New Results on B → Vγ Decays

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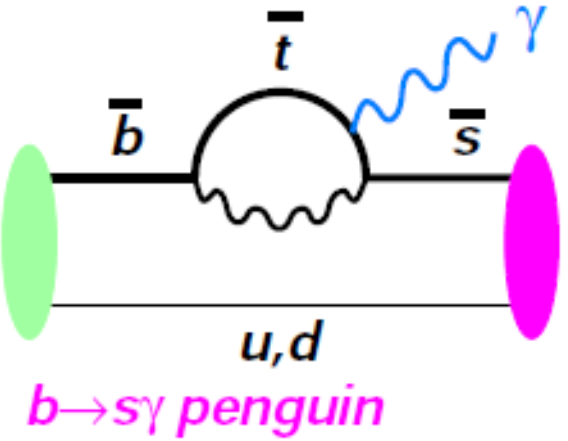
This talk summaries recent results from BaBar and Belle.

Introduction

- $b \to s\gamma$: FCNC (Flavor Changing Neutral Current) process.
- EW penguin diagram is dominant: Sensitive to New Physics.
- Photon is almost polarized in the SM.

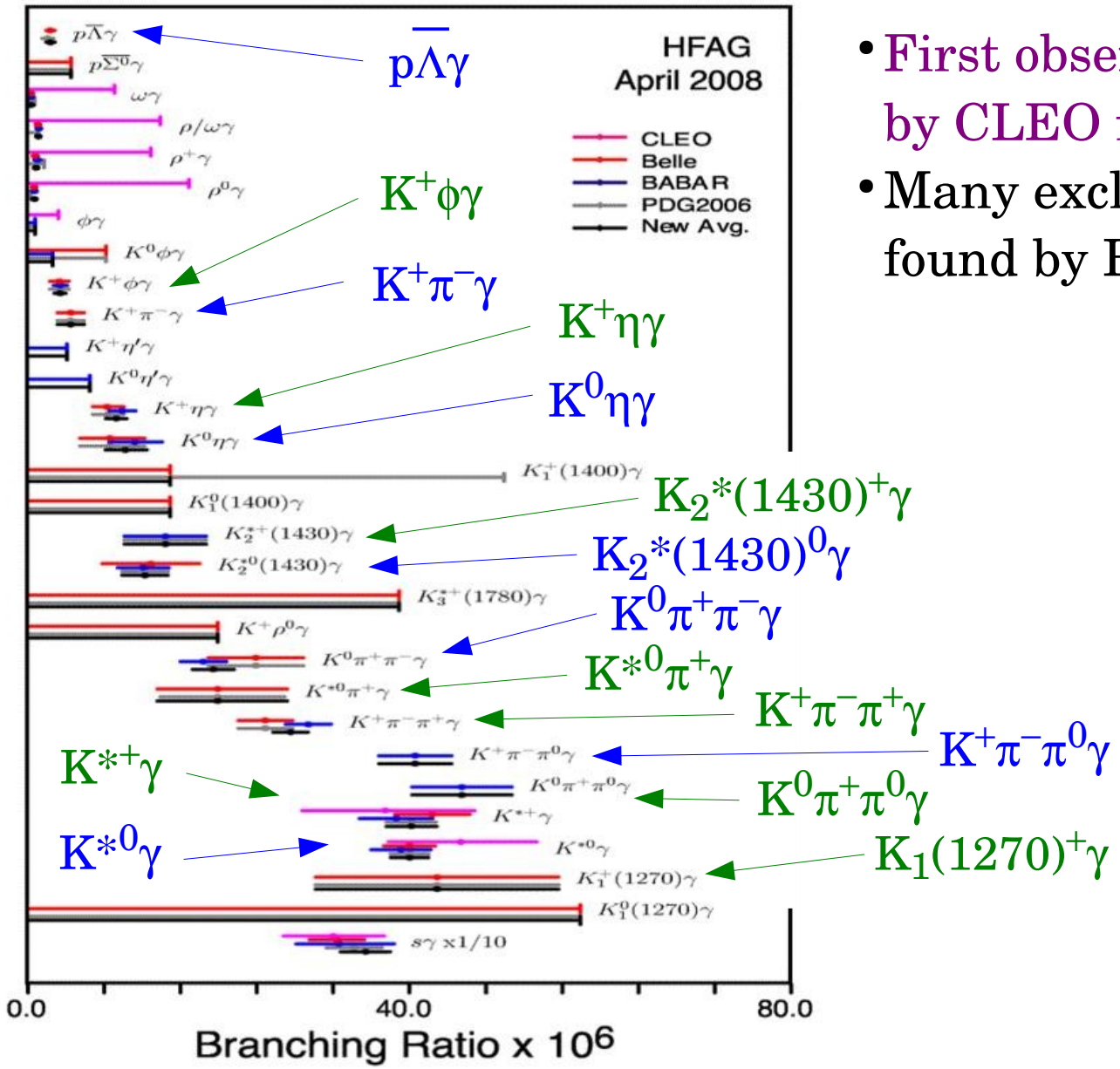


$b \to s\gamma$ penguin

Exclusive modes:

- Experimentally simple analysis, compared to the inclusive analysis.
- Difficult to predict the branching fraction due to form factors.
- Asymmetry can be predicted precisely (~O(1%)):
  - Charge asymmetry (direct CP asymmetry)
  - Isospin asymmetry
  - Time dependent CP asymmetry (tCPV)

Introduction



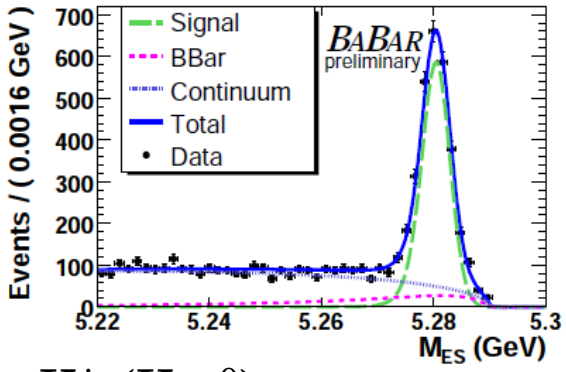
- First observation of $B \to K^*(892)\gamma$ by CLEO in 1993.
- Many exclusive final states are found by BaBar and Belle.

$B \to K^*\gamma$

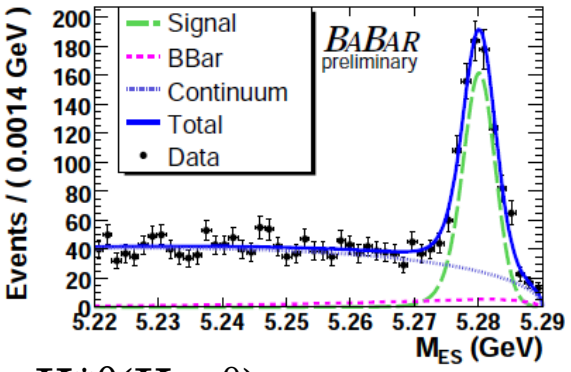
[arXiv:0808.1915 [hep-ex]] New 347 M $B\bar{B}$

85 M $B\bar{B}$

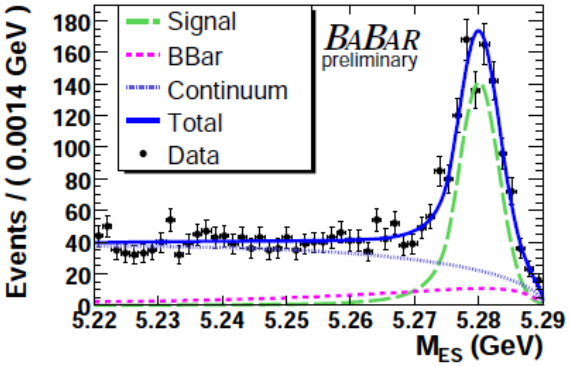
$K^{*0}(K^+\pi^-)\gamma$



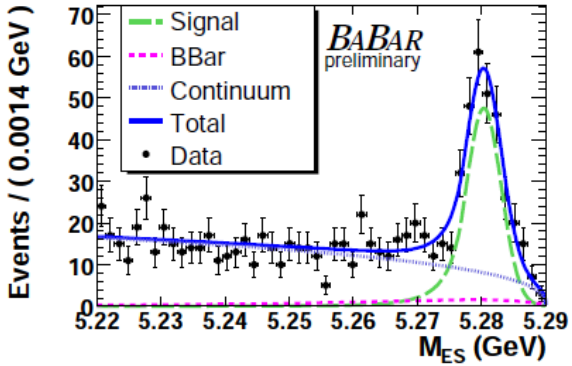
$K^{*+}(K_S\pi^+)\gamma$



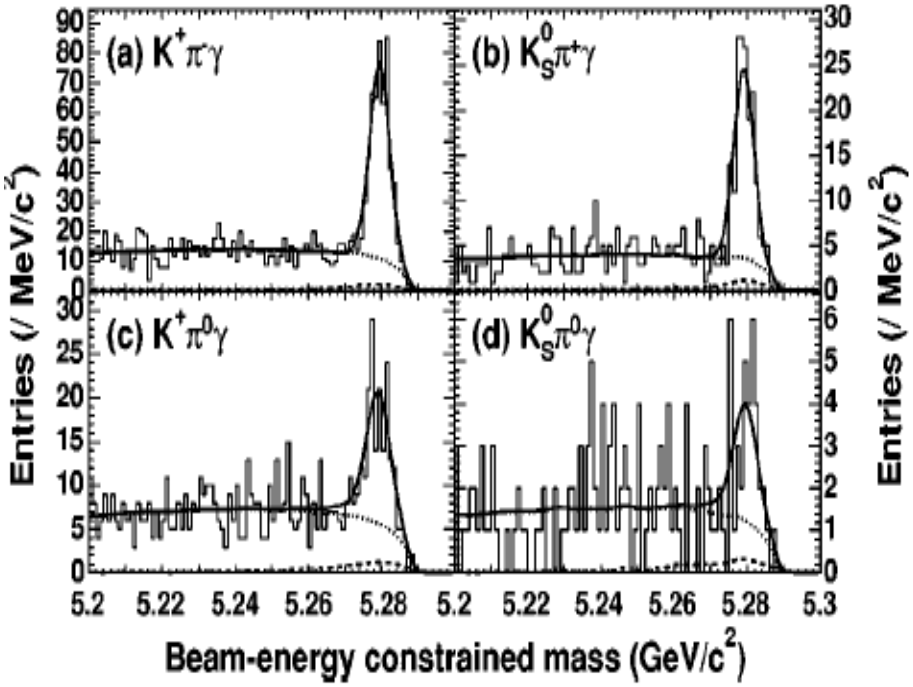
$K^{*+}(K^+\pi^0)\gamma$



$K^{*0}(K_S\pi^0)\gamma$



[PRD 69, 112001 (2004)]



B → K*γ

Mode	N_S	$\epsilon(\%)$	$\mathcal{B}(\times 10^{-5})$
$K^+\pi^-$	2394.1±55.6	20.6±0.7	$4.55 \pm 0.11 \pm 0.16$
$K_s\pi^0$	256.0 ±20.6	11.7±0.8	$5.01 \pm 0.40 \pm 0.37$
$K^+\pi^0$	872.7±37.6	13.7±0.7	$5.05 \pm 0.22 \pm 0.27$
$K_s\pi^+$	759.1±33.8	18.8±0.7	$4.56 \pm 0.20 \pm 0.17$
$B^0 \to K^{*0}\gamma$			$4.58 \pm 0.10 \pm 0.16$
$B^+ \to K^{*+}\gamma$			$4.73 \pm 0.15 \pm 0.17$

	Signal yield	Efficiency	$\mathcal{B}$ $(\times 10^{-5})$
$K^{*0}\gamma$	473.9±25.0±6.2	13.92±0.58	4.01±0.21±0.17
$K^{*+}\gamma$	274.1±20.1±6.6	7.59±0.39	4.25±0.31±0.24
$(K^+\pi^-)\gamma$	450.1±24.2±6.1	12.83±0.54	4.13±0.22±0.18
$(K^0_S\pi^0)\gamma$	23.8±6.4±1.0	1.09±0.07	2.57±0.69±0.20
$(K^0_S\pi^+)\gamma$	145.0±13.7±3.6	3.96±0.25	4.31±0.41±0.29
$(K^+\pi^0)\gamma$	129.1±14.7±5.5	3.63±0.19	4.19±0.48±0.28

- Almost systematic dominant.
- BaBar B.F. is higher than Belle?
- No precise prediction.

$B \to K^*\gamma$

Charge asymmetry

$$A_{CP} = \frac{\Gamma(\bar{B} \to \bar{K}^*\gamma) - \Gamma(B \to K^*\gamma)}{\Gamma(\bar{B} \to \bar{K}^*\gamma) + \Gamma(B \to K^*\gamma)}$$

$A_{CP} < 0.01$ in SM

(Greub,Simma,Wyler
Nuc Phys B 434 39 1995)

$A_{CP} = -0.009 \pm 0.017 \pm 0.011$

$A_{CP} = -0.015 \pm 0.044 \pm 0.012$

Isospin asymmetry

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

$\Delta_{0+} = +0.026 \pm 0.008$ in SM

Matsumori, Sanda, Keum
PRD 72, 014013 (2005)

$\Delta_{0+} = 0.029 \pm 0.019 \pm 0.016 \pm 0.018$

assuming $f_+/f_0 = 1.020 \pm 0.034$

$\Delta_{0+} = 0.012 \pm 0.044 \pm 0.026$

assuming $f_+/f_0 = 1$

or $\Delta_{0+} = 0.034 \pm 0.044 \pm 0.026 \pm 0.025$

assuming $f_+/f_0 = 1.044 \pm 0.050$

These values are well predicted, and can be used for NP search.

So far, consistent with SM

3rd error is from f_+/f_0 (B^0/B^+ production ratio)

$B \to K\eta\gamma$

- η is reconstructed from $\eta \to \gamma\gamma$ or $\eta \to \pi^+\pi^-\pi^0$
- Neutral mode can be used for tCPV study.

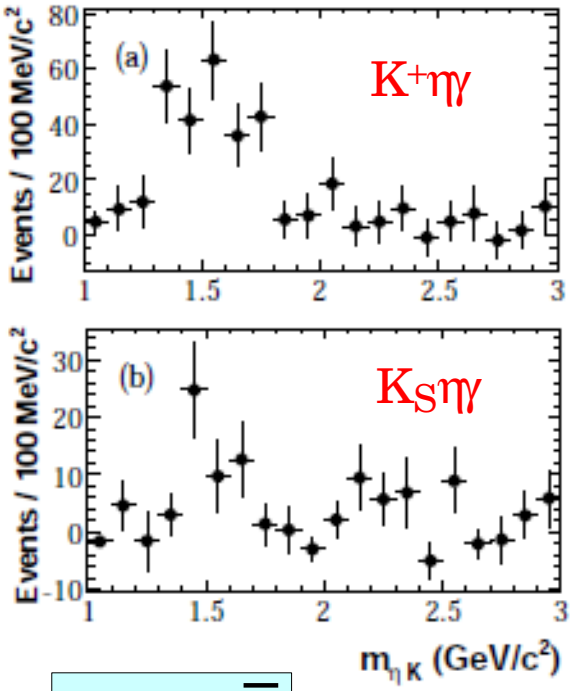
New

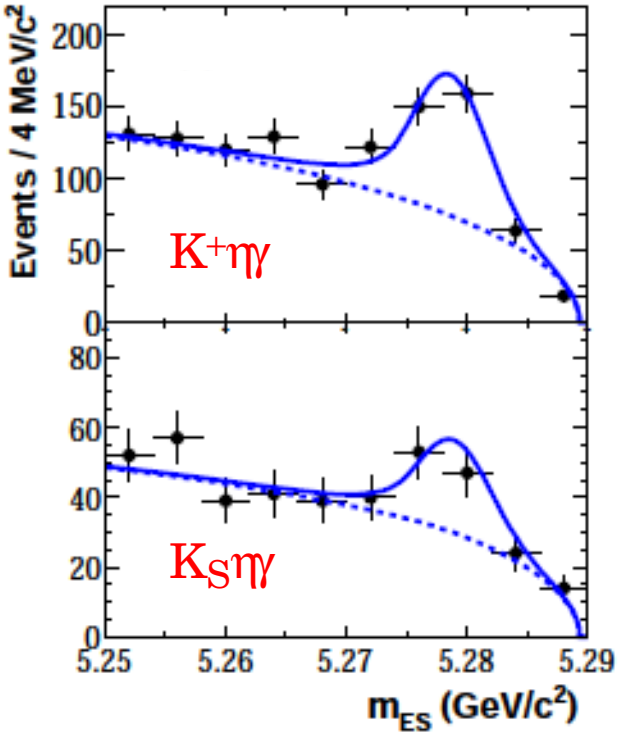
465 M $B\bar{B}$

[arXiv:0805.1317 [hep-ex]]

Mode	Yield	$\mathcal{B}(10^{-6})$
$\eta_{\gamma\gamma}K^0\gamma$	58^{+19}_{-18}	$7.4^{+2.5}_{-2.3}$
$\eta_{3\pi}K^0\gamma$	24^{+13}_{-12}	$6.6^{+3.6}_{-3.2}$
$\eta K^0\gamma$		$7.1^{+2.1}_{-2.0} \pm 0.4$
$\eta_{\gamma\gamma}K^+\gamma$	266^{+37}_{-36}	$7.8^{+1.1}_{-1.0}$
$\eta_{3\pi}K^+\gamma$	111^{+26}_{-24}	$7.4^{+1.7}_{-1.6}$
$\eta K^+\gamma$		$7.7 \pm 1.0 \pm 0.4$

$A_{CP} = (-9.0^{+10.4}_{-9.8} \pm 1.4) \times 10^{-2}$





[PLB610, 23 (2005)]

275 M $B\bar{B}$

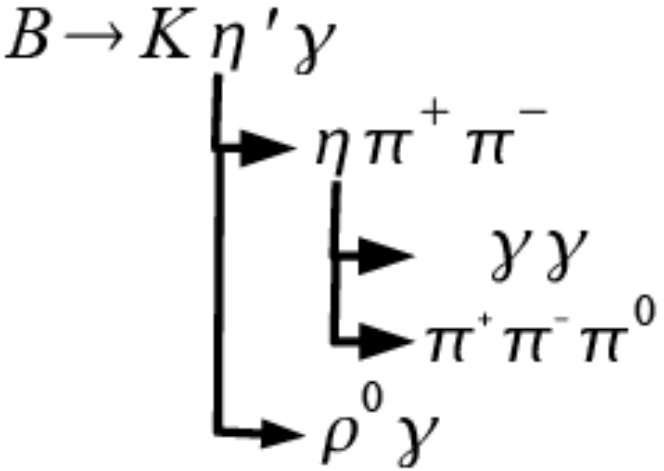
Mode	Yield	Efficiency (%)	$\mathcal{B}$ ($\times 10^{-6}$)	$\mathcal{S}$
$B^+ \to K^+\eta\gamma$	$81 \pm 14^{+10}_{-6}$	3.50 ± 0.27	$8.4 \pm 1.5^{+1.2}_{-0.9}$	6.8
$B^0 \to K^0\eta\gamma$	$20.9^{+7.3\,+4.2}_{-6.5\,-3.2}$	0.87 ± 0.08	$8.7^{+3.1\,+1.9}_{-2.7\,-1.6}$	3.4
$B \to K\eta\gamma$	$102 \pm 16^{+13}_{-8}$	4.37 ± 0.31	$8.5 \pm 1.3^{+1.2}_{-0.9}$	7.7

M(Kη) < 2.4 GeV

$A_{CP} = -0.16 \pm 0.09 \pm 0.06$

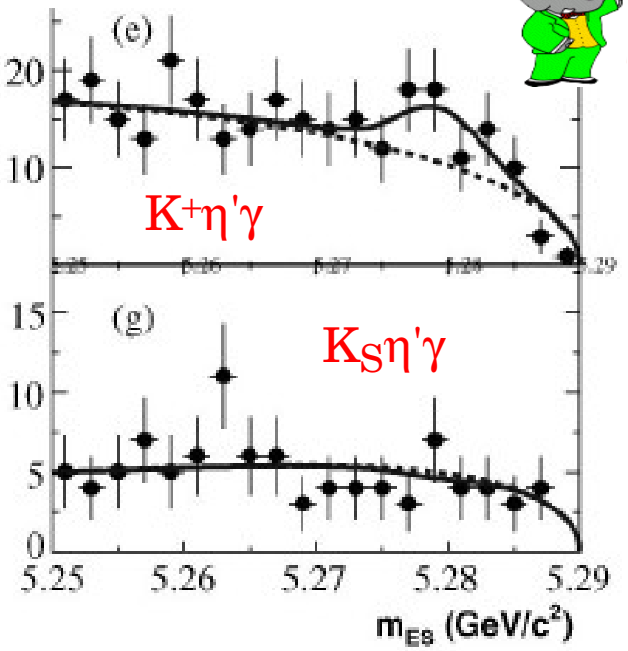
$B \to K\eta'\gamma$

- $B \to K\eta'\gamma$ has not been observed yet.
  - $B(B^+ \to K^+\eta'\gamma) < 6.6 \times 10^{-6}$ @ BaBar (232 M BB) [PRD74, 031102 (2006)]
- 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)]



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

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



New Belle Measurement with 657 M $B\bar{B}$

Veto
- D0 veto ($1.84 < M(K\pi) < 1.89$ GeV) for K^+
- J/ψ veto ($3.07 < M(\eta'\gamma) < 3.12$ GeV)

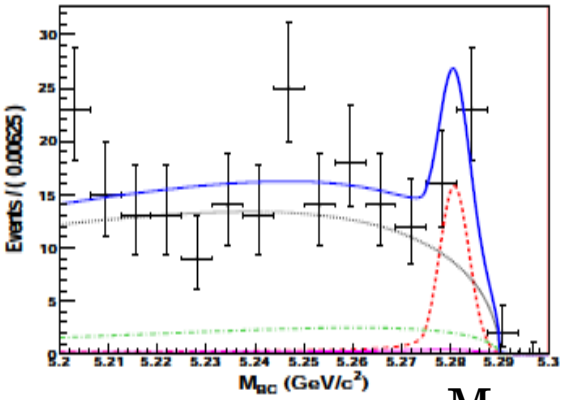
Fit Combine all submode and perform 2-d fit on M_{bc}-ΔE

$B \to K\eta'\gamma$

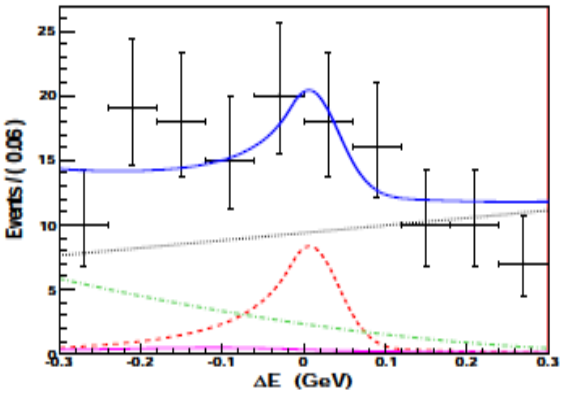
Preliminary Result

657 M $B\bar{B}$

$B(B^+ \to K^+\eta'\gamma) = (3.2\ ^{+1.2}_{-1.1} \pm 0.3) \times 10^{-6}$



M_{bc}



ΔE

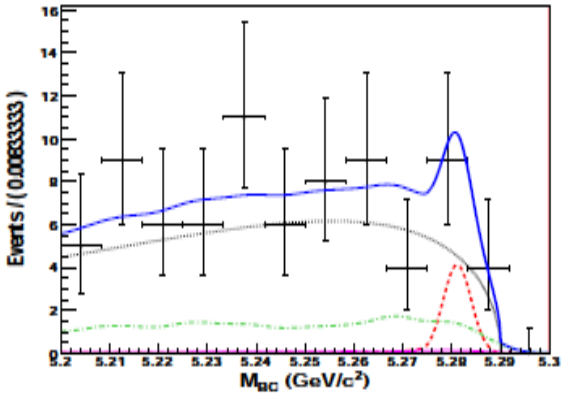
Charged Mode

Significance 3.3σ

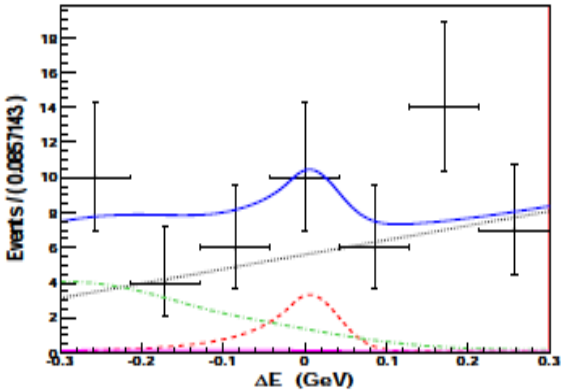
(3.4σ w/o syst. error)

First evidence!!

$B(B^0 \to K^0\eta'\gamma) = (2.4\ ^{+2.4\,+0.4}_{-0.9\,-0.5}) \times 10^{-6} < 6.3 \times 10^{-6}$



M_{bc}



ΔE

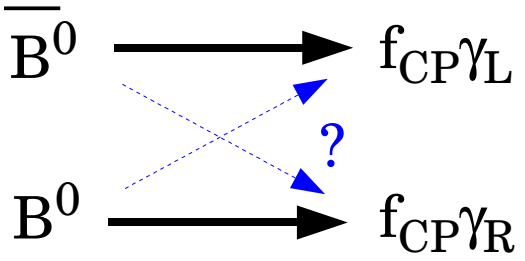
Neutral Mode

Significance 1.3σ

tCPV of Radiative B Decays

In the SM, the photon from $b \to s\gamma$ is almost left-handed (polarized).

⇨ Mixing induced (time-dependent) CPV does not occur in $B \to f_{CP}\gamma$



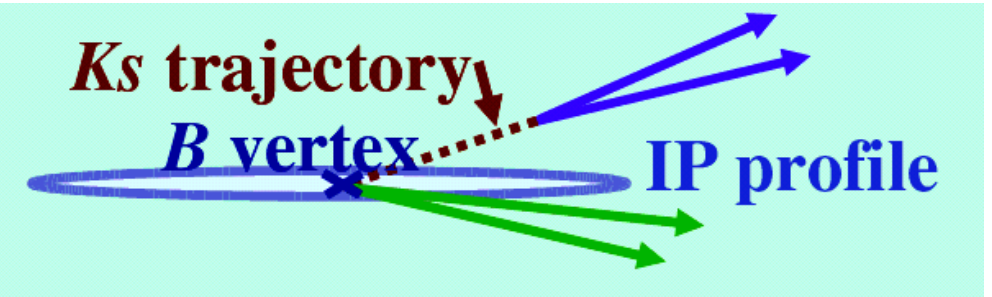
Large time-dependent CP asymmetry is an indication of New Physics.

- $B \to K^{*0}\gamma \to K_S\pi^0\gamma$.
- Final state can be any of $P^0Q^0\gamma$ (e.g. $K_S\rho^0\gamma$, $K_S\eta\gamma$) [PRD72, 076003 (2005)]
- Strong interaction may enhance S (a few %) even within SM.

$$P(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\left\{1 + q \cdot \left[\mathcal{S}\sin(\Delta m_d \Delta t) + \mathcal{A}\cos(\Delta m_d \Delta t)\right]\right\}$$

Technique:

- In modes like $K_S\pi^0\gamma$, the B vertex has to be caluclated using trajectory (Ks vertex).



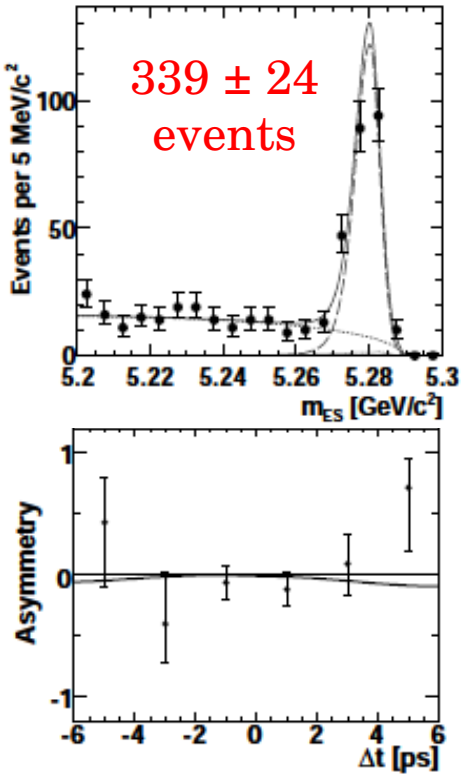
tCPV in B → $K_S\pi^0\gamma$

465 M $B\bar{B}$ New [arXiv:0807.3103 [hep-ex]]

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

K* region

$0.8 < M_{K\pi} < 1.0$ GeV

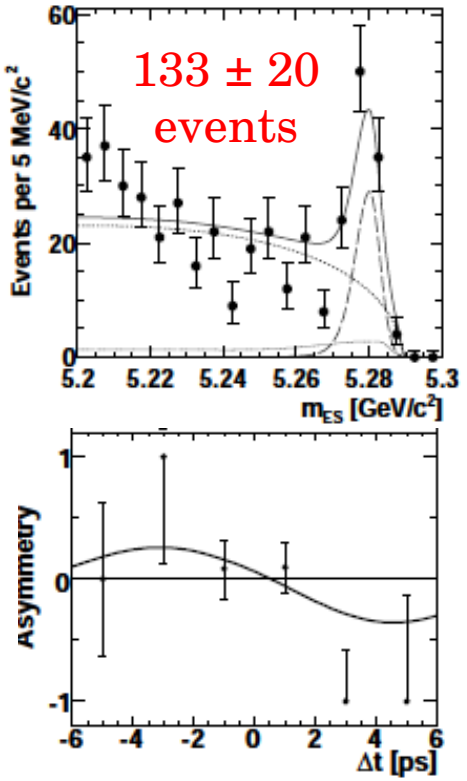


S = −0.03 ± 0.29 ± 0.03

C = −0.14 ± 0.06 ± 0.03

non K* region

$1.1 < M_{K\pi} < 1.8$ GeV

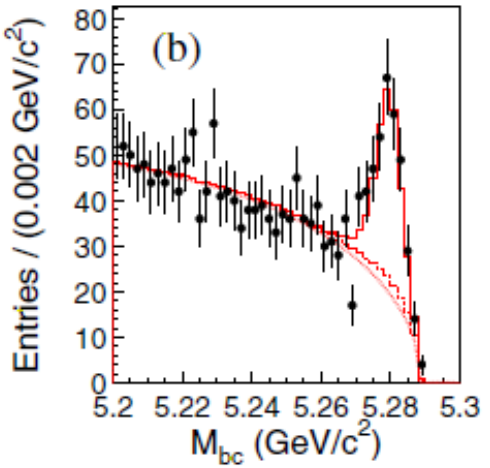


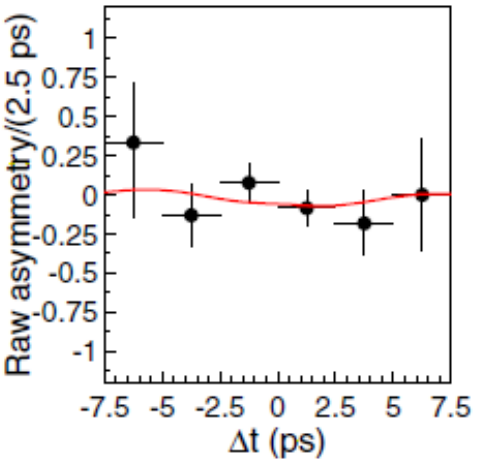
S = −0.78 ± 0.59 ± 0.09

C = −0.36 ± 0.33 ± 0.04

K* + non-K*

$M_{K\pi} < 1.8$ GeV





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

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

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

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

Consistent with no CPV

tCPV in B → Kηγ

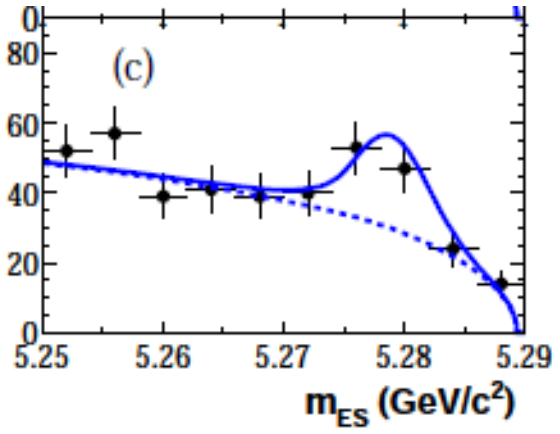
[arXiv:0805.1317 [hep-ex]]

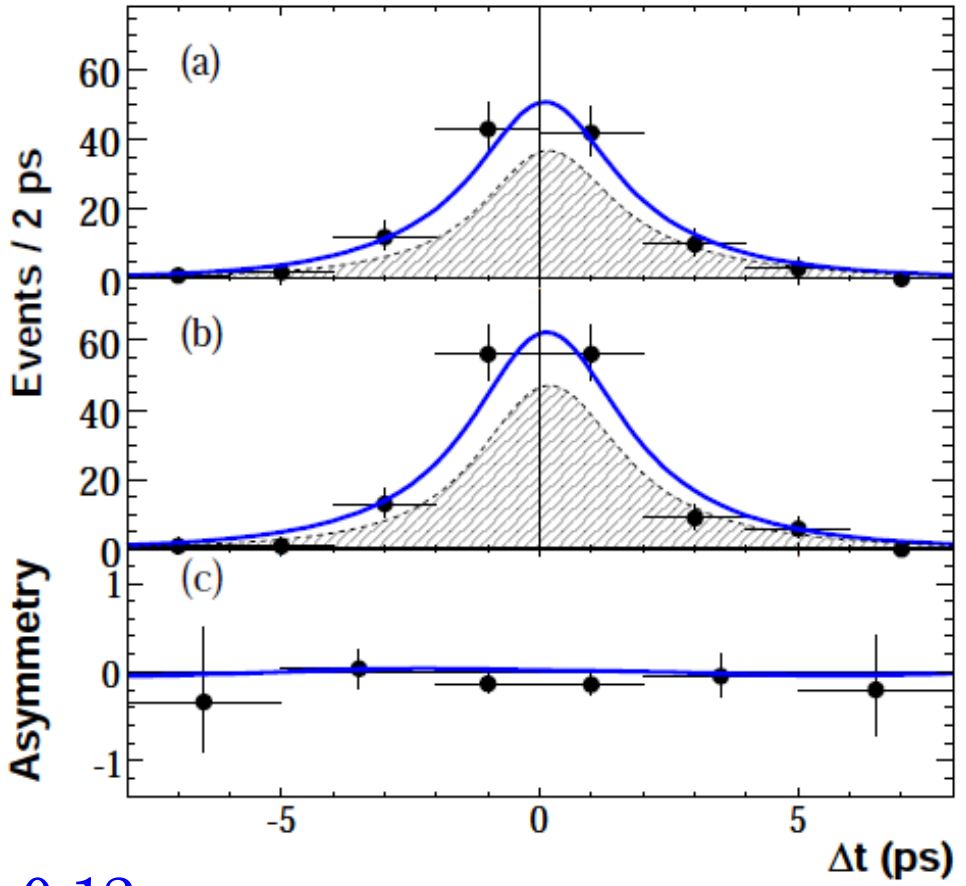
465 M $B\bar{B}$

New

B → Ksηγ

$82\ ^{+23}_{-22}$ events





$S = 0.18\ ^{+0.49}_{-0.46} \pm 0.12$

$C = -0.32\ ^{+0.40}_{-0.39} \pm 0.07$

tCPV in $B \to K_S \rho^0 \gamma$

$B^0 \to K_S \rho^0 \gamma$: final state is $K_S \pi^+ \pi^- \gamma$

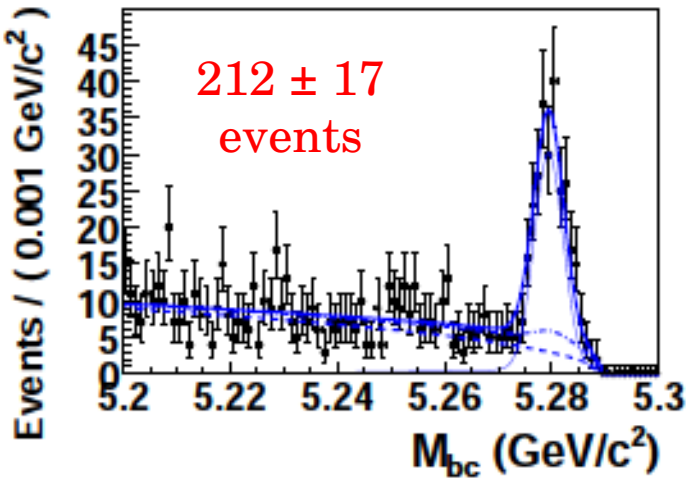
[arXiv:0806.1980 [hep-ex]] 657 M $B\bar{B}$

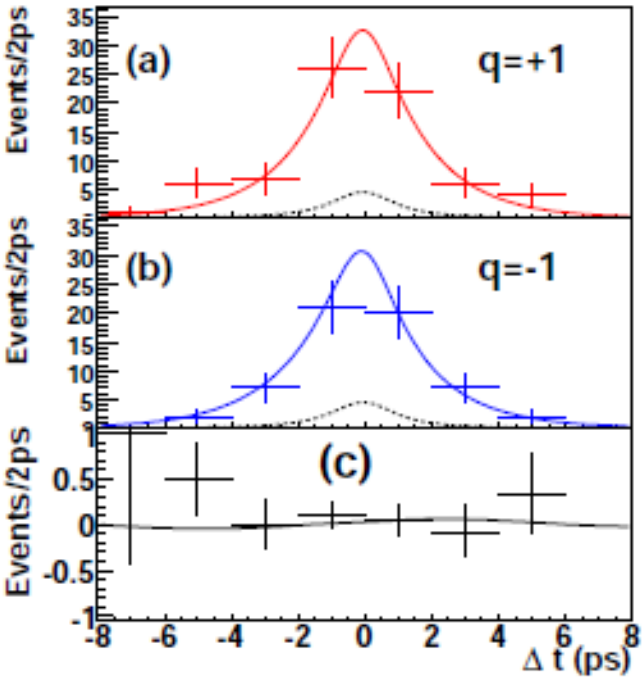
- Vertex from $\pi^+\pi^-$: No need to use K_S vertex.
- Contamination from other resonance e.g. $K^{*+}\pi^-\gamma$

- CP fit is performed for events in ρ region : $0.6 < M(\pi^+\pi^-) < 0.9$ GeV

$M(K\pi^+\pi^-) < 1.8$ GeV

ρ region (vertex info required)





Effective CP parameter (events in ρ region)

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

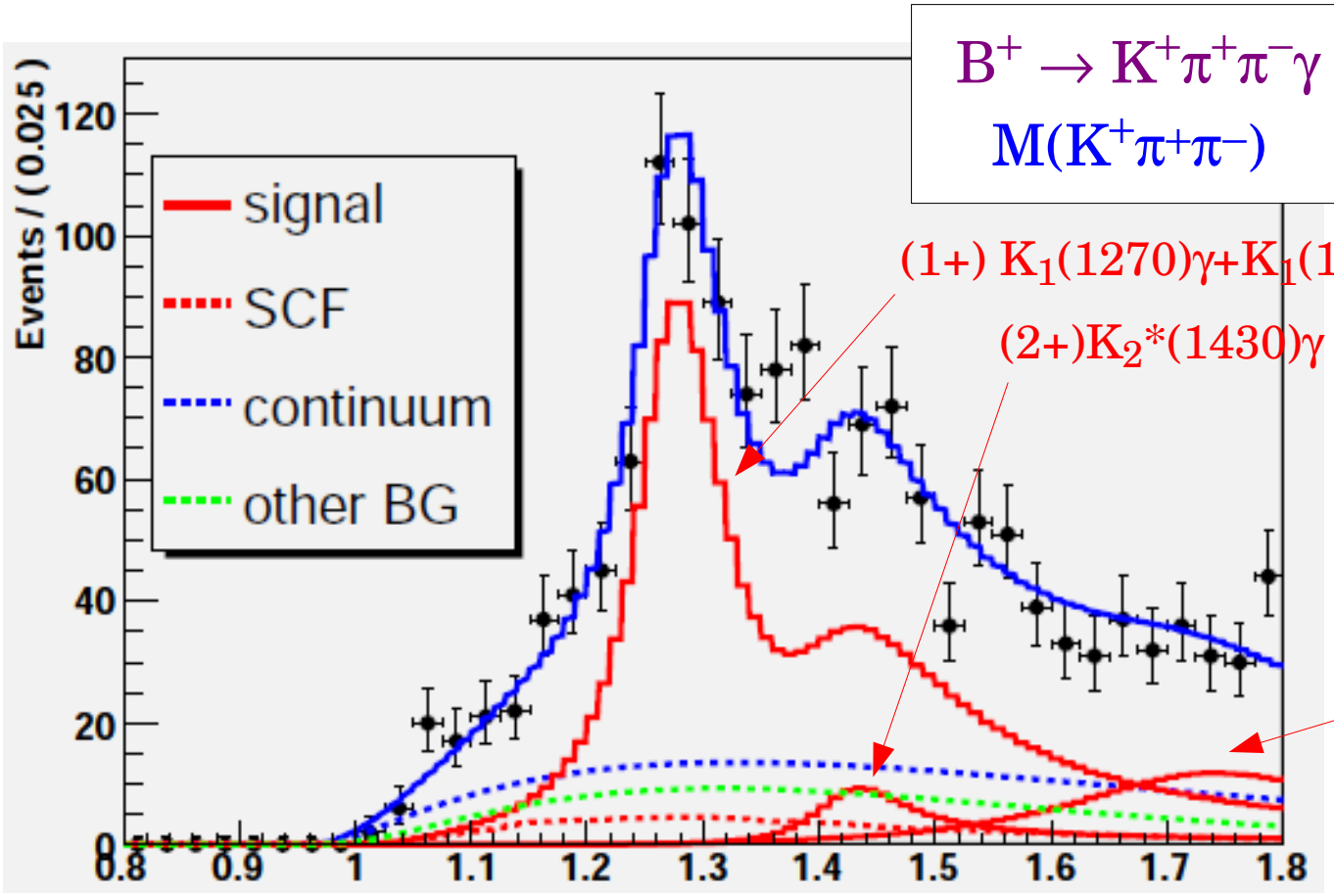
$A_{eff} = 0.35 \pm 0.18 \pm 0.06$

A=−C

tCPV in $B \to K_S \rho^0 \gamma$

$B^+ \to K^+\pi^+\pi^-\gamma$ is used for the understanding of other resonant decay.

(1) Determine resonant structure from $M(K^+\pi^+\pi^-)$ fit (in K* rich region)



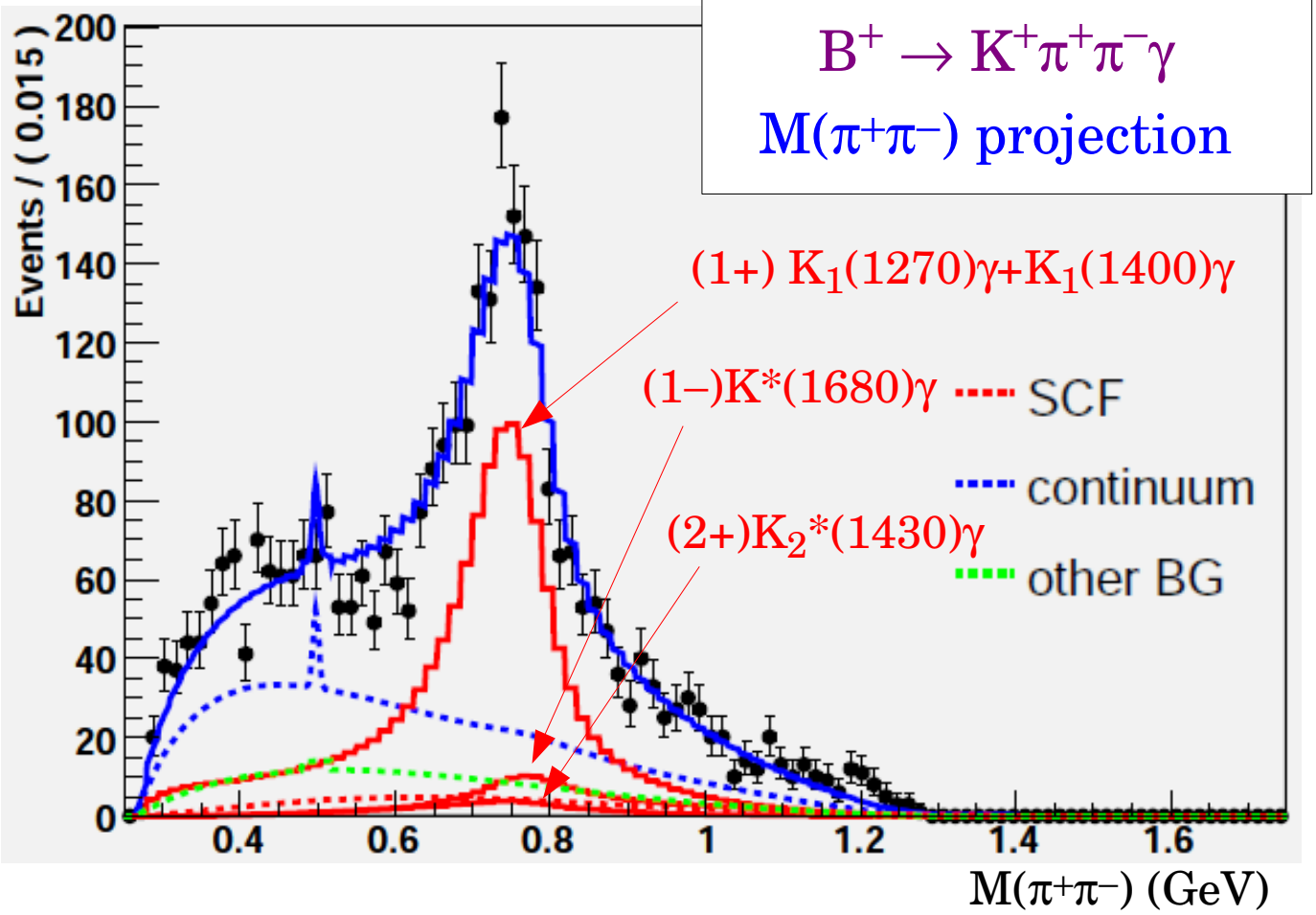
normalization of each resonances are obtained from the fit.

tCPV in $B \to K_S \rho^0 \gamma$

(2) perform 2D fit on $M(K^+\pi^-)$,$M(\pi^+\pi^-)$ in K* rich region

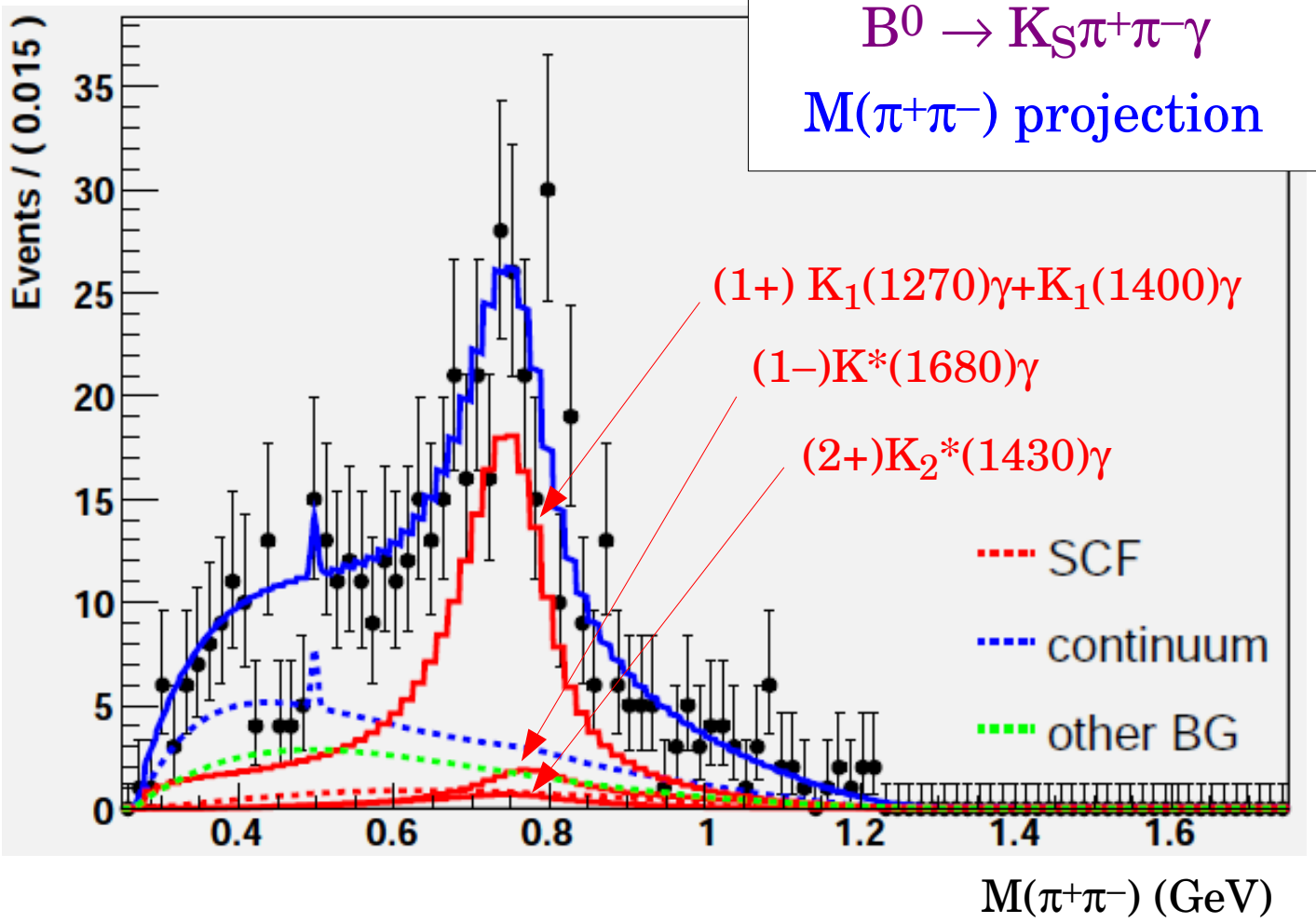
The rate and phase of the $K_1(1270) \to K^*\pi$ component (relative to $K_1(1270) \to K\rho$) is obtained.

[the plot is for entire region]



tCPV in $B \to K_S \rho^0 \gamma$

(3) Using the isospin asymmetry, the composition of $B^0 \to K_S \pi^+ \pi^- \gamma$ is determined.



looks O.K.

ρ^0 component is dominant

tCPV in B → Ksρ⁰γ

($K_S\pi^+\pi^-$) system in $B^0 \to K_S\pi^+\pi^-\gamma$

	Total	$K^0_S\rho^0\gamma$	$K^{*+}\pi^-\gamma$	Interf.	$F^*_B(\bar{K})\cdot F_B(K)$
$K_{\rm res}(1^+)\gamma$	193.6	151.0	35.1	7.5	4.4
$(K_1(1270)\gamma)$	(167.6)	(151.0)	(38.0)	(−21.4)	(5.2)
$K_{\rm res}(1^-)\gamma$	24.2	11.3	8.0	4.9	1.3
$K^{*0}_2(1430)\gamma$	10.4	2.2	6.1	2.0	4.5
Sum	228.1	164.4	49.2	14.5	10.2

$$\mathcal{D} = \frac{\mathcal{S}_{\rm eff}}{\mathcal{S}_{K^0_S\rho^0\gamma}} = \frac{\int[|F_A|^2 + 2\Re(F_A^* F_B) + F_B^*(\bar{K})F_B(K)]}{\int[|F_A|^2 + 2\Re(F_A^* F_B) + |F_B|^2]} = 0.83\,^{+0.19}_{-0.03}$$

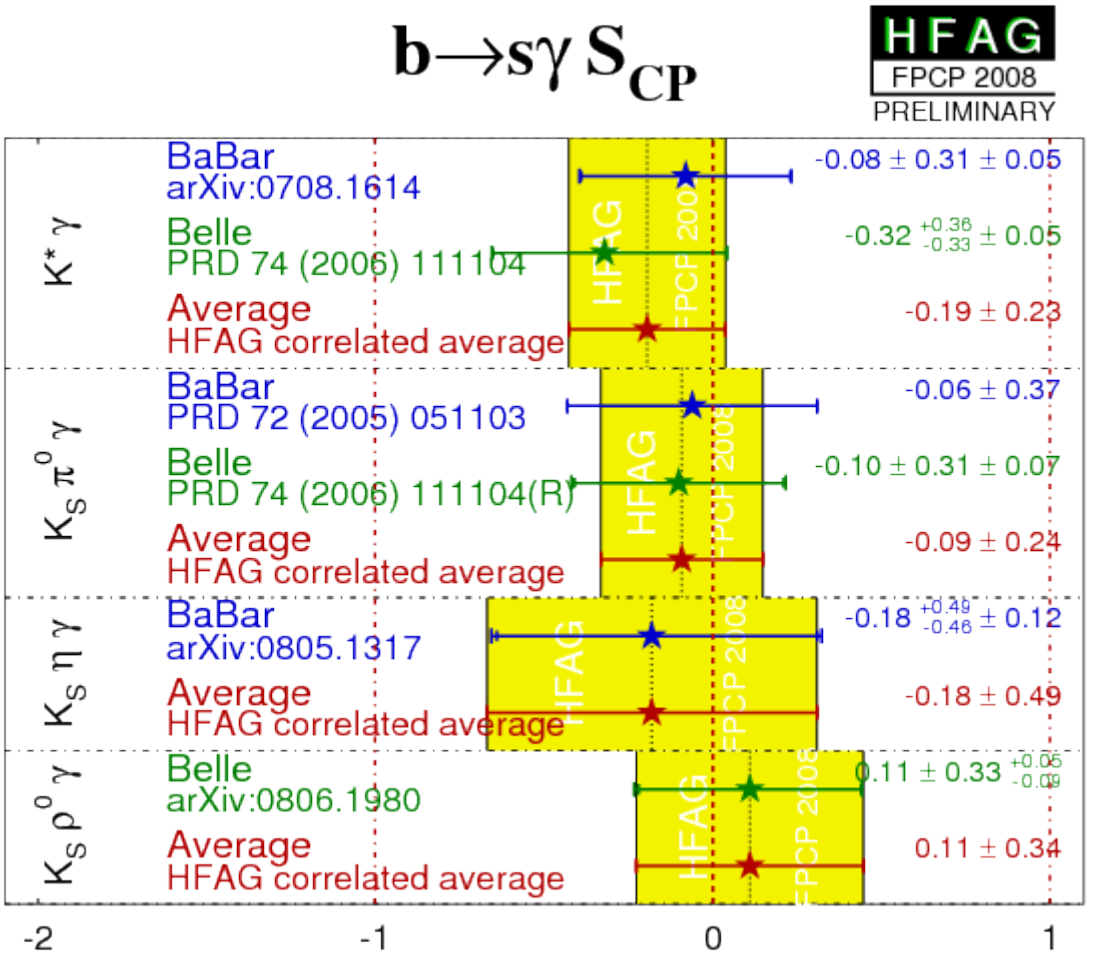
Dilution factor

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

Competitive to $K_S\pi^0\gamma$

Summary

- $B \to K^*\gamma$ (BaBar)
  - B.F., A_{CP} etc. + tCPV
- $B \to K\eta\gamma$, $K\eta'\gamma$
  - tCPV of $K_S\eta\gamma$ (BaBar)
  - Evidence of $K^+\eta'\gamma$ (Belle).
- tCPV of $K_S\rho^0\gamma$ (Belle)



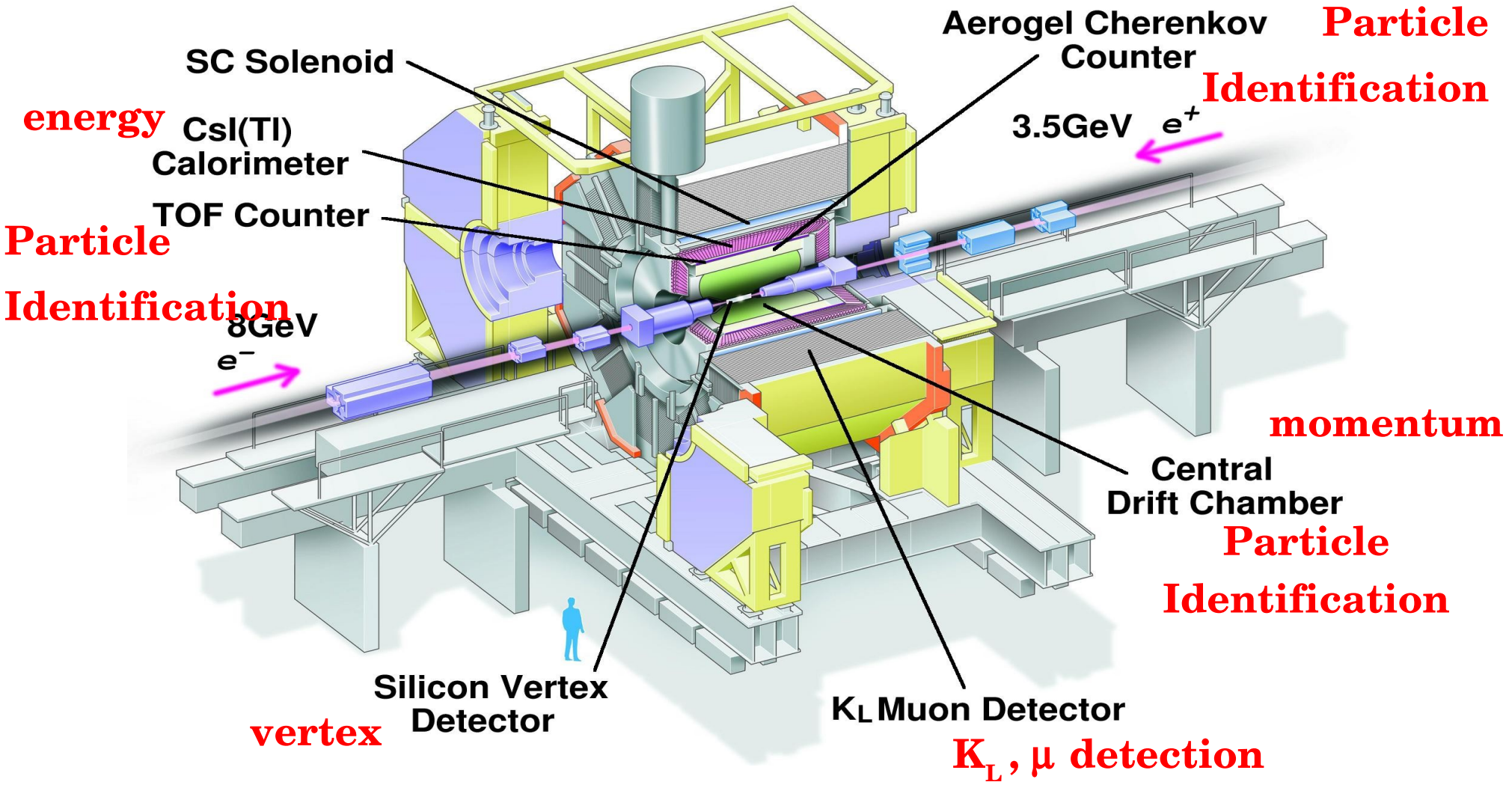
Other measured exclusive radiative B decays:

$B \to K_1(1270)\gamma$, $K_2^*(1430)\gamma$, $K\phi\gamma$, $K\pi\pi\gamma$ ($K^*\pi\gamma$, $K\rho\gamma$), $\Lambda\bar{p}\gamma$ .....

and more ?

Backup

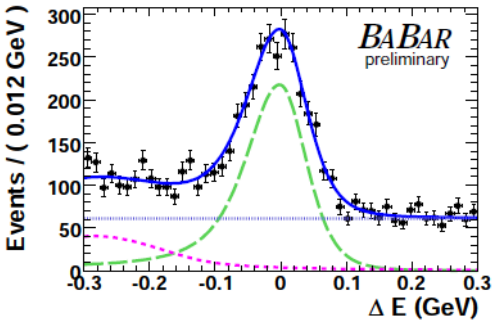
Belle Detector



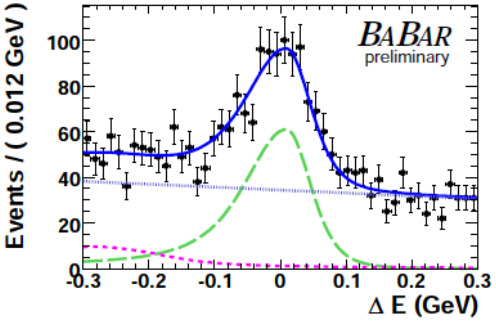
$B \to K^*\gamma$

ΔE | 347 M $B\bar{B}$ | $\cos\theta_{hel}$

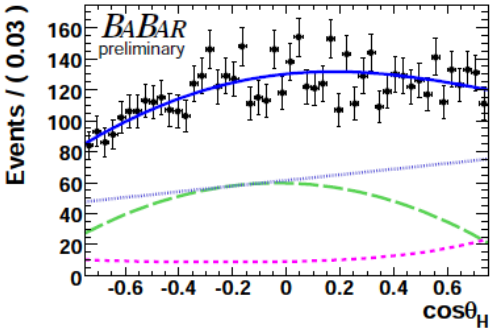
$K^{*0}(K^+\pi^-)\gamma$



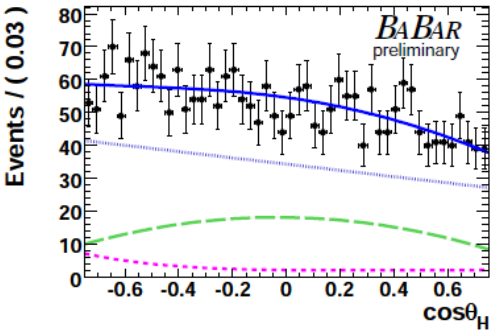
$K^{*+}(K_S\pi^+)\gamma$



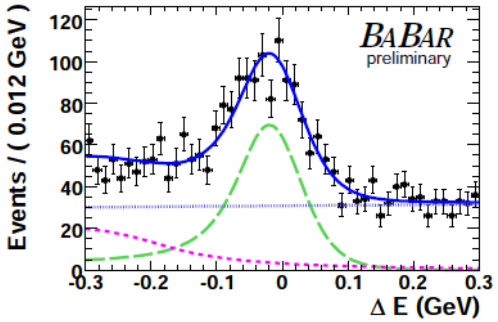
$K^{*0}(K^+\pi^-)\gamma$



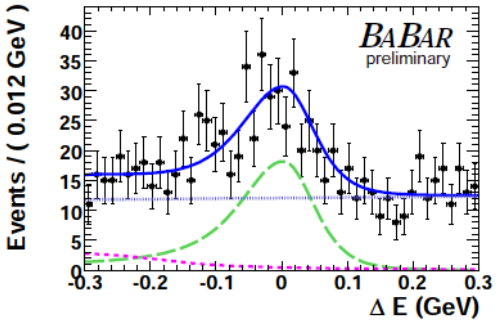
$K^{*+}(K_S\pi^+)\gamma$



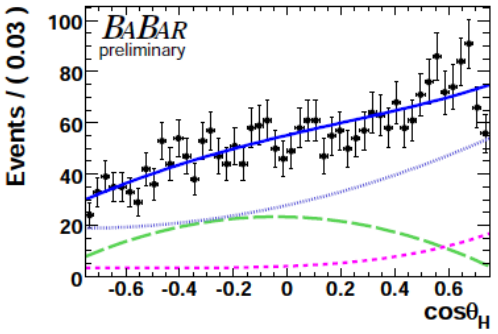
$K^{*+}(K^+\pi^0)\gamma$



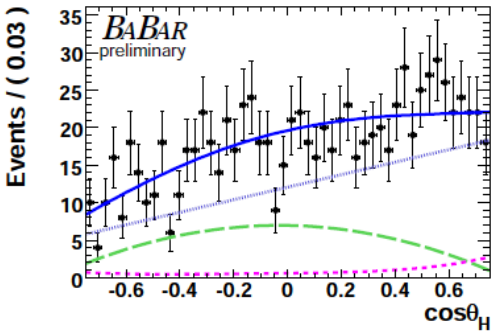
$K^{*0}(K_S\pi^0)\gamma$



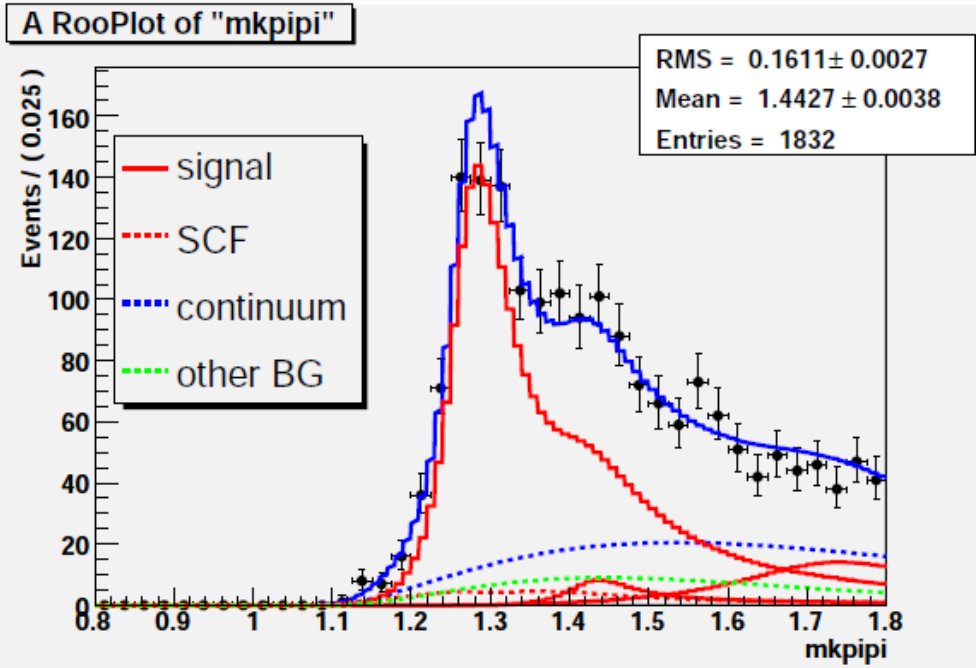
$K^{*+}(K^+\pi^0)\gamma$



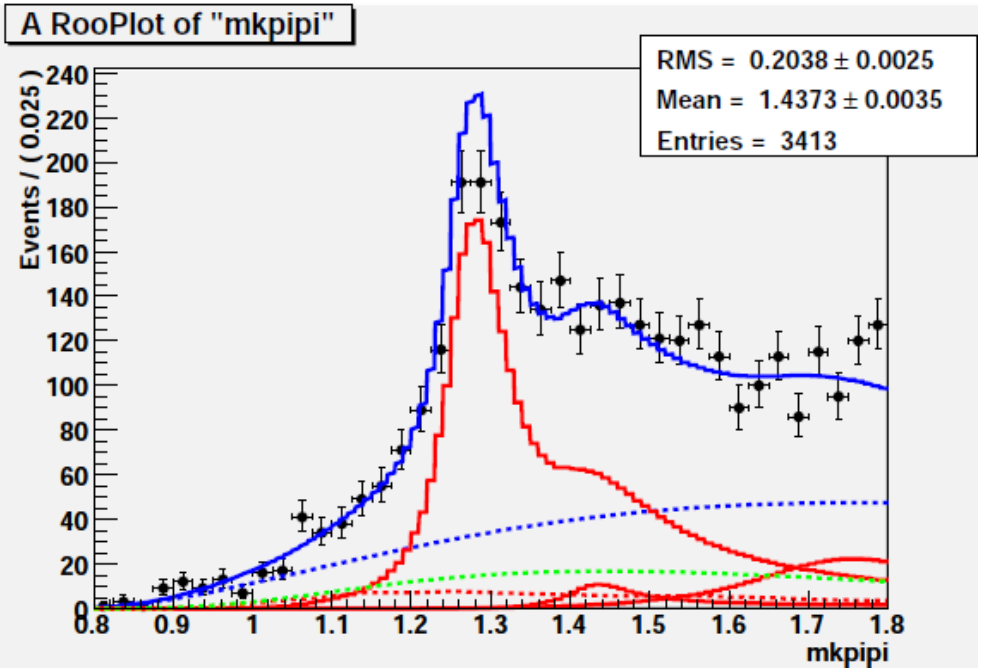
$K^{*0}(K_S\pi^0)\gamma$



tCPV in $B \to K_S \rho^0 \gamma$



charged ; rho region



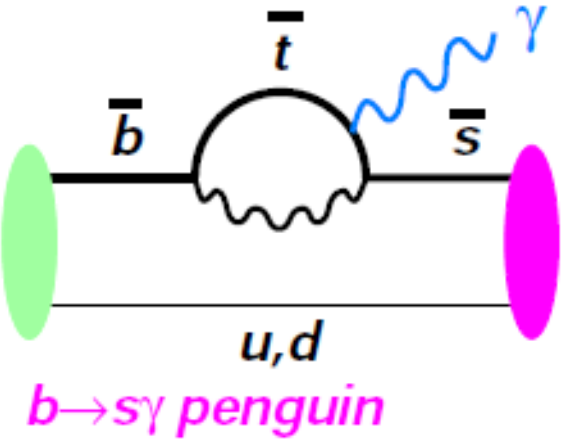
charged ; whole region

Introduction

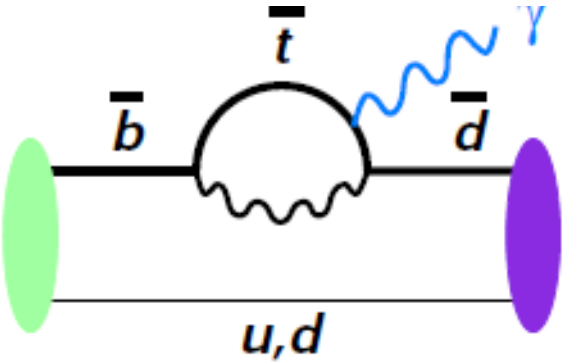
- $b \to s\gamma$ ($d\gamma$) : FCNC (Flavor Changing Neutral Current) process.
- EW penguin diagram (loop diagram) is dominant: Sensitive to New Physics.
- Photon is almost polarized in the SM.
- $b \to d\gamma$ is suppressed by $|V_{td}/V_{ts}|^2$ compared to $b \to s\gamma$; Annihilation diagram exists for B^-.

Many exclusive measurements:

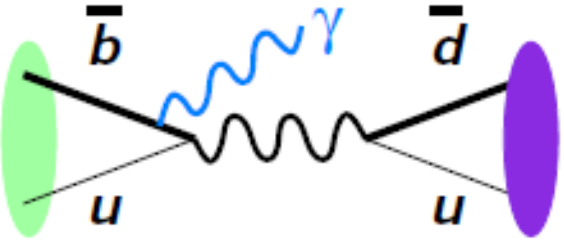
- Branching fraction measurement.
- Isospin symmetry ($K^{*0}\gamma$ v.s. $K^{*+}\gamma$)
- Charge asymmetry (DCPV).
- tCPV (photon polarization).
- Exclusive $b \to d\gamma$ process for $|V_{td}/V_{ts}|$ measurement



$b \to s\gamma$ penguin



$b \to d\gamma$ penguin



$b \to d\gamma$ annihilation

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

- Exclusive modes of $b \to d\gamma$; B.F. ~ 10^{-6}.
- First observation by Belle in 2005; confirmed by BaBar.
- Constraint for $|V_{td}/V_{ts}|^2$ from the branching ratio to $B \to K^*\gamma$.
- Direct CP Violation ~10% in the SM.
- Isospin relation:

$$\mathcal{B}(B \to (\rho,\omega)\gamma) = \mathcal{B}(B^- \to \rho^-\gamma) = 2\frac{\tau_{B^+}}{\tau_{B^0}}\mathcal{B}(\overline{B}^0 \to \rho^0\gamma) = 2\frac{\tau_{B^+}}{\tau_{B^0}}\mathcal{B}(\overline{B}^0 \to \omega\gamma)$$

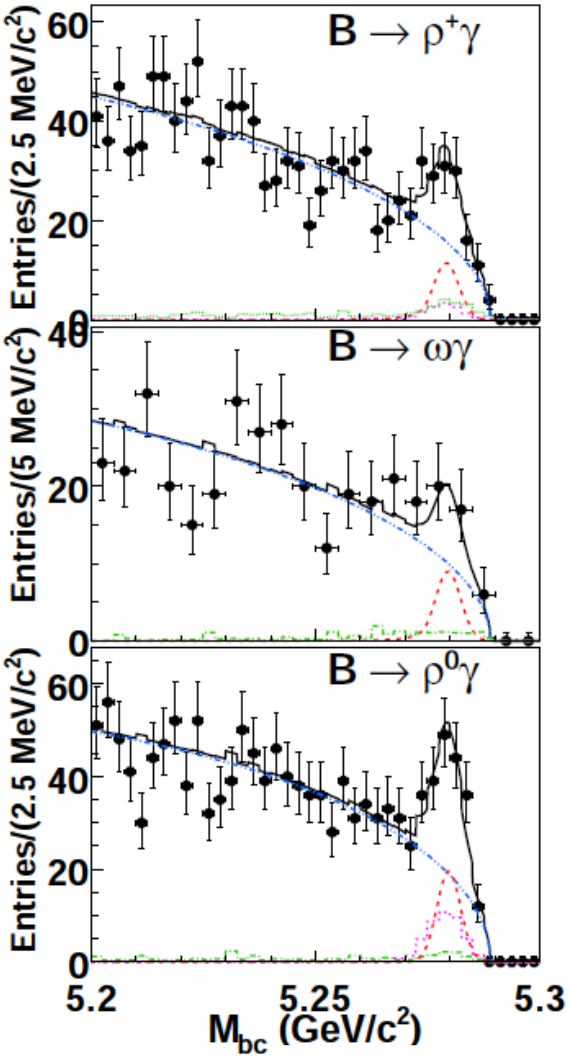
Prediction ($\times 10^{-6}$)

	[hep-ph/0610149] Ali & Parkhomenko	[NPB621, 459 (2002)] Bosch & Buchalla	[PRD75, 054004(2007)] Ball & Jones & Zwicky
$B^+ \to \rho^+\gamma$	1.37 ± 0.28	$1.58\ ^{+0.53}_{-0.46}$	1.16 ± 0.26
$B^0 \to \rho^0\gamma$	0.65 ± 0.12		0.55 ± 0.13
$B^0 \to \omega\gamma$	0.53 ± 0.12		0.44 ± 0.10

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

657 M $B\bar{B}$ [arXiv:0804.4770v1 [hep-ex]]

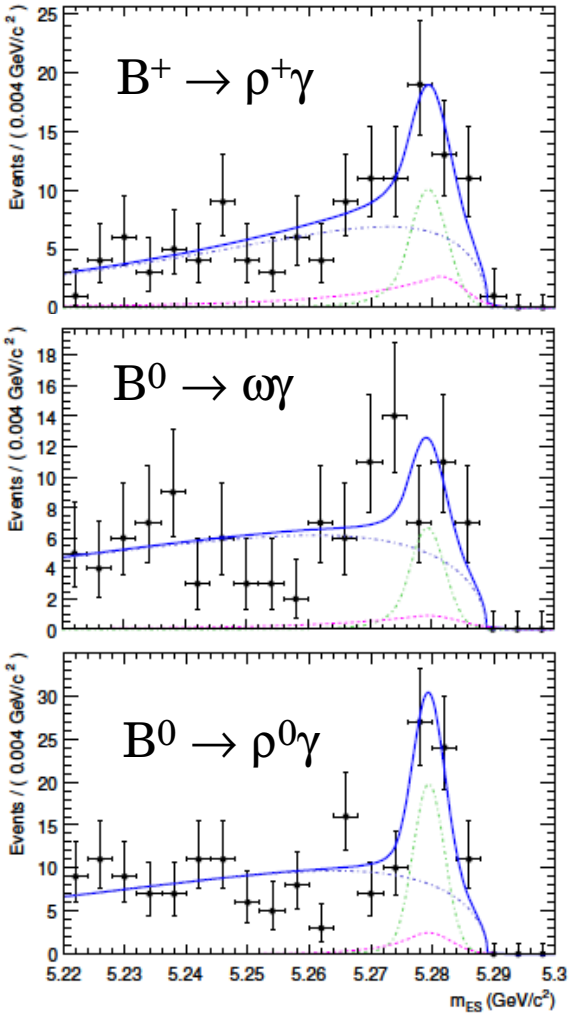
465 M $B\bar{B}$ [arXiv:0808.1379v1 [hep-ex]]



(3.3σ)

(2.6σ)

(5.6σ)



(3.2σ)

(2.2σ)

(5.4σ)

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

B.F. ($\times 10^{-6}$)	BELLE		BABAR	
$B^+ \to \rho^+\gamma$	$0.87\ ^{+0.29}_{-0.27}\ ^{+0.09}_{-0.11}$	(3.3σ)	$1.20^{+0.42}_{-0.37} \pm 0.20$	(3.2σ)
$B^0 \to \rho^0\gamma$	$0.78\ ^{+0.17}_{-0.16}\ ^{+0.09}_{-0.10}$	(5.6σ)	$0.97^{+0.24}_{-0.22} \pm 0.06$	(5.4σ)
$B^0 \to \omega\gamma$	$0.40\ ^{+0.19}_{-0.17} \pm 0.13$	(2.6σ)	$0.50^{+0.27}_{-0.23} \pm 0.09$	(2.2σ)
$B \to \rho\gamma$	$1.21\ ^{+0.24}_{-0.22} \pm 0.12$	(5.8σ)	$1.73^{+0.34}_{-0.32} \pm 0.17$	(6.0σ)
$B \to (\rho,\omega)\gamma$	$1.14 \pm 0.20\ ^{+0.10}_{-0.02}$	(6.2σ)	$1.63^{+0.30}_{-0.28} \pm 0.16$	(6.5σ)

Isospin symmetry breaking

$$\Delta_\rho = \frac{\Gamma(B^+ \to \rho^+\gamma)}{2\Gamma(B^0 \to \rho^0\gamma)} - 1 = -0.43^{+0.25}_{-0.22} \pm 0.10.$$

$\Delta_\rho = -A_I/(1+A_I)$

$$A_I(B \to \rho\gamma) = 2\frac{\tau_{B^+}}{\tau_{B^0}}\mathcal{B}(B^0 \to \rho^0\gamma)/\mathcal{B}(B^+ \to \rho^+\gamma) - 1 = 0.92\ ^{+0.76\ +0.30}_{-0.71\ -0.35}$$

CP asymmetry $A_{CP}(B^+ \to \rho^+\gamma) = -0.11 \pm 0.32(stat) \pm 0.09(sys)$

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

Can determine $|V_{td}/V_{ts}|$ from the ratio to $B \to K^*\gamma$ B.F.

$$\frac{\mathcal{B}(B \to (\rho,\omega)\gamma)}{\mathcal{B}(B \to K^*\gamma)} = |V_{td}/V_{ts}|^2 \frac{(1 - m^2_{(\rho,\omega)}/m^2_B)^3}{(1 - m^2_{K^*}/m^2_B)^3} \zeta^2 [1 + \Delta R]$$

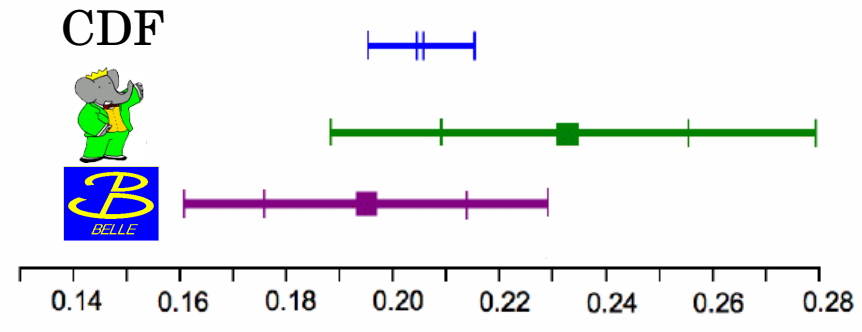
$\zeta = 0.85 \pm 0.10$ (form factor ratio),
$\Delta R = 0.1 \pm 0.1$ ($SU(3)$ breaking correction)

$|V_{td}/V_{ts}| = 0.195^{+0.020}_{-0.019}$ (exp.) ± 0.015(theo.)

$|V_{td}/V_{ts}| = 0.233^{+0.025}_{-0.024}$ (exp.) $^{+0.022}_{-0.021}$ (theo.)

(from the $B \to (\rho,\omega)\gamma$ combined result)

Similar result from $B \to \rho\gamma$



CDF B mixing (PRL 97 242003)
|Vtd/Vts| = 0.206 ±0.001 ±0.008

BaBar exclusive
|Vtd/Vts| = 0.233 ±0.025 ±0.022

Belle exclusive (arXiv:804.4770)
|Vtd/Vts| = 0.195 ±0.020 ±0.015

(first error experiment, second theory)