Exclusive Leptonic and Radiative B Meson Decays at Belle

S. Nishida

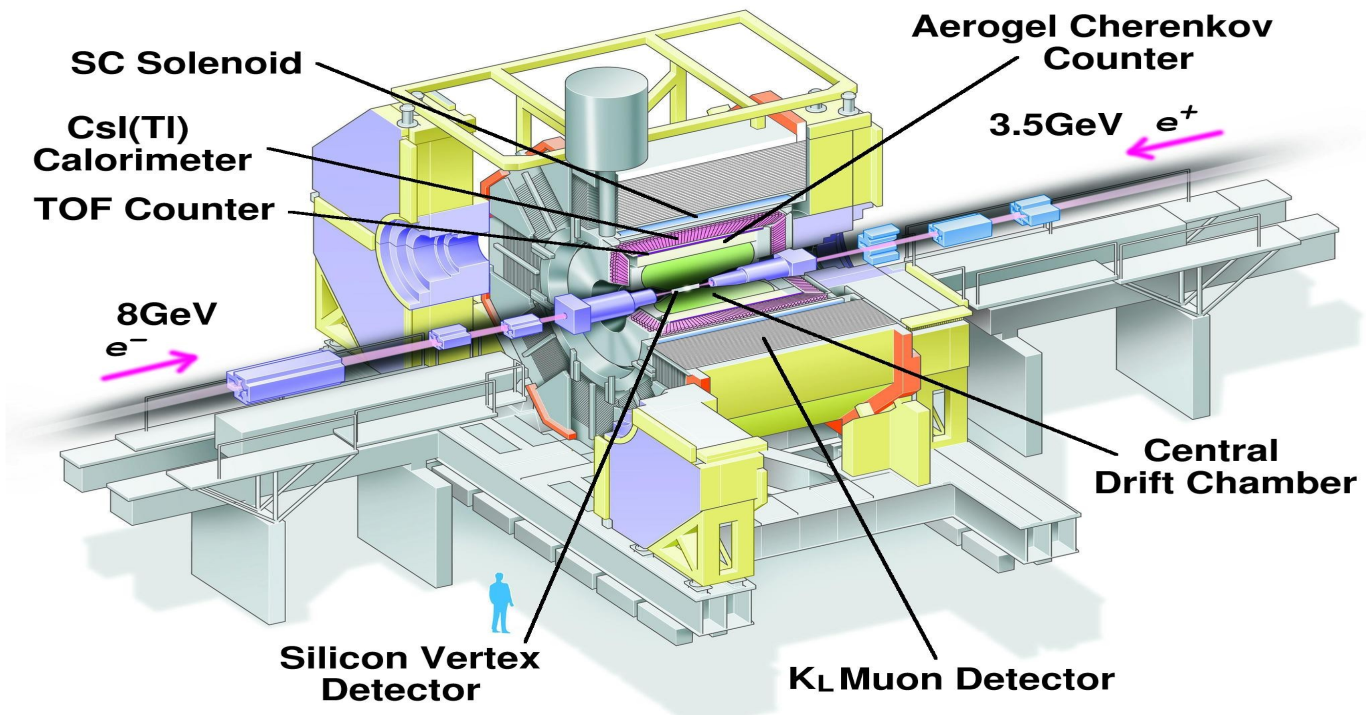
KEK

EPS HEP 2009 @ Krakow

Jul. 17, 2009

Contents

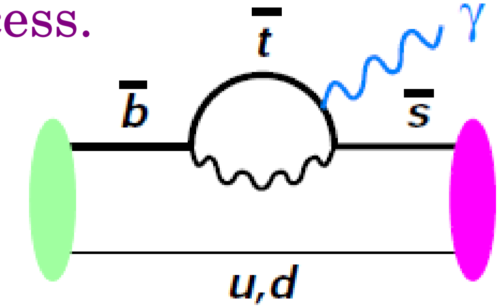
- Introduction
- $B \to K\eta'\gamma$
- $B \to K^{(*)}ll$
- Summary



Introduction

$b \to s\gamma$, sl^+l^- : FCNC (Flavour Changing Neutral Current) process.

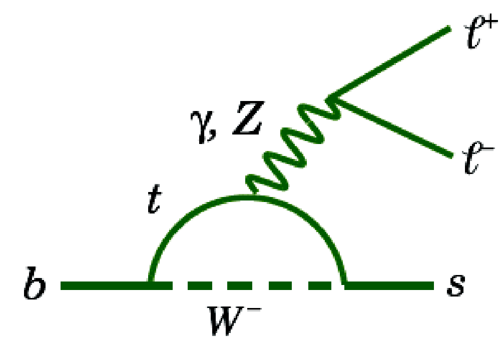
- Sensitive to New Physics (NP)



$b \to s\gamma$ penguin

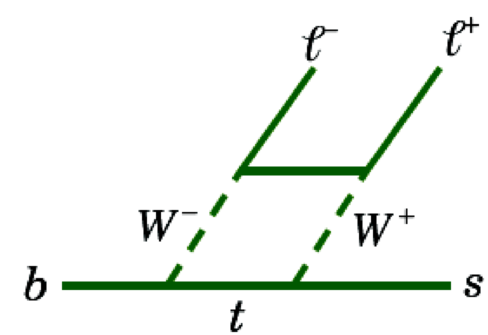
$b \to s\gamma$

- EW penguin diagram.
- Exclusive modes suffer large uncertainty in BF calculation.
- Photon is almost polarized in the SM.
  - Large mixing induced CP violation is an indication of NP.
  - Final state can be any of $P^0Q^0\gamma$ (e.g. $Ks\pi\gamma$, $Ks\rho^0\gamma$)
    - $S(Ks\pi^0\gamma) = -0.10 \pm 0.31 \pm 0.07$ [PRD 74, 111104(R) (2006)]
    - $S(Ks\rho^0\gamma) = 0.11 \pm 0.33 +0.05/-0.09$ [PRL101, 251601(2008)]



$b \to sl^+l^-$

- One loop penguin or box diagram.
- Sensitive to C_7, C_9, C_{10} Wilson coefficient.
  - $b \to s\gamma$: $|C_7|$ only; doesn't limit C_9, C_{10}, sign of C_7
- Many observables (3 body).

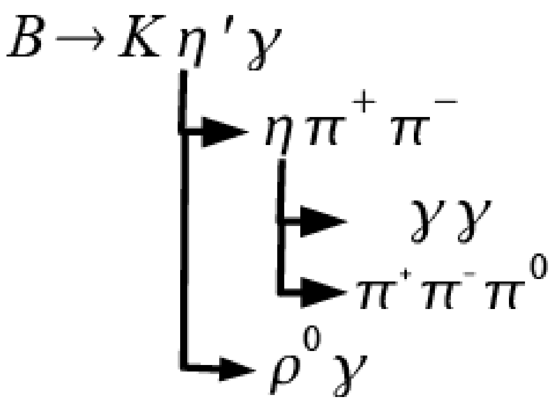


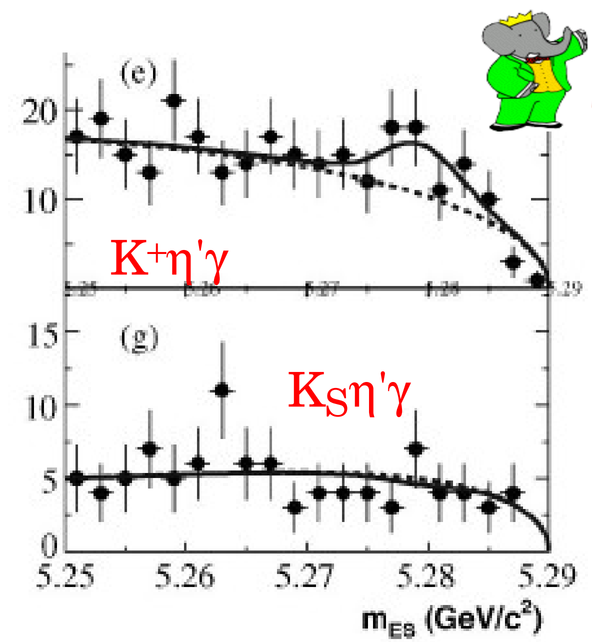
$B \to K\eta'\gamma$

$B \to K\eta'\gamma$ [Abstract 628]

- Not observed yet.
- Possible suppression $K\eta'\gamma$ of with respect to $K\eta\gamma$ due to interference btw two penguin diagram [H.J.Lipkin, PLB 254, 247 (1991)]
- Neutral mode can be used for time dependent CPV study.

Analysis Procedure





[PRD74, 031102 (2006)]

c.f.) BaBar

$< 6.6 \times 10^{-6}$

$< 4.2 \times 10^{-6}$

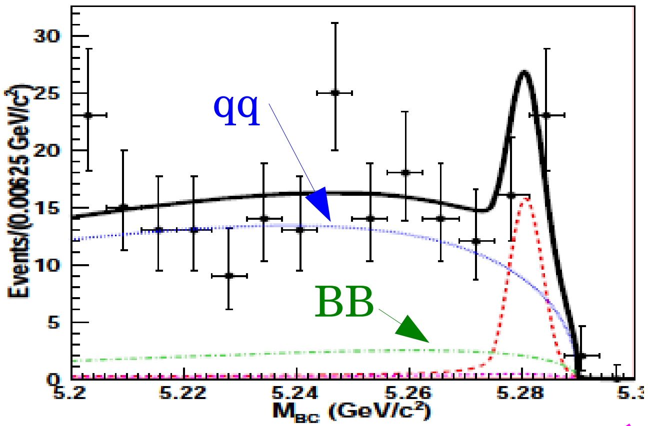
- $M(K\eta') < 3.4$ GeV
- D0 veto ($1.84 < M(K\pi) < 1.89$ GeV) for K^+
- J/ψ veto ($3.07 < M(\eta'\gamma) < 3.12$ GeV)
- Combine all submode and perform 2-d fit on M_{bc}-ΔE

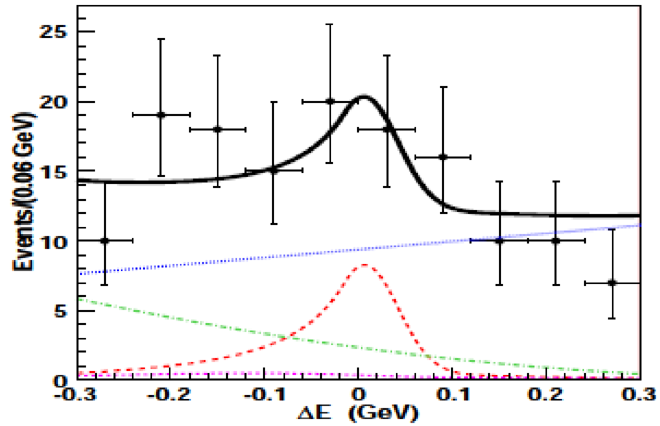
$B \to K\eta'\gamma$

To be submitted to PRD(RC).

657 M $B\bar{B}$

$B^+ \to K^+\eta'\gamma$





33^{+12}_{-11} events

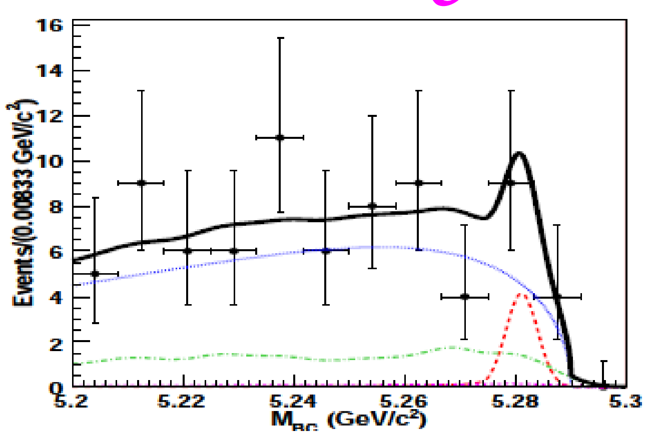
Significance 3.3σ

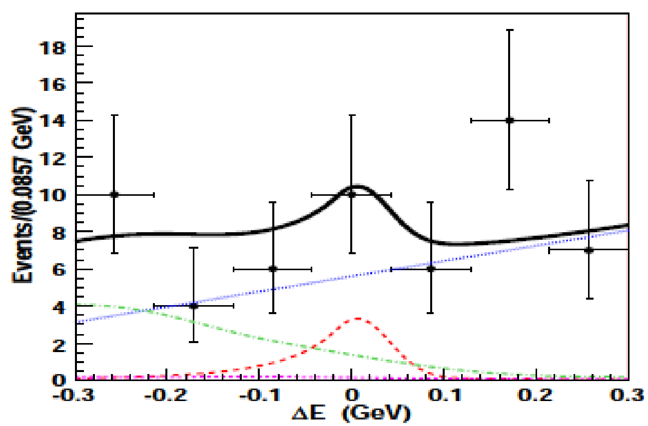
First evidence!!

Updated.

$\mathcal{B}(B^+ \to K^+\eta'\gamma) = (3.6 \pm 1.2 \pm 0.3) \times 10^{-6}$

$B^0 \to K_S\eta'\gamma$





$5.0^{+5.0}_{-4.0}$ events

Significance 1.3σ

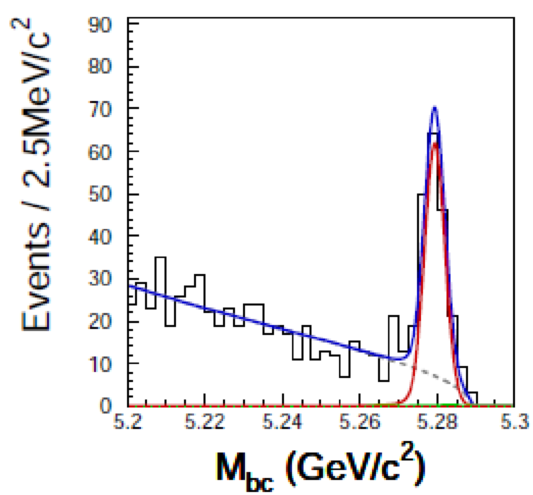
$\mathcal{B}(B^0 \to K^0\eta'\gamma) = (2.5^{+2.4}_{-1.9}{}^{+0.4}_{-0.5}) \times 10^{-6} < 6.4 \times 10^{-6}$

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

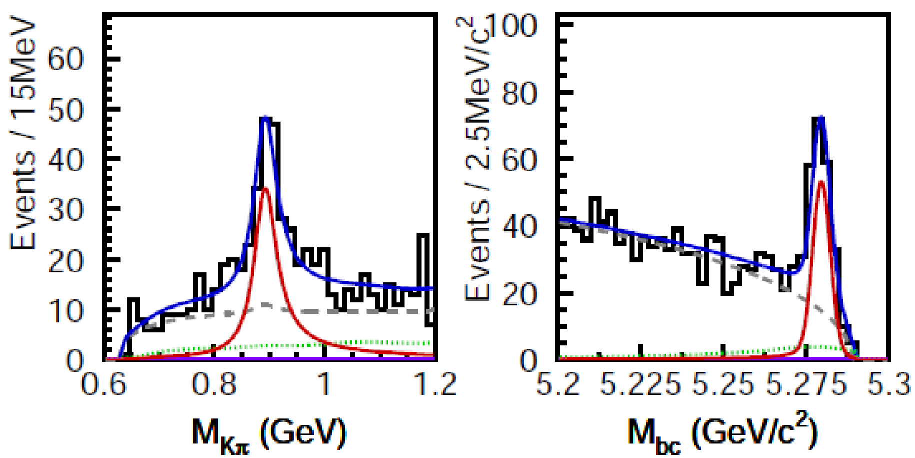
Analysis of $B \to K^{(*)}ll$ — Submitted to PRD(RC). 657 M $B\overline{B}$

[arXiv:0904.0770]

- Combine K or K* (from $K^+\pi^-$, $K_S\pi^+$, $K^+\pi^0$) with e/μ pair (l^+l^-).
- Bremsstrahlung photons (20-500MeV, <50mrad) from e recovered
- Dominant background: continuum and semileptonic B decays. [Abstract 626]
  - ✓ Suppress using event shape variables, missing mass etc.
- J/ψ (ψ') veto to remove $B \to J/\psi X$, $\psi' X$ events ($q^2 = M_{ll}^2$)
  - ✓ $8.68<q^2<10.09$, $12.86<q^2<14.18$ for muon pair
  - ✓ $8.11<q^2<10.03$, $12.15<q^2<14.11$ for electron pair
- Peaking background from $K^{(*)}\pi\pi$.
- M_{bc}-$M_{K\pi}$ 2d fit for K^*ll, M_{bc} 1d fit for Kll.



166 ± 15 events

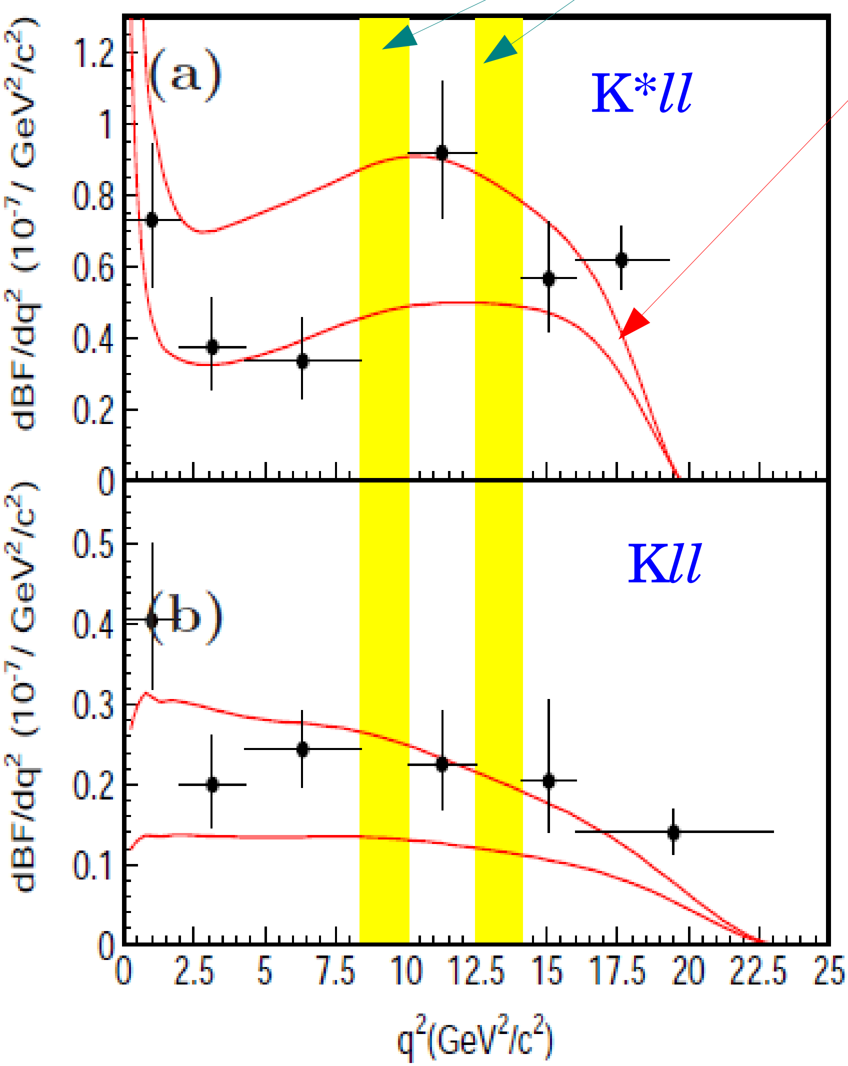


K^*ll

230 ± 24 events

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

Branching Ratio



[A.Ali et al. PRD61, 074024 (2000), A.Ali et al. PRD66, 034002 (2006)]

Total Branching Fraction

$$\mathcal{B}(B \to K^* \ell^+ \ell^-) = (10.7^{+1.1}_{-1.0} \pm 0.9) \times 10^{-7},$$
$$\mathcal{B}(B \to K \ell^+ \ell^-) = (4.8^{+0.5}_{-0.4} \pm 0.3) \times 10^{-7};$$

Lepton Flavor Ratio

$$R_{K^{(*)}} = \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)}$$

$R_{K^*} = 0.75$ (due to photon pole) and
$R_K = 1$ in the SM, but larger value in the Higgs doublet model at large tanβ.

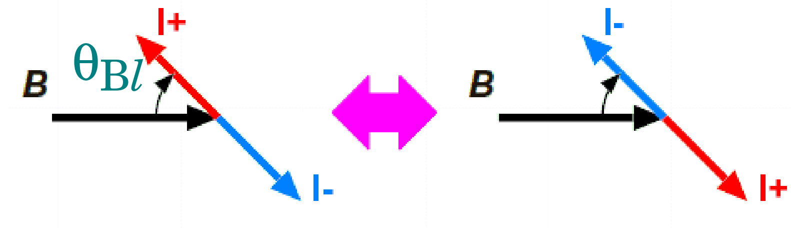
$$R_{K^*} = 0.83 \pm 0.17 \pm 0.05$$
$$R_K = 1.03 \pm 0.19 \pm 0.06$$

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

Asymmetries

F_L : K* longitudinal polarization fraction

A_{FB} : Forward Backward Asymmetry



θ_{K^*} : angle btw K and opposite of B in K* rest frame.

$$\frac{d\Gamma}{d\cos\theta_{K^*}} = \frac{3}{2} F_L \cos^2\theta_{K^*} + \frac{3}{4}(1-F_L)\sin^2\theta_{K^*}$$

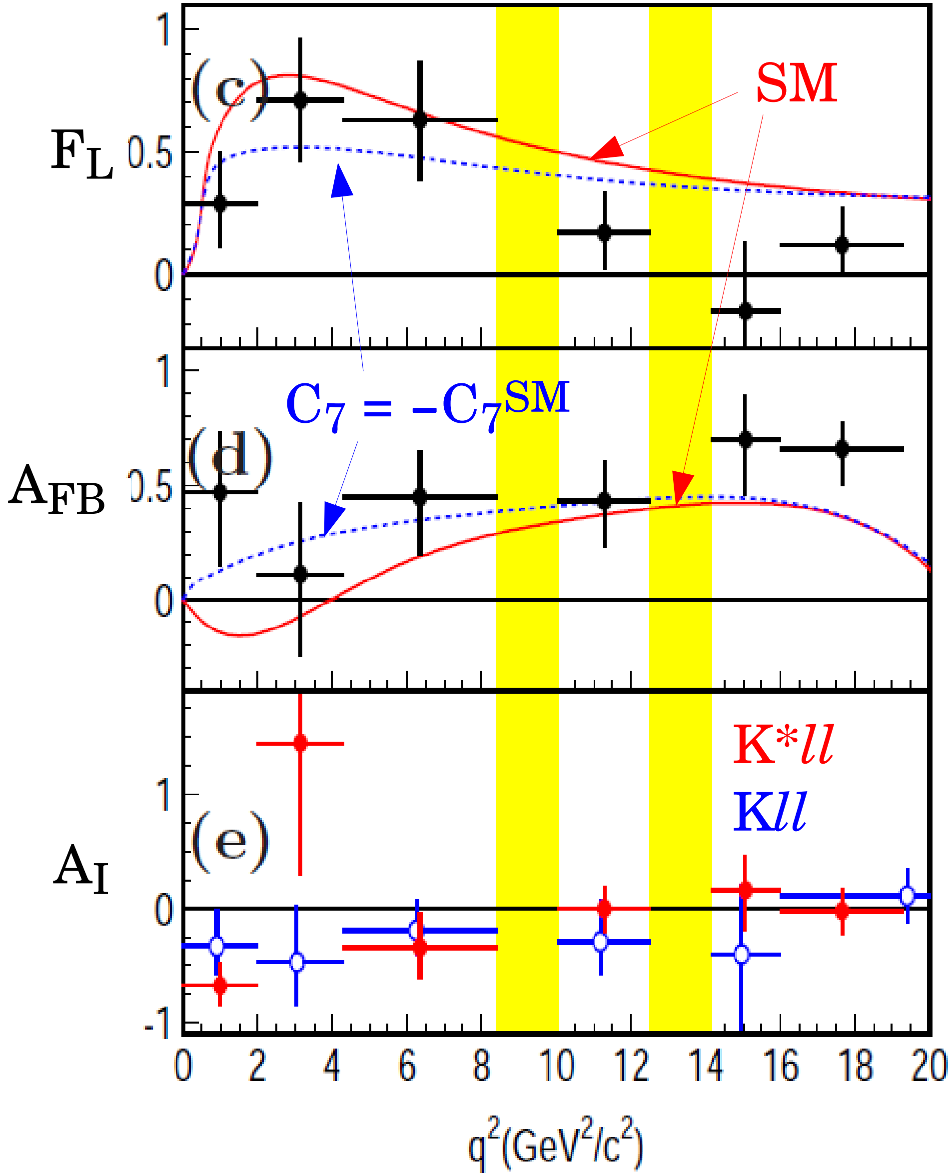
$$\frac{d\Gamma}{d\cos\theta_{Bl}} = \frac{3}{4} F_L \sin^2\theta_{Bl} + \frac{3}{8}(1-F_L)(1+\cos^2\theta_{K^*}) + A_{FB}\cos\theta_{Bl}$$

A_I : Isospin Asymmetry

$$A_I \equiv \frac{(\tau_{B^+}/\tau_{B^0})\times B(B^0 \to K^{(*)0}ll) - B(B^\pm \to K^{(*)\pm}ll)}{(\tau_{B^+}/\tau_{B^0})\times B(B^0 \to K^{(*)0}ll) + B(B^\pm \to K^{(*)\pm}ll)}$$

BaBar observed large discrepancy from null asymmetry at low q^2 region.

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



For F_L and A_{FB}, SM prediction and flipped C_7 case (non-SM) are plotted.

All consistent with the SM.
(though for A_{FB}, flipped C_7 case looks more favored)

$$A_I(B \to K^*\ell^+\ell^-) = -0.29^{+0.16}_{-0.16} \pm 0.03 \quad \sigma = 1.40$$
$$A_I(B \to K\ell^+\ell^-) = -0.31^{+0.17}_{-0.14} \pm 0.05 \quad \sigma = 1.75$$
$$A_I(B \to K^{(*)}\ell^+\ell^-) = -0.30^{+0.12}_{-0.11} \pm 0.04 \quad \sigma = 2.24$$

Summary

- $b \to s\gamma$ and $b \to s l^+ l^-$ provide sensitive probe to NP.
- Evidence of $B^+ \to K^+\eta'\gamma$
  - ✓ Can be used for mixing-induced CP violation study in future.
- Updated measurement of $B \to K^{(*)}ll$.
  - ✓ Measurements of branching fraction, forward-backward asymmetry, iso-spin asymmetry etc. show consistent results with the SM.
  - ✓ More luminosity is necessary to distinguish NP scenario.
- Can be done at Super KEKB / Belle-II.

Backup

Wilson Coefficient and $B \to K^{(*)}ll$

- Wilson coefficients to identify type of new physics

C_7 for magnetic penguin operator $[\frac{e}{8\pi^2} m_b \bar{s}_i \sigma^{\mu\nu}(1+\gamma_5) b_i F_{\mu\nu}]$

(size is determined from $b \to s\gamma$, but sign is from $b \to s\ell^+\ell^-$)

C_9 for vector electroweak operator $[(\bar{b}s)_{V-A}(\bar{\ell}\ell)_V]$

C_{10} for axial-vector electroweak operator $[(\bar{b}s)_{V-A}(\bar{\ell}\ell)_A]$

- Foward-backward asymmetry ($A_{\rm FB}$) and Wilson coefficients

$$A_{\rm FB}(q^2) = -C_{10}^{\rm eff}\xi(q^2)\left[Re(C_9^{\rm eff})F_1 + \frac{1}{q^2}C_7^{\rm eff}F_2\right]$$

(similar to γ-Z interference at high energy)

- Angular distributions to extract FB asymmetries

K^* logitudinal polarization F_L from kaon angle θ_K

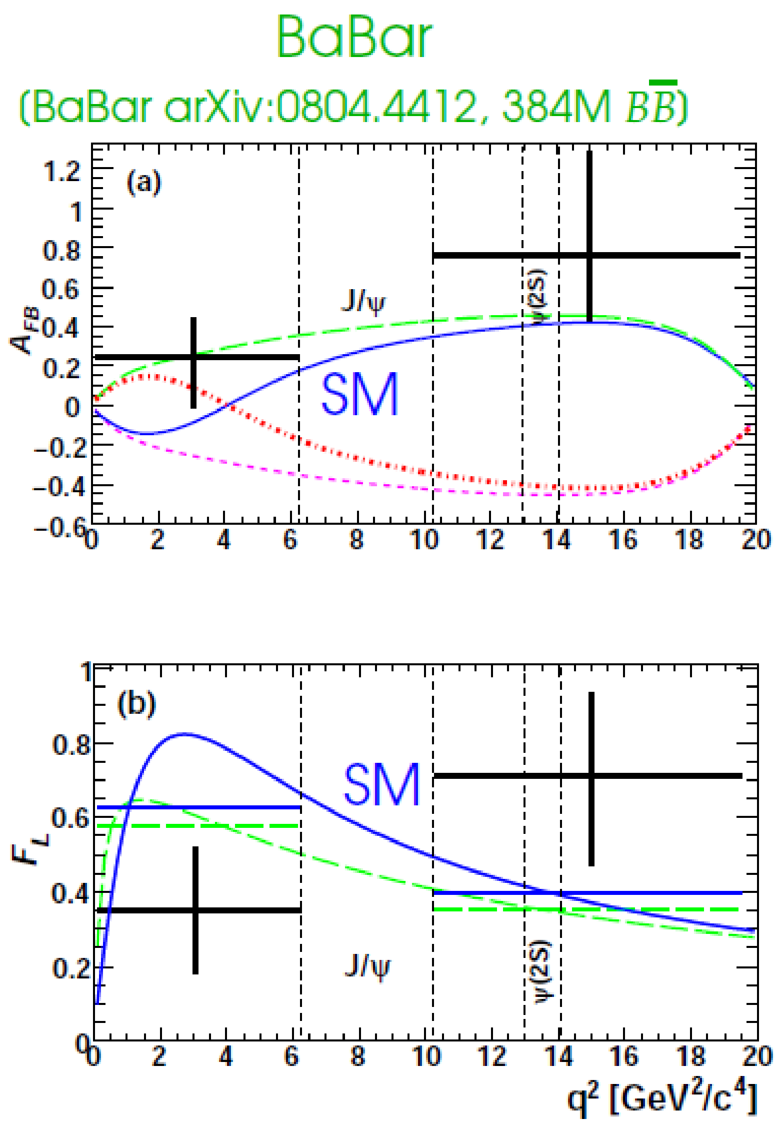
$$\tfrac{3}{2}F_L\cos^2\theta_K + \tfrac{3}{4}(1-F_L)(1-\cos^2\theta_K)$$

Forward-backward asymmetry $A_{\rm FB}$ from lepton angle θ_ℓ

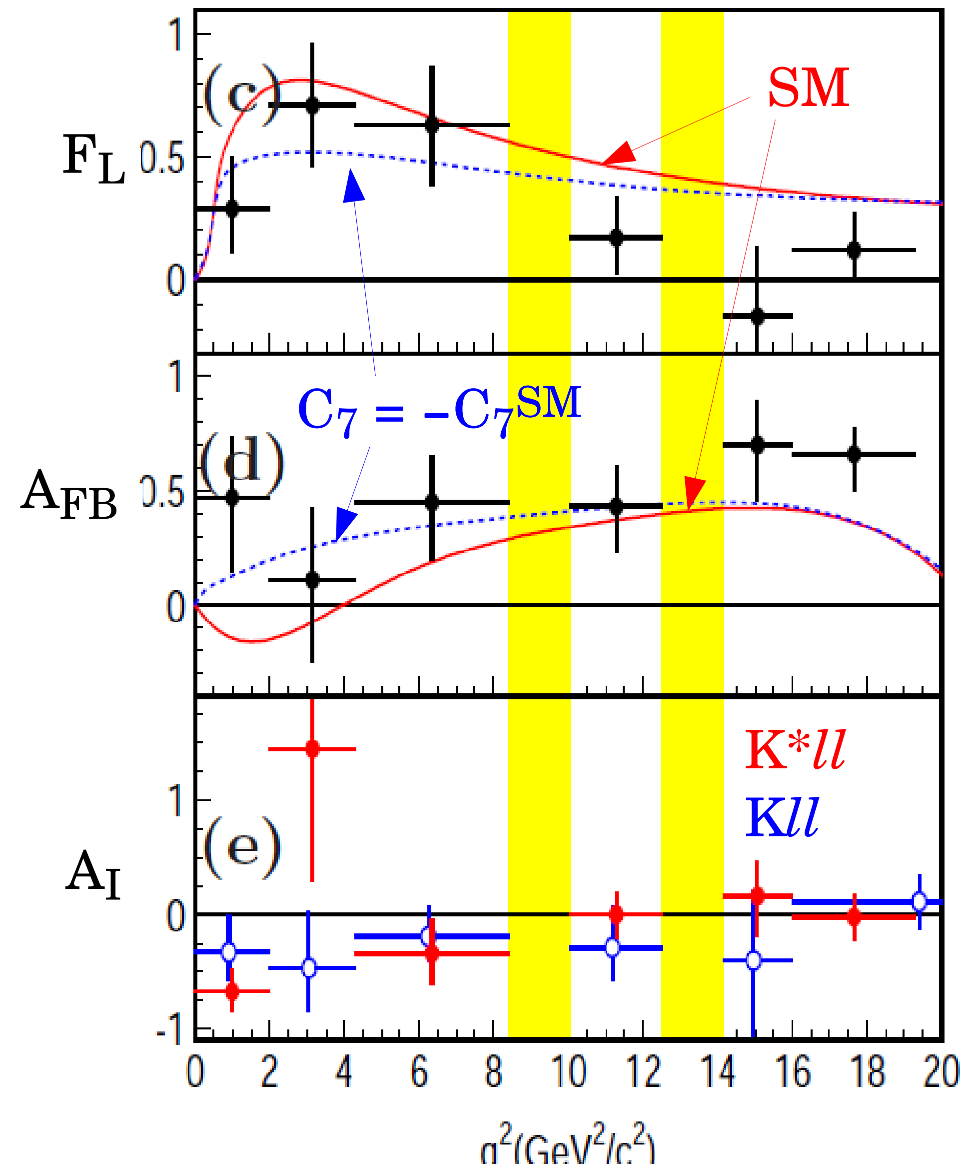
$$\tfrac{3}{4}F_L(1-\cos^2\theta_\ell) + \tfrac{3}{8}(1-F_L)(1+\cos^2\theta_\ell) + A_{\rm FB}\cos\theta_\ell$$

Review of Radiative Penguin Measurements — M. Nakao — p.15

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

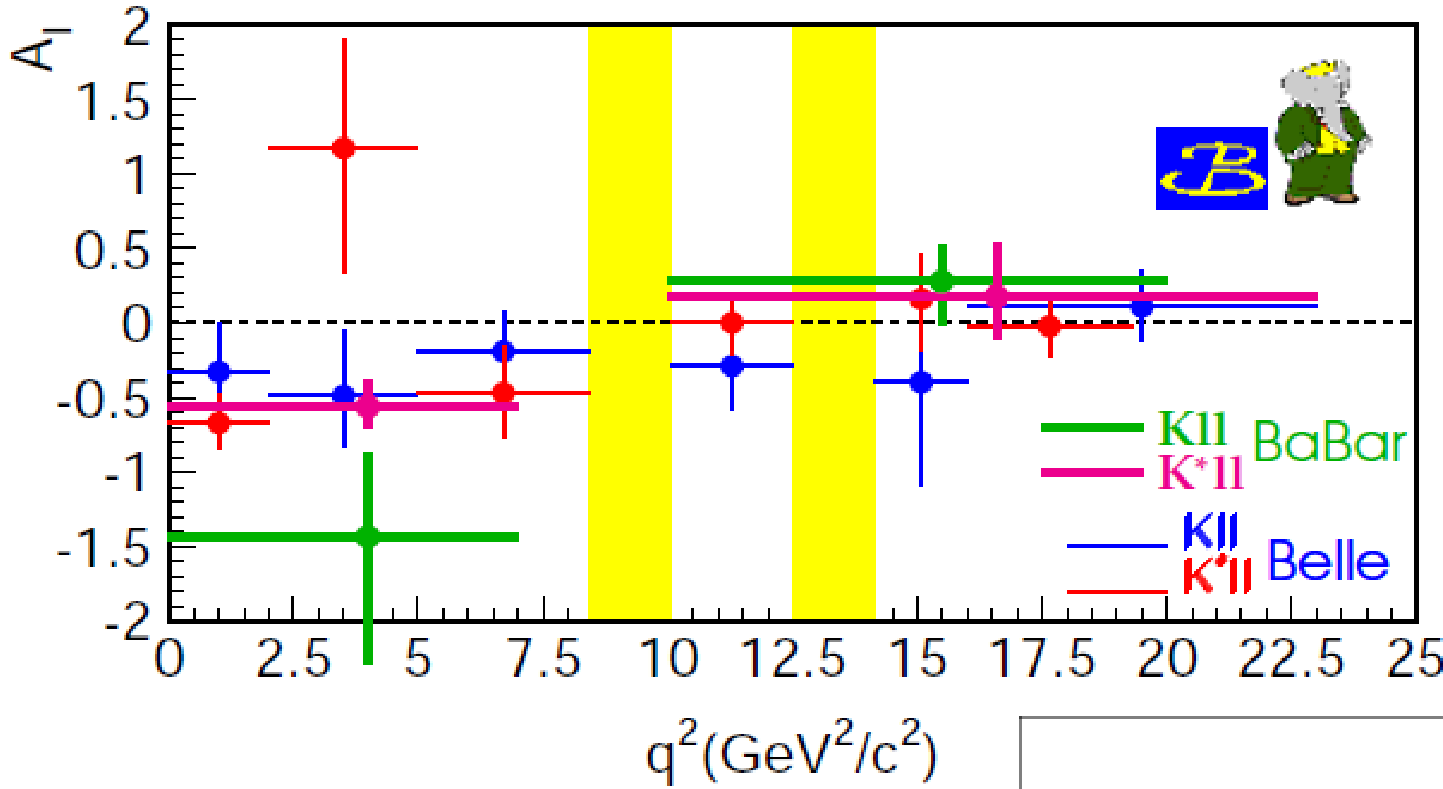


BaBar
(BaBar arXiv:0804.4412, 384M $B\bar{B}$)
(a)
A_{FB}
J/ψ
ψ(2S)
SM
(b)
F_L
SM
J/ψ
ψ(2S)
q² [GeV²/c⁴]

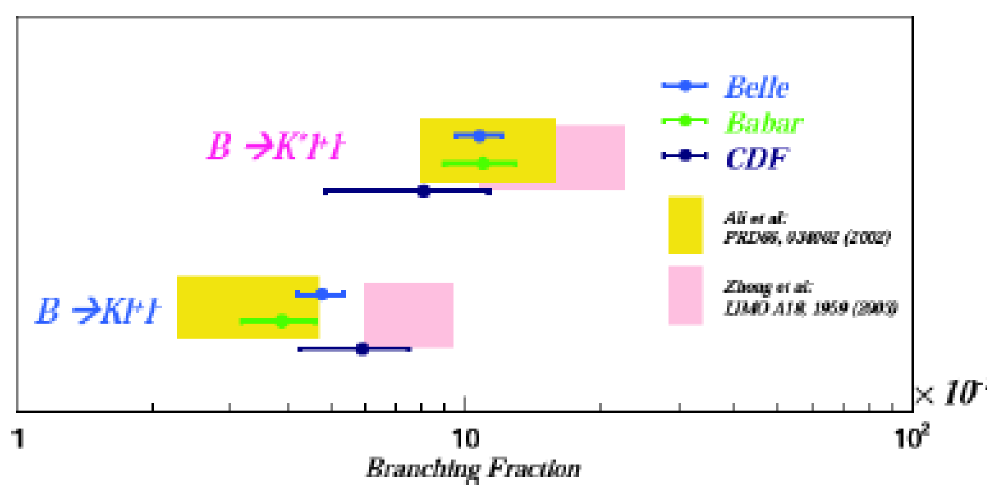


(c)
F_L
SM
(d)
A_{FB}
$C_7 = -C_7^{SM}$
(e)
A_I
K^*ll
Kll
q²(GeV²/c²)

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



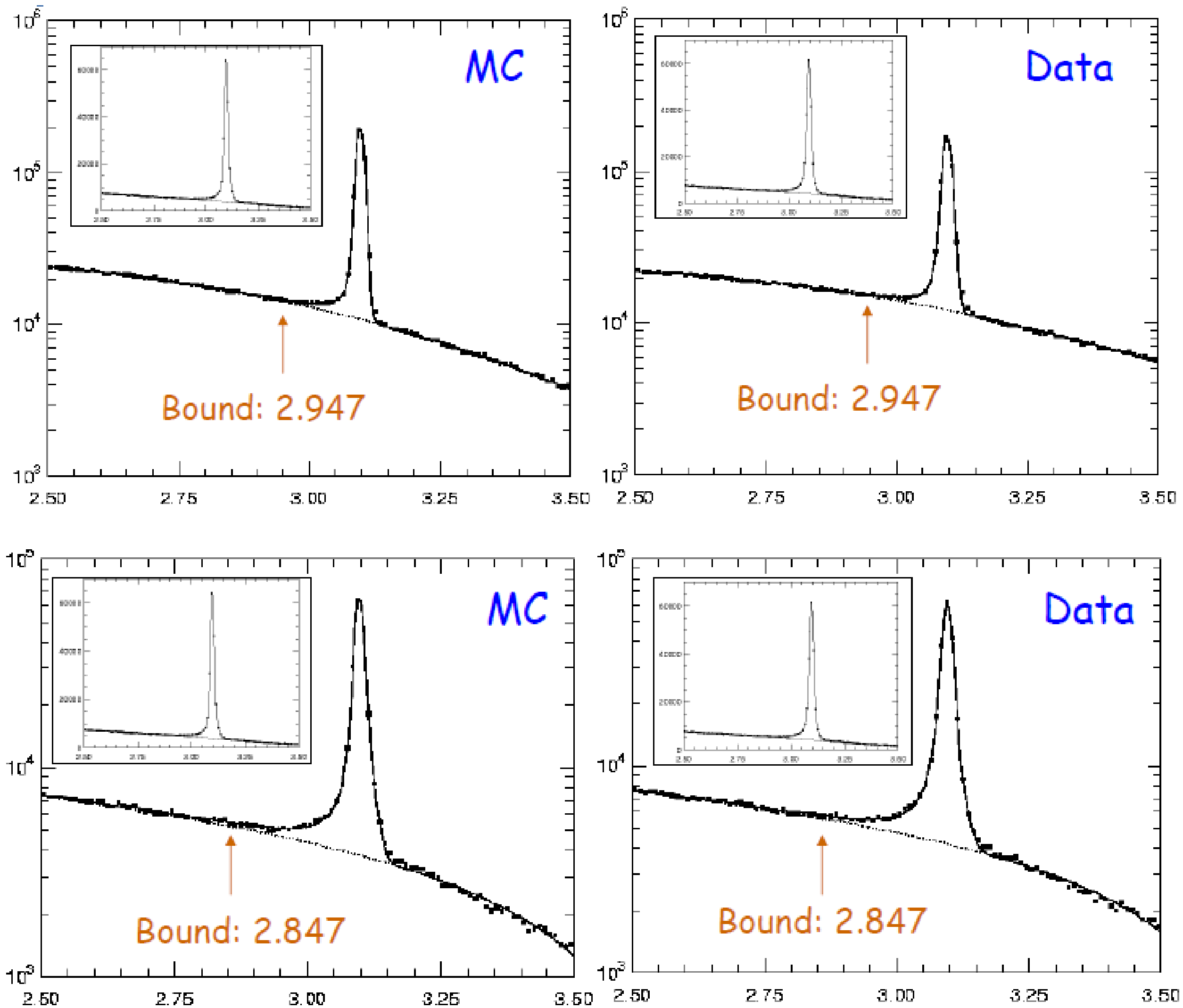
A_I
$q^2(\mathrm{GeV}^2/c^2)$
Kll
K*ll
BaBar
Kll
K*ll
Belle



Belle
Babar
CDF
$B \to K^* l^+ l^-$
$B \to K l^+ l^-$
Ali et al:
Zhong et al:
$\times 10^{-7}$
Branching Fraction

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

J/ψ tail (inclusive J/ψ sample)



Muon mode

MC tail slightly longer than data

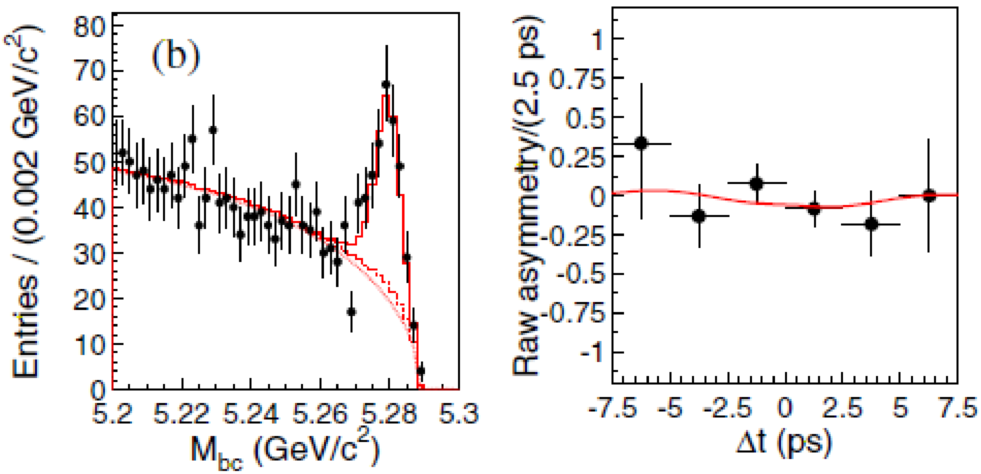
Electron mode

$B \to K_S\pi^0\gamma$, $K_S\rho^0\gamma$

535 M $B\bar{B}$ [PRD 74, 111104(R) (2006)]

K* + non-K*

$M_{K\pi} < 1.8$ GeV



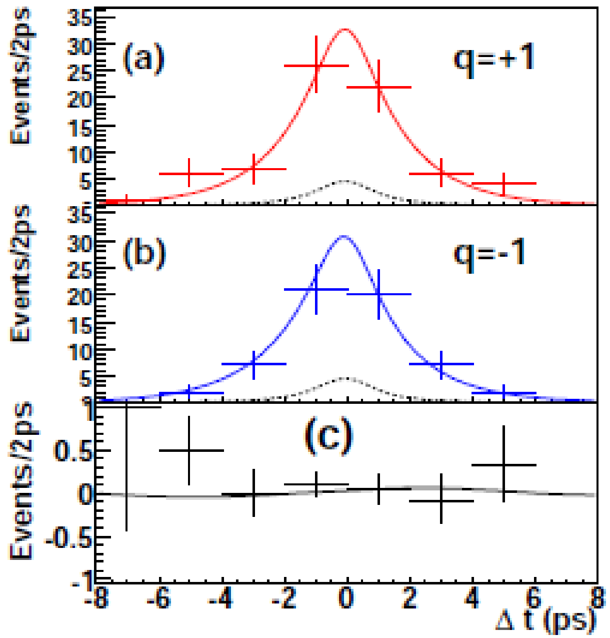
$S(K_S\pi^0\gamma) = -0.10 \pm 0.31 \pm 0.07$

$A(K_S\pi^0\gamma) = -0.20 \pm 0.20 \pm 0.06$

$S(K^{*0}\gamma) = -0.32\,^{+0.36}_{-0.33} \pm 0.05$

$A(K^{*0}\gamma) = -0.20 \pm 0.24 \pm 0.05$

657 M $B\bar{B}$



$S_{\rm eff} = 0.09 \pm 0.27\,^{+0.04}_{-0.07}$

$A_{\rm eff} = 0.35 \pm 0.18 \pm 0.06$

$D = 0.83\,^{+0.19}_{-0.03}$

$$S_{K_S\rho^0\gamma} = S_{\rm eff}/D = 0.11 \pm 0.33(stat.)^{+0.05}_{-0.09}(syst.)$$