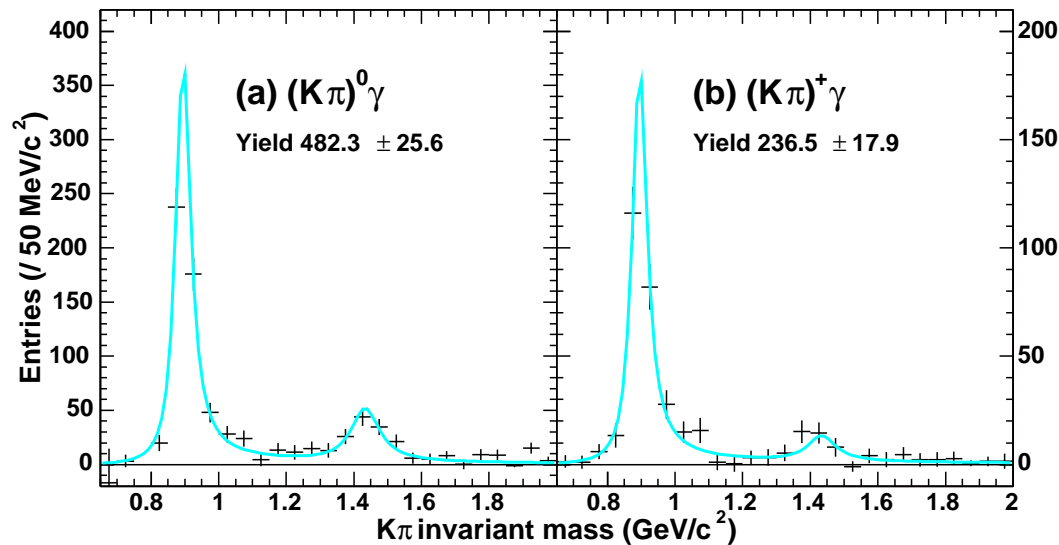


$$B \rightarrow K^* \gamma$$

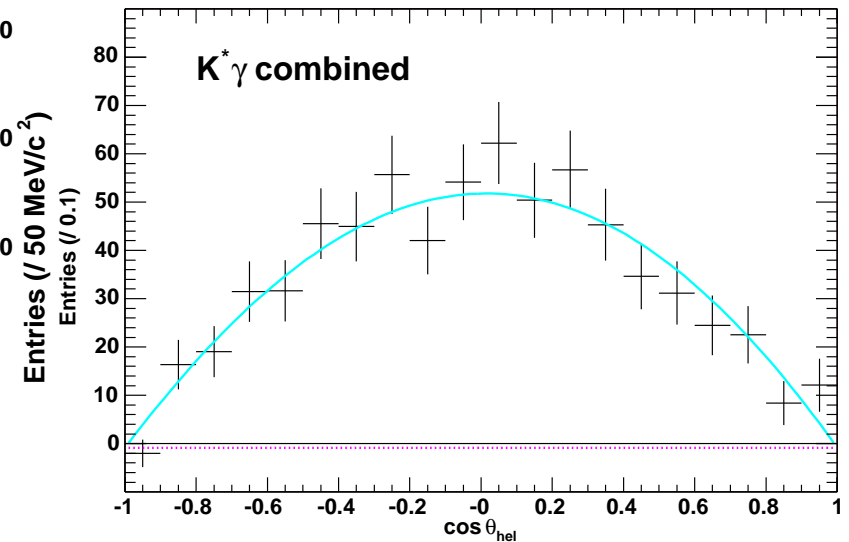
[Abs.537, BELLE-CONF-0319]

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

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



$K\pi \cos(\text{helicity})$

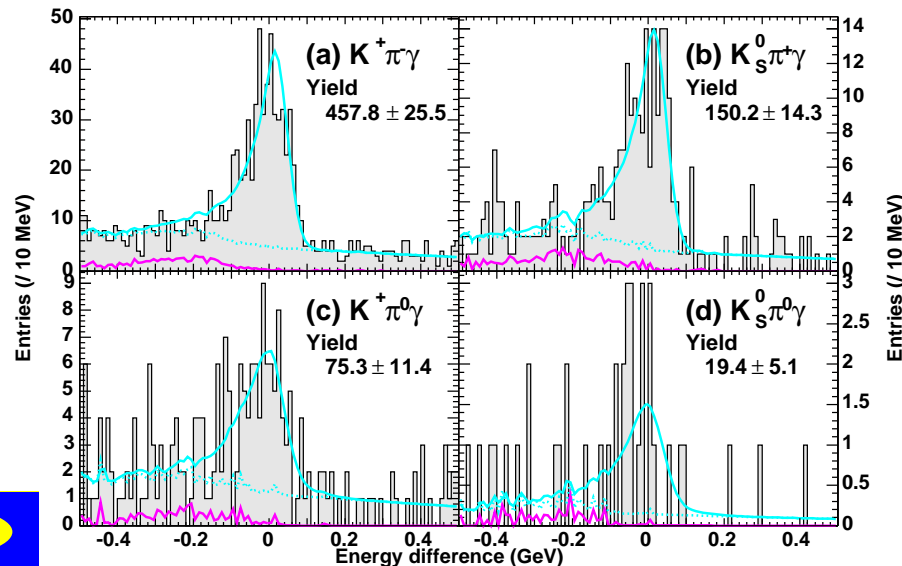


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- $-200 < \Delta E < 100$ MeV

$$\Delta E = E_B^* - E_{\text{beam}}^*$$



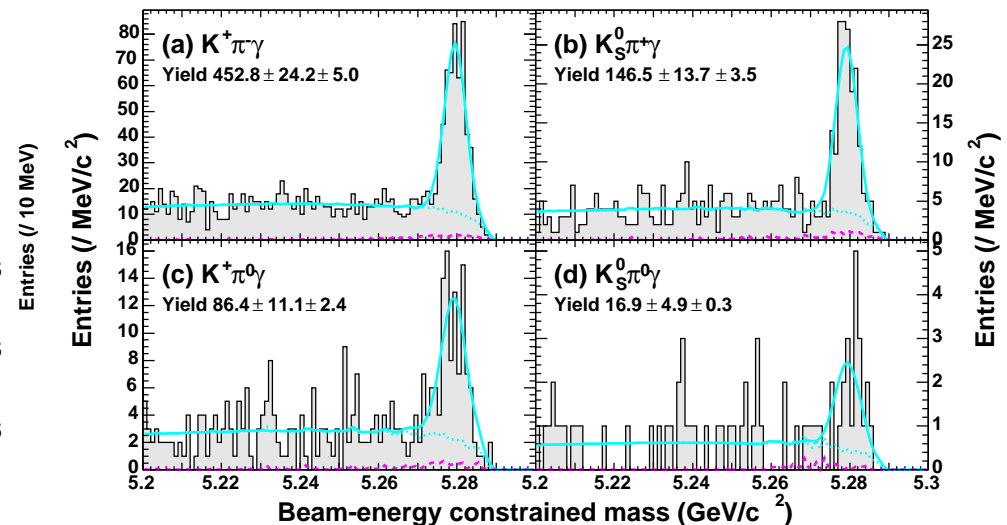
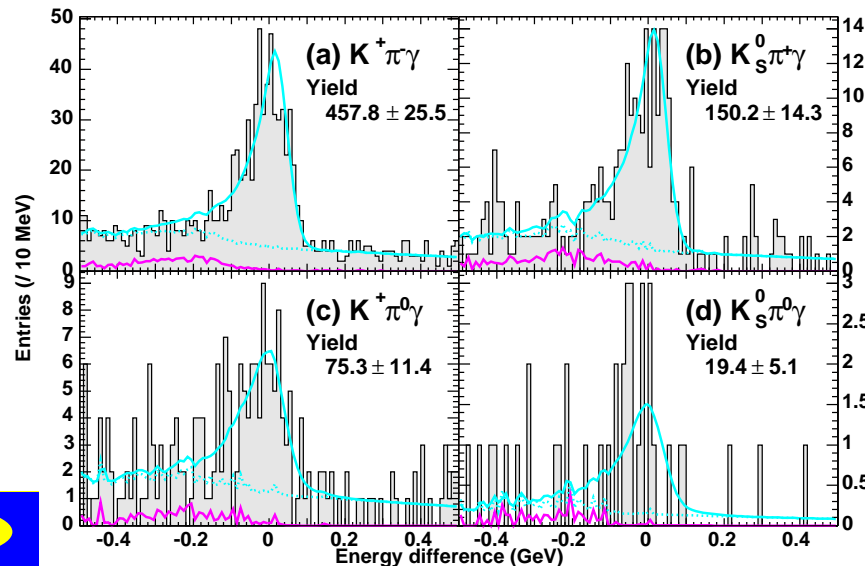
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$$\Delta E = E_B^* - E_{\text{beam}}^*$$

$$M_{\text{bc}} = \sqrt{E_{\text{beam}}^* - |p_B^2|^2}$$



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

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

$$\text{BR}(B^0 \rightarrow K^{*0} \gamma) = (40.9 \pm 2.1 \pm 1.9) \cdot 10^{-6}$$

$$\text{BR}(B^+ \rightarrow K^{*+} \gamma) = (44.0 \pm 3.3 \pm 2.4) \cdot 10^{-6}$$

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^+ :

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

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



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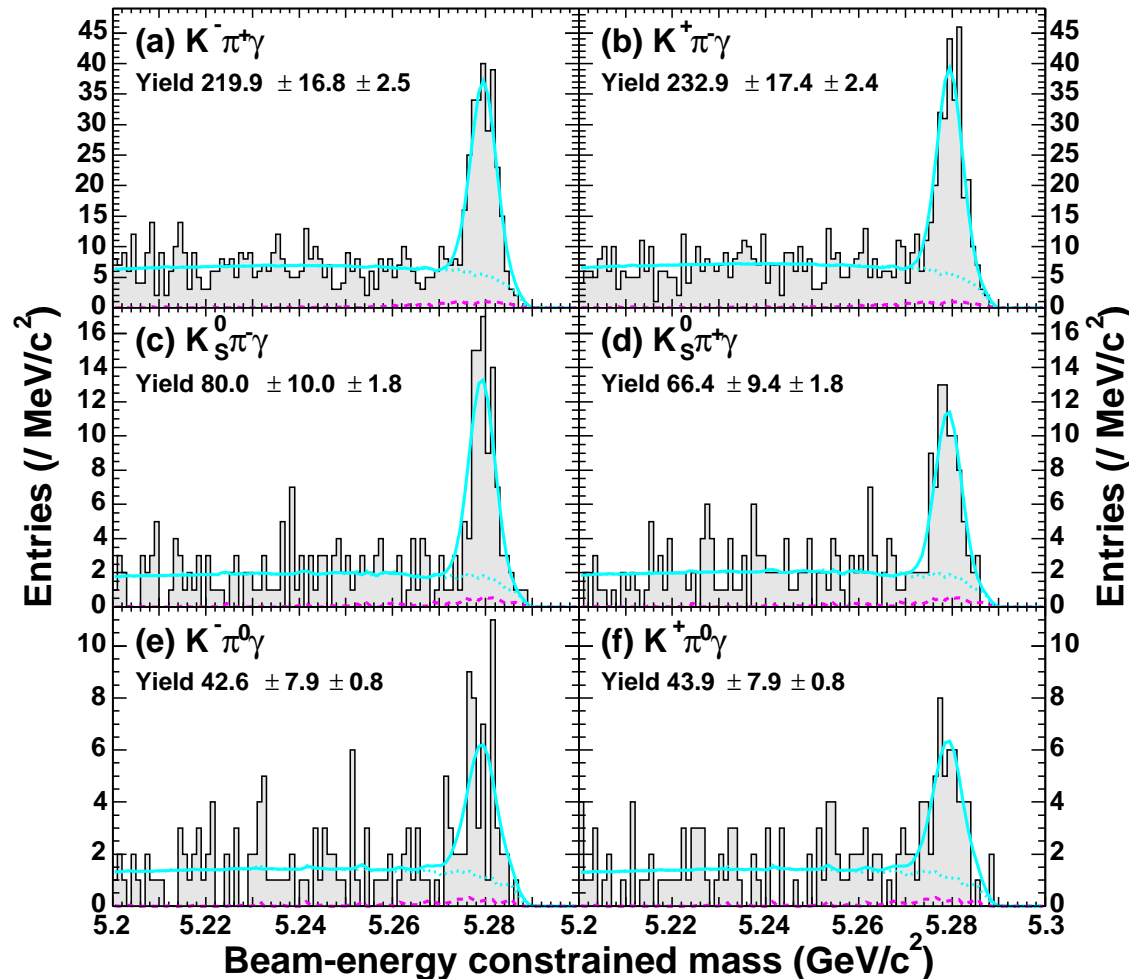
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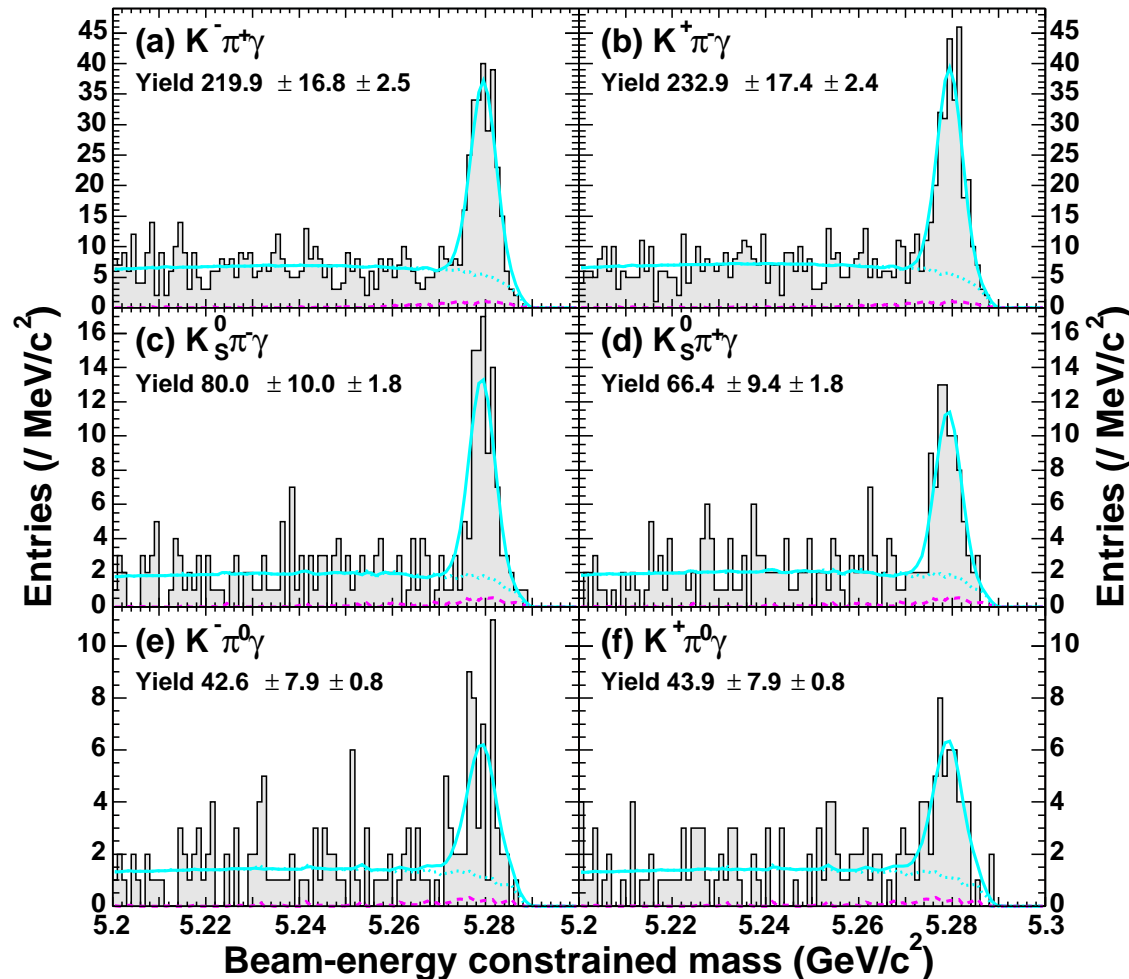


A_{CP} in $B \rightarrow K^* \gamma$



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

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

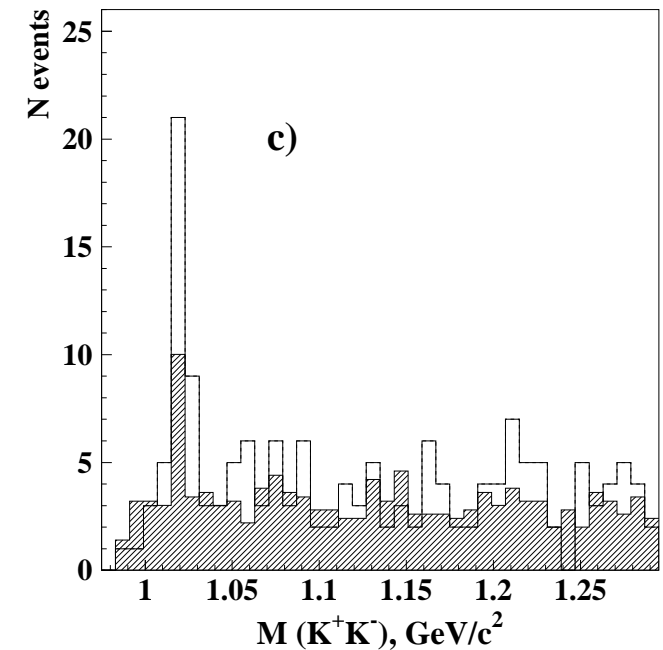
Most systematic errors cancel. Error is still statistics-dominated.



$$B^+ \rightarrow \phi K^+ \gamma$$

[Abs.542, BELLE-CONF-0322]

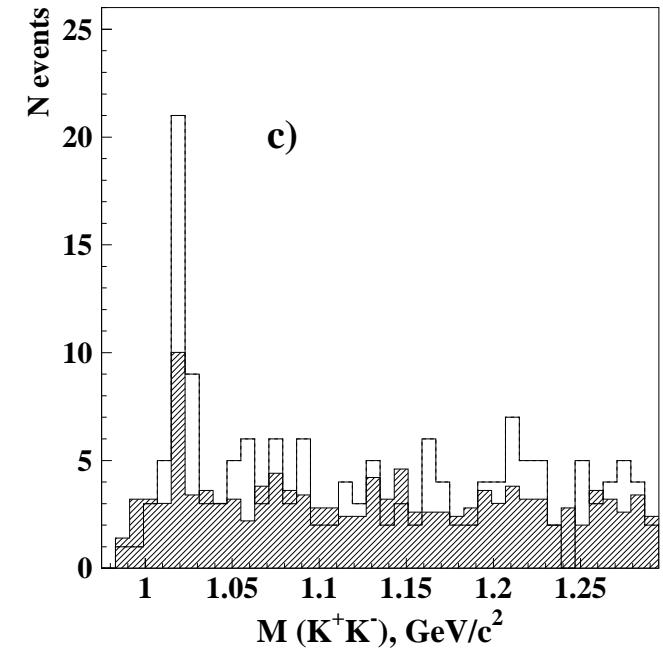
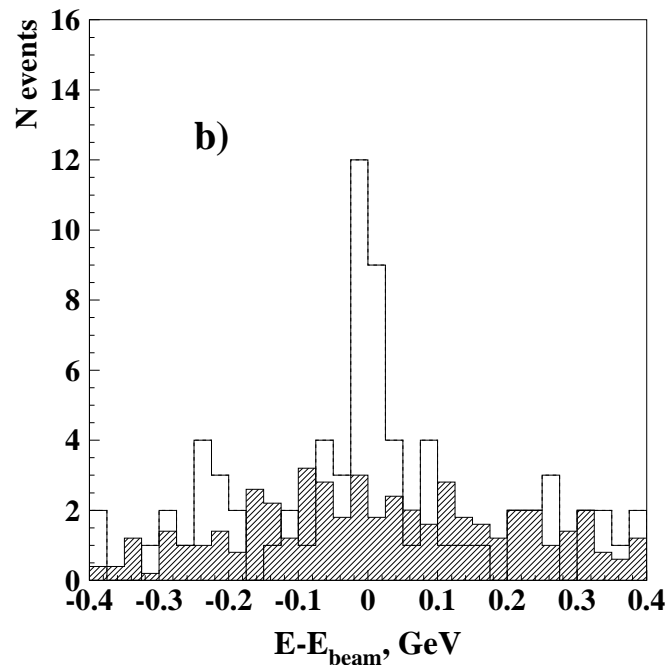
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- 3 charged K
- $|m_{KK} - m_\phi| < 10$ MeV/ c^2



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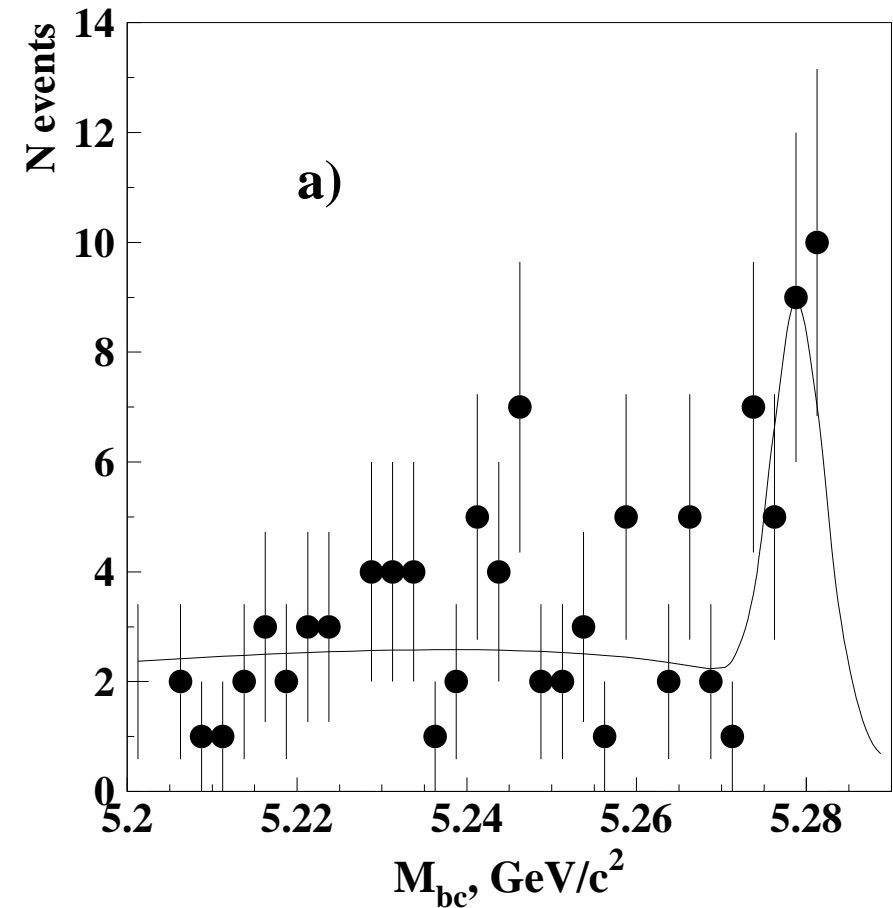
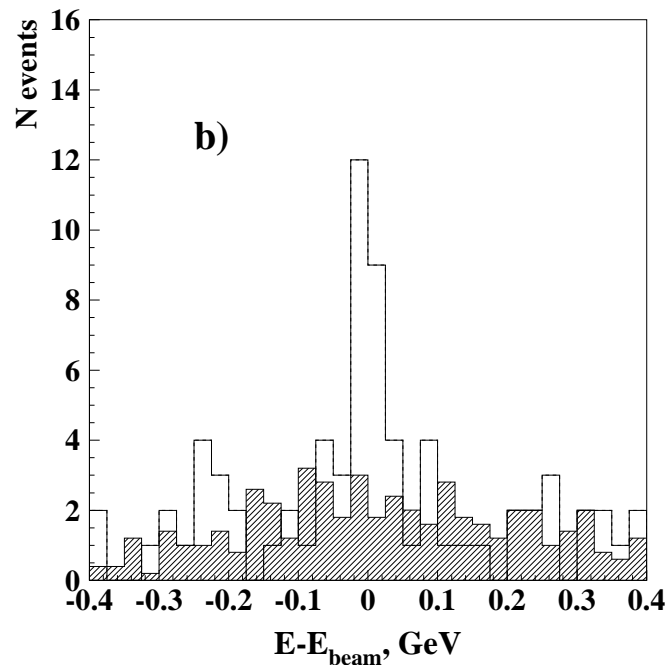
- Photon with $2.0 < E_\gamma^* < 2.7$ GeV not from π^0, η
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- $|\Delta E| < 400$ MeV



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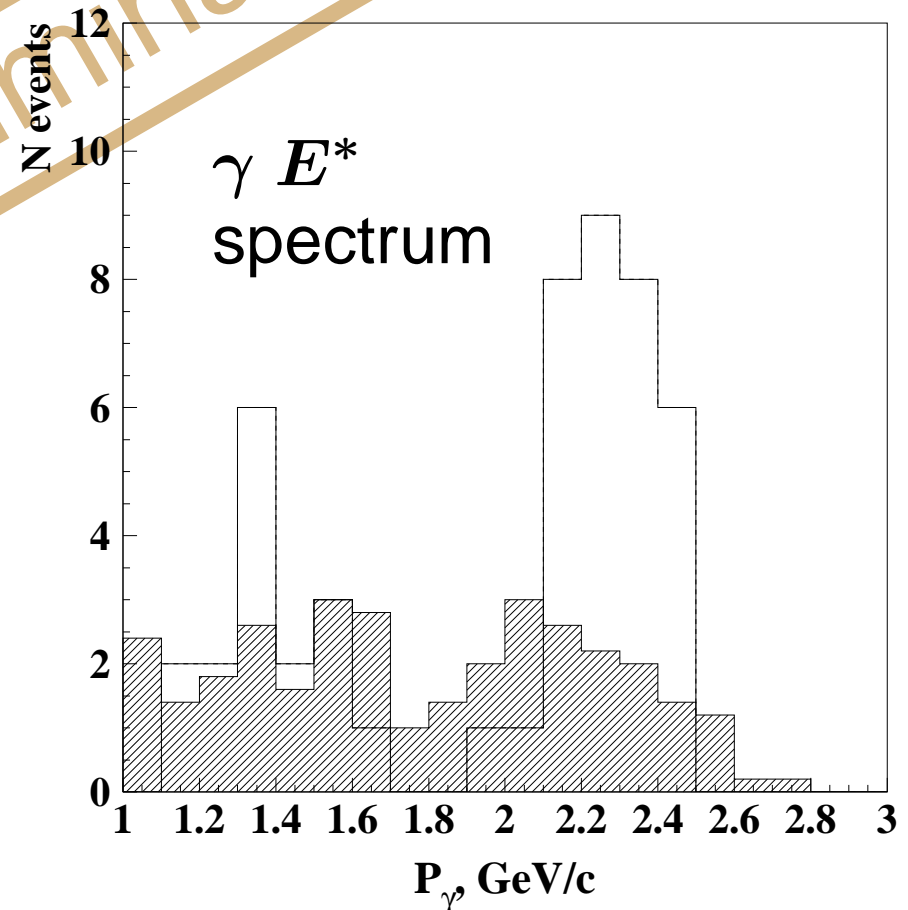
[Abs.542, BELLE-CONF-0322]

$$\text{BR}(B^+ \rightarrow \phi K^+ \gamma) = (3.4 \pm 0.9 \pm 0.4) \cdot 10^{-6} \quad (90 \text{ fb}^{-1})$$

(5.5 σ significance)

First observation!

[Abs.542, BELLE-CONF-0322]



$$B^+ \rightarrow \phi K^+ \gamma$$

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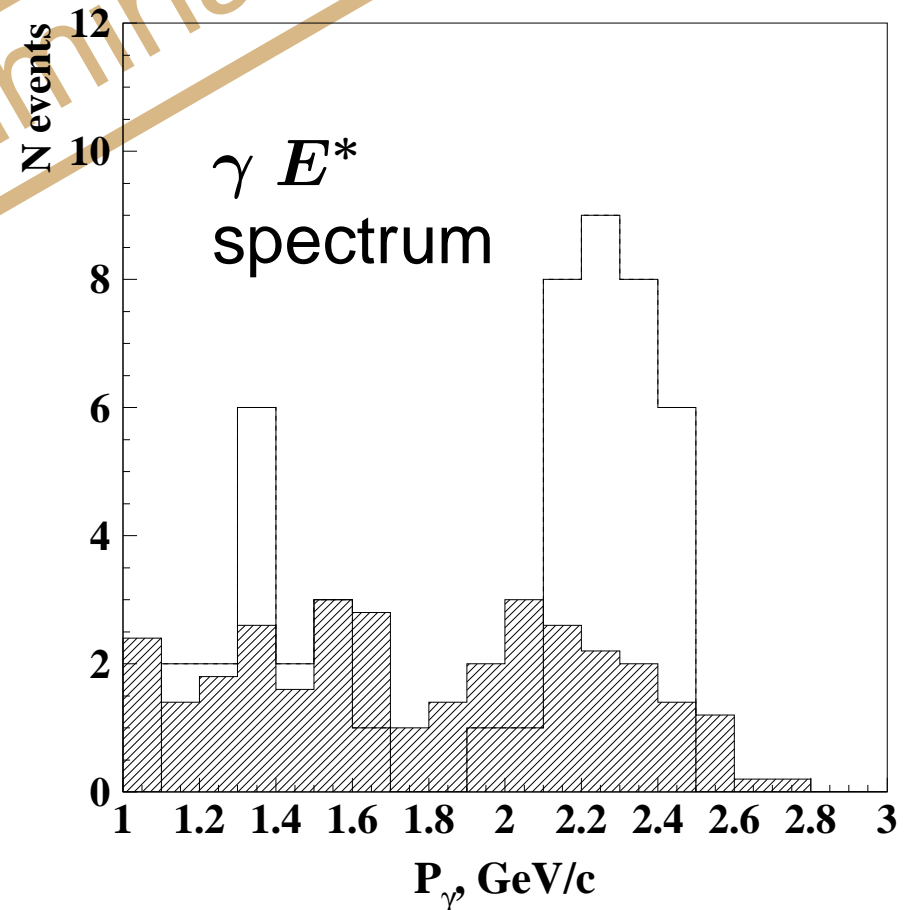
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$B^0 \rightarrow \phi K_S^0 \gamma$ is promising for time-dependent CP violation searches (Δt in $K^*(K_S^0 \pi^0) \gamma$ is too difficult to measure).



All radiative results

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

[4] [Abs.542, BELLE-CONF-0322] —Preliminary



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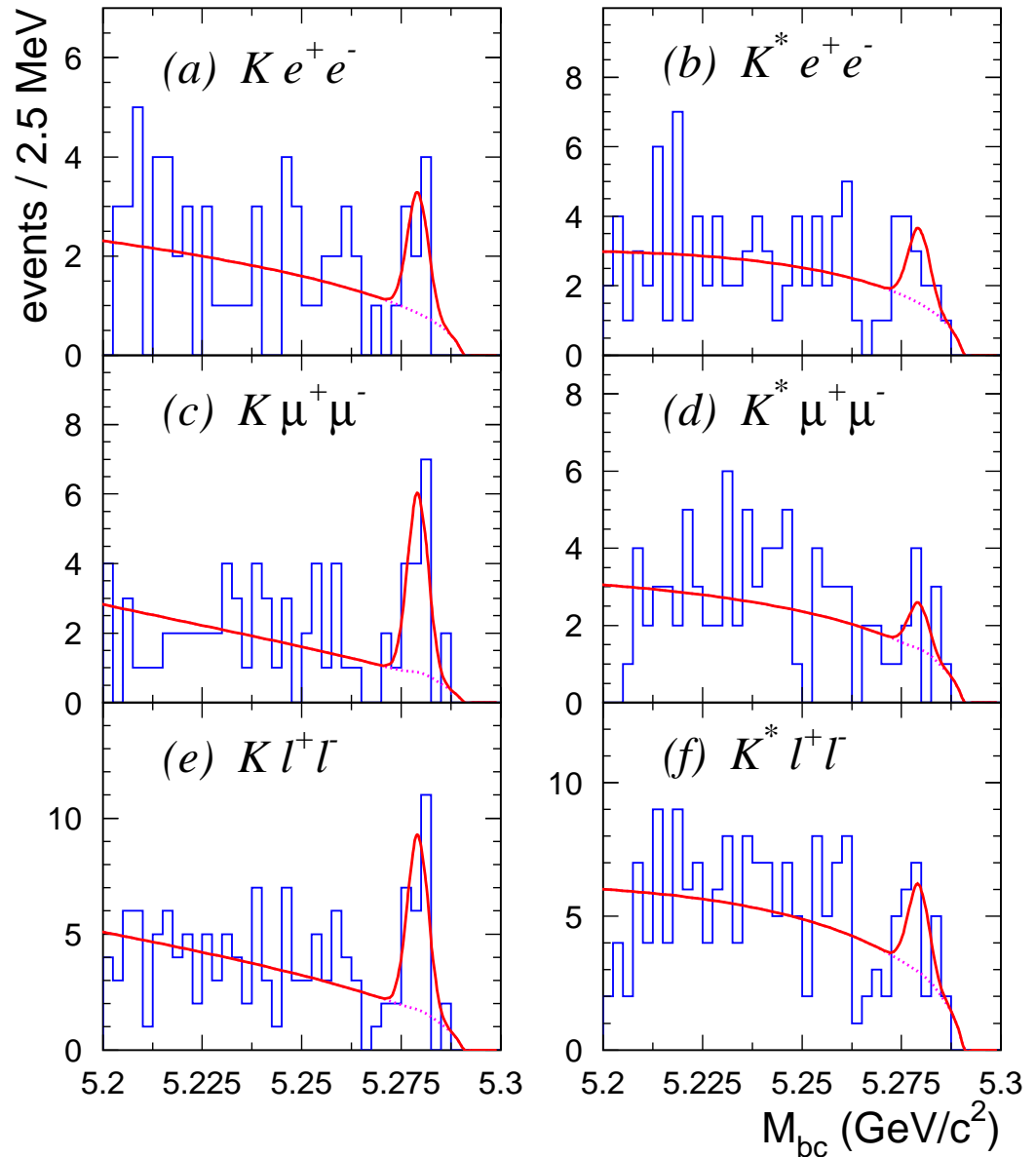
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$B^+ \rightarrow \rho^+ \gamma$	< 2.7 (90% C.L.)	78 fb^{-1}	[5]
$B^0 \rightarrow \rho^0 \gamma$	< 2.6 (90% C.L.)	78 fb^{-1}	[5]
$B^0 \rightarrow \omega(783) \gamma$	< 4.4 (90% C.L.)	78 fb^{-1}	[5]

[5] Moriond 2003 —Preliminary



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

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



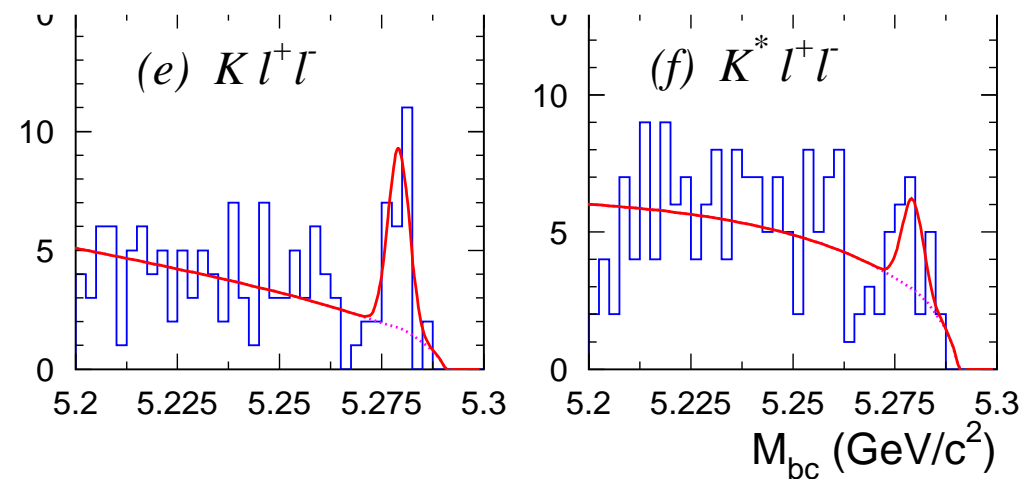
$B \rightarrow K\ell\ell$ and $B \rightarrow K^*\ell\ell$

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

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

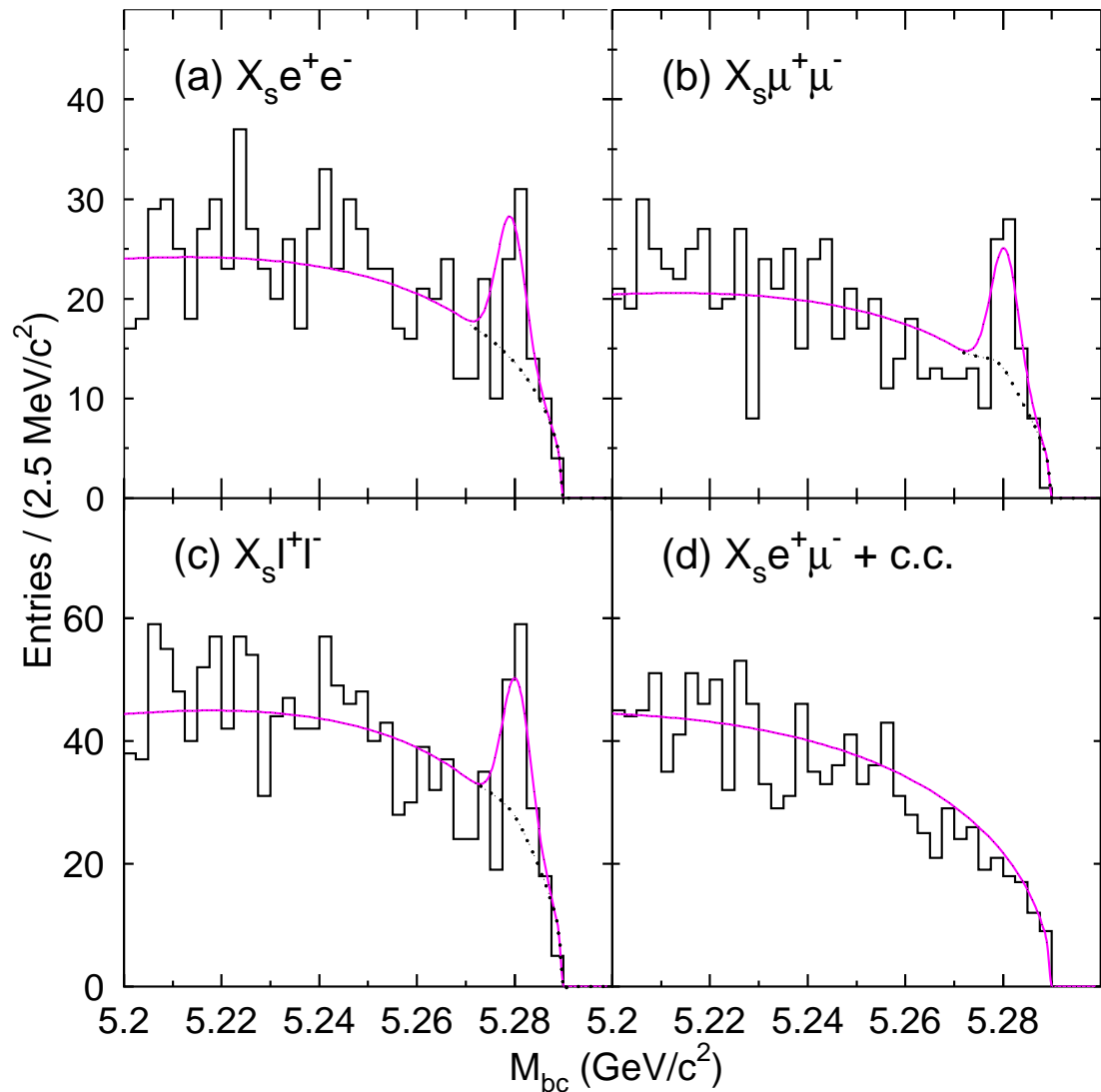
Precision on $B \rightarrow K\ell\ell$
is as good as theory

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

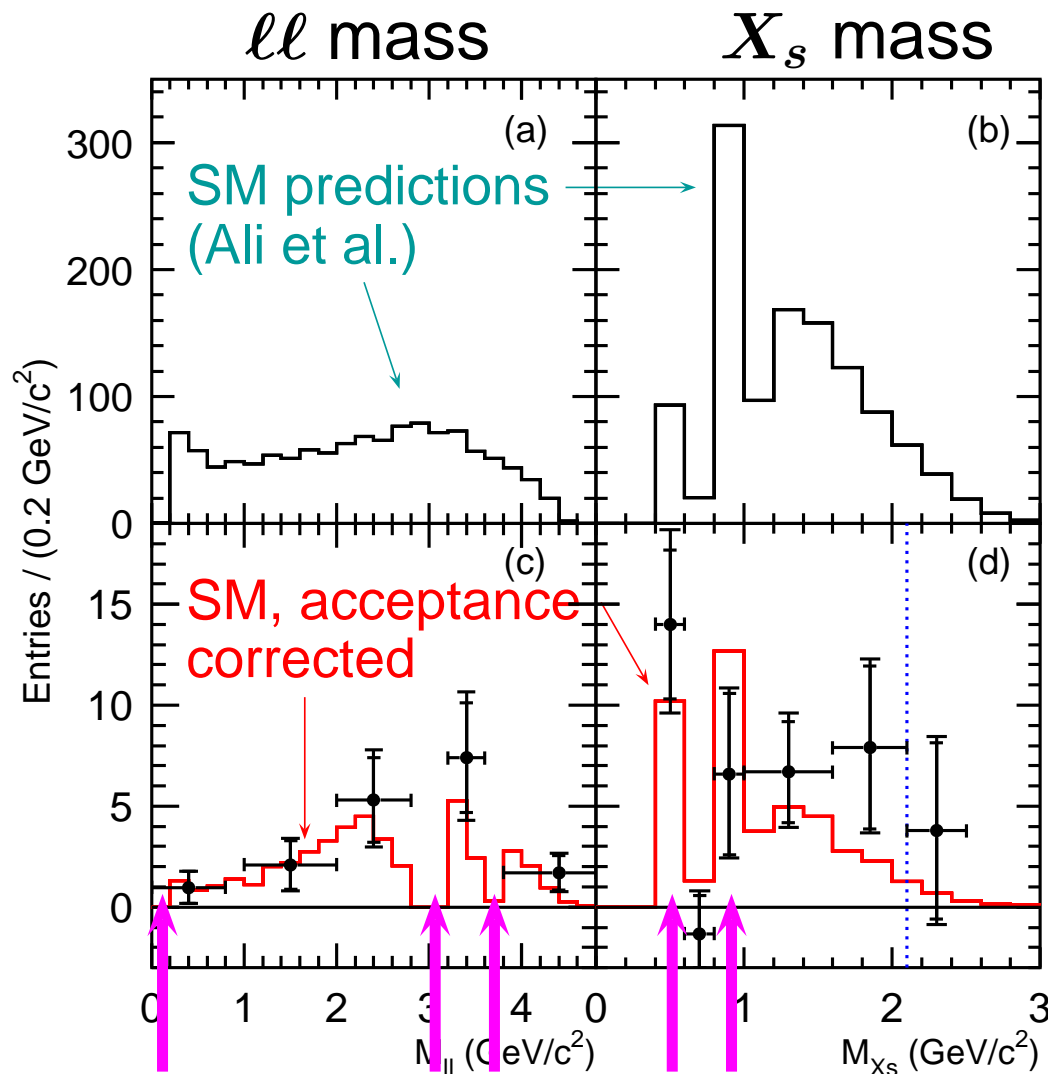


Semi-Inclusive $B \rightarrow X_s \ell \ell$

- X_s :
 - 1 K^\pm or K_S^0
 - 0–4 π ($\leq 1 \pi^0$)
 - $m_{X_s} < 2.1 \text{ GeV}/c^2$
- a pair of e or μ
 - $p(e) > 0.5 \text{ GeV}/c$
 - $p(\mu) > 1.0 \text{ GeV}/c$
 - $m_{\ell\ell} > 0.2 \text{ GeV}/c^2$
- J/ψ , $\psi(2S)$ are vetoed



Semi-Inclusive $B \rightarrow X_s ll$



$q^2 = 0$
[removed] $\psi(')$
[vetoed]

KK^*

First measurement,
using 60 fb^{-1}

	BR in 10^{-6}	
$\mu\mu$	7.9 ± 2.1	$+2.1$ -1.5
ee	5.0 ± 2.3	$+1.3$ -1.1
ll	6.1 ± 1.4	$+1.4$ -1.1

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

K and K^* yields are
compatible with exclu-
sive analysis



Search for leptonic B^0 decays

Predicted BR in SM:

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

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

$B \rightarrow e\mu$ decays are forbidden in SM, but may occur in SUSY or Lepto-Quark models.



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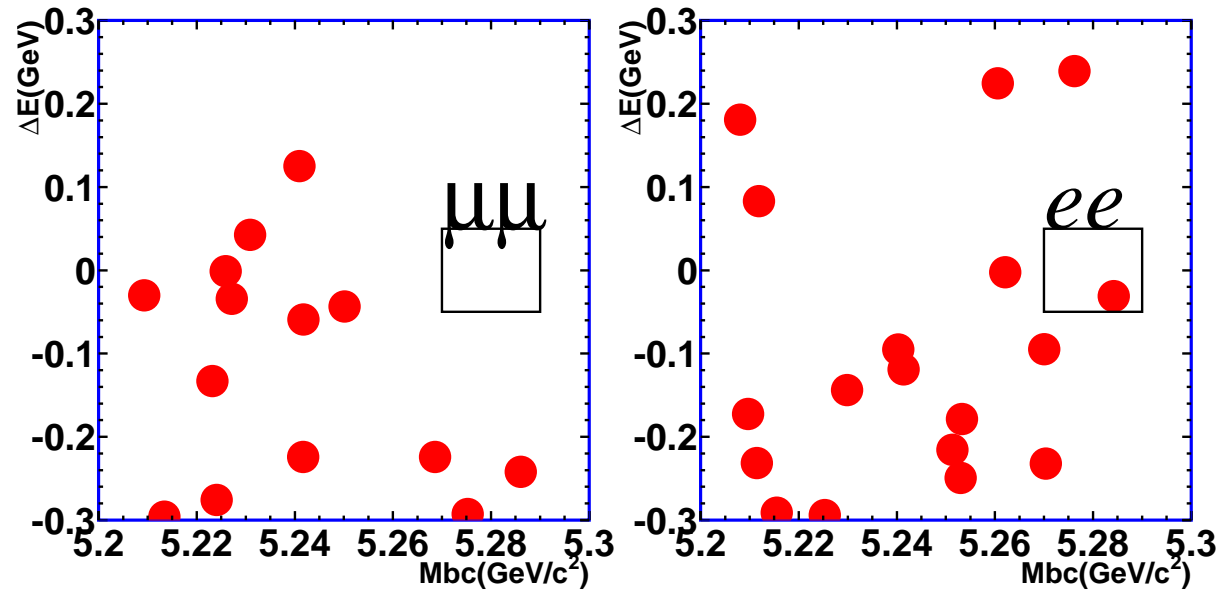
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- Reconstruction:**
- Two leptons with tight ID ($\mathcal{L} > 0.9$)
 - $5.27 < M_{bc} < 5.29 \text{ GeV}/c^2$
 - $|\Delta E| < 0.05 \text{ GeV}$

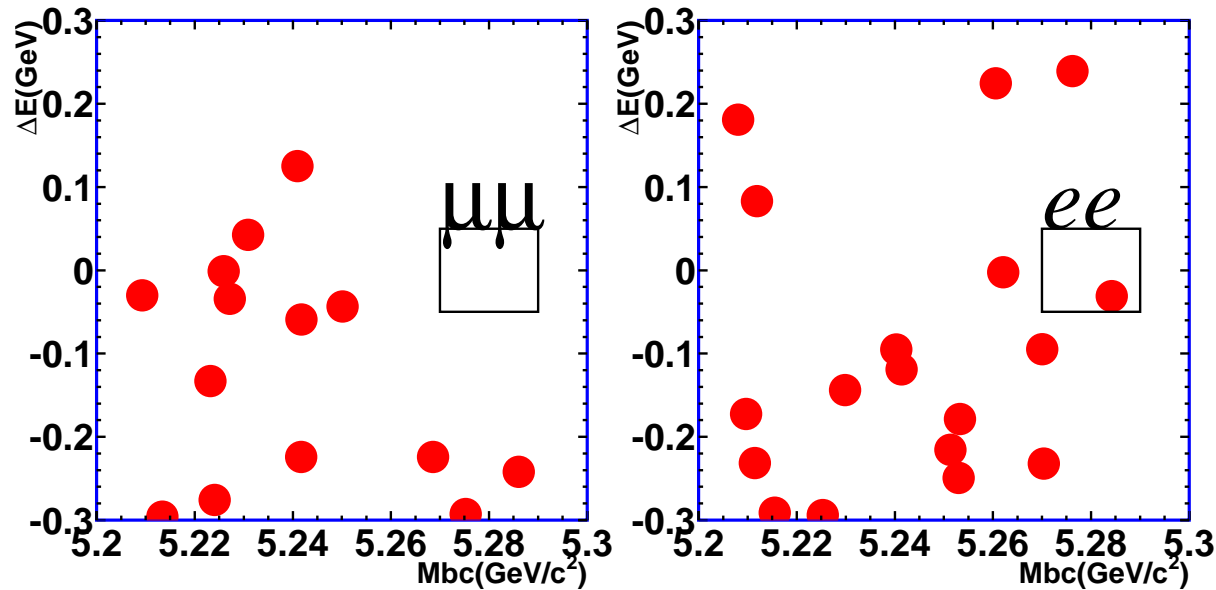
Main background from light-quark continuum
 \Rightarrow Topology, missing energy, number of tracks...



Search for leptonic B^0 decays



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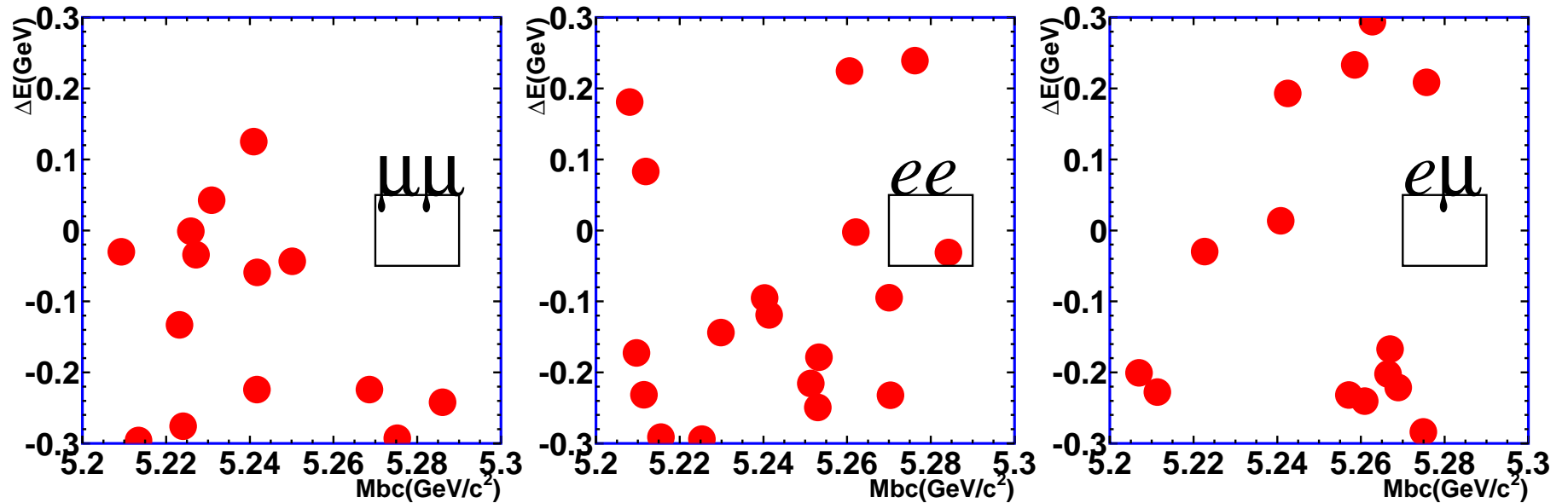
	Branching ratio
$B \rightarrow \mu\mu$	$< 0.9 \cdot 10^{-7}$ (90% C.L.)
$B \rightarrow ee$	$< 2.0 \cdot 10^{-7}$ (90% C.L.)

This improves the previous best limits by a factor 2

[Belle Preliminary, FPCP'03]



Search for leptonic B^0 decays



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$B \rightarrow e\mu$	$< 0.9 \cdot 10^{-7}$ (90% C.L.)

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



Conclusion

$B \rightarrow X_s \gamma$:

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



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$B \rightarrow X_d \gamma$: No signal yet



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$B \rightarrow X_d \gamma$: No signal yet

$B \rightarrow X_s \ell \ell$:

- Clear $B \rightarrow K \ell \ell$ signal. No $B \rightarrow K^* \ell \ell$ yet
- First measurement of semi-inclusive $B \rightarrow X_s \ell \ell$
- Waiting for more data to measure asymmetries



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- Waiting for more data to measure asymmetries

$B \rightarrow \ell \ell$: New upper limits at 10^{-7} !



Conclusion

$B \rightarrow X_s \gamma$:

- Precise measurements of $B \rightarrow X_s \gamma$ deviation from SM is seen in A_{FB}^{ℓ}
- Rare decays $B \rightarrow X_s \gamma$ 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

- $B \rightarrow K^* \ell \ell$ yet
- more data to measure asymmetries
- for semi-inclusive $B \rightarrow X_s \ell \ell$

$B \rightarrow \ell \ell$: New upper limits at 10^{-7} !

