



# Radiative B Meson Decays at Belle

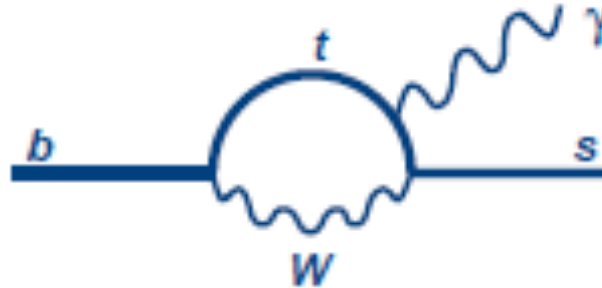
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for the Belle Collaboration

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- ⊙  $B \rightarrow K_S \rho^0 \gamma$
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- ⊙ Summary

# $b \rightarrow s \gamma$ Process

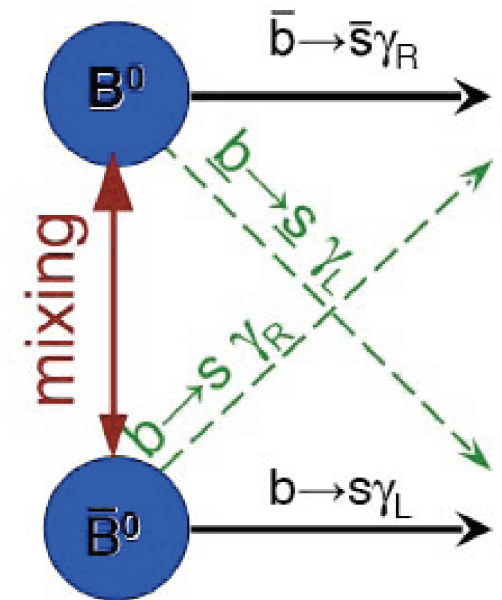


- Flavor changing neutral current (FCNC) processes.
- Forbidden at tree-level in SM  
==> allowed through penguin diagrams.
- Sensitive to non-SM particles mediating the loop  
==> can affect BF and CP violation measurements.

# Search for right-handed currents

D. Atwood, M.Gronau, A.Soni,  
PRL79, 185 (1997)

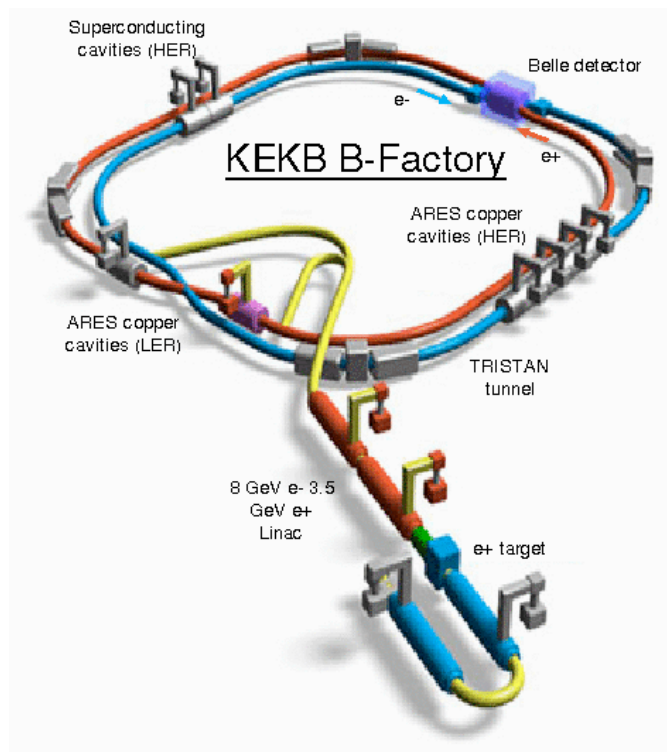
D.Atwood, T.Gerson, M.Hazumi, A.Soni,  
PRD71, 076003(2005)



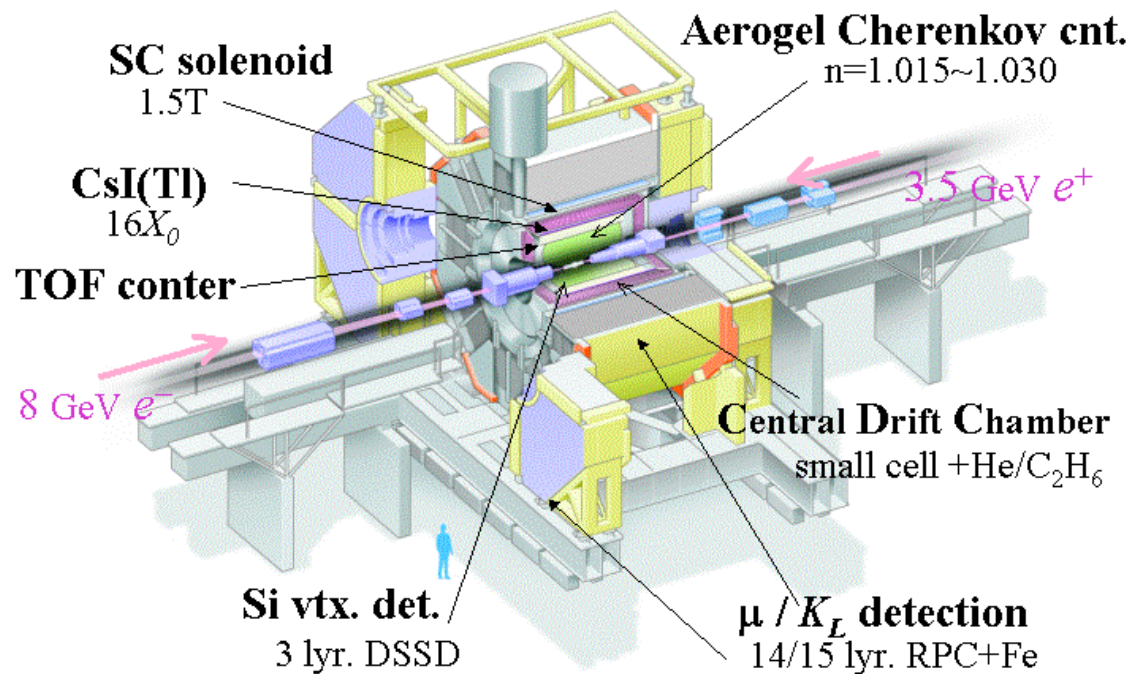
- In SM, the photon from  $b \rightarrow s \gamma$  transition is flavor-specific.
- The CP asymmetry is suppressed by the quark mass ratio ( $2m_s/m_b$ ).
- Sensitive to right-handed non-SM currents.
- Photon polarization measurement via time-dependent CP violation measurement.

# KEKB/Belle

- Asymmetric energy  $e^+$  (3.5 GeV)  $e^-$  (8.0 GeV) collider
- Located at KEK, Tsukuba, Japan



## Belle Detector



- Peak Luminosity :  $2.1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
- Integrated Luminosity :  $\sim 950 \text{ fb}^{-1}$

world record!



# TCPV in $B \rightarrow K_S \pi^0 \gamma$

535 M  $B\bar{B}$   
PRD 74, 1111(R) (2006)

Reconstruction is in  $B \rightarrow K^* (\rightarrow K_S \pi^0) \gamma$  [0.8 < M(K\_S  $\pi^0$ ) < 1.0 GeV]

and also in full range of M(K\_S  $\pi^0$ ) :

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

Reconstructed variables:

Energy difference :  $\Delta E \equiv E_B^{\text{c.m.s.}} - E_{\text{beam}}^{\text{c.m.s.}}$

Beam-energy constrained mass :

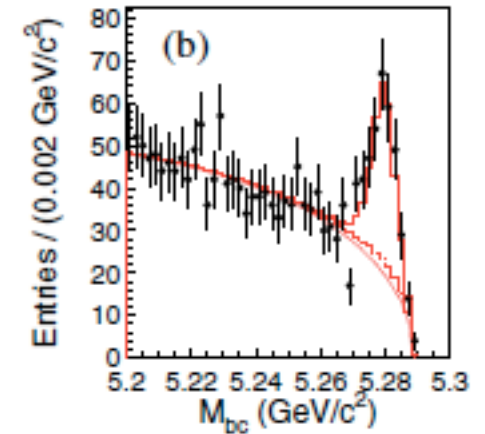
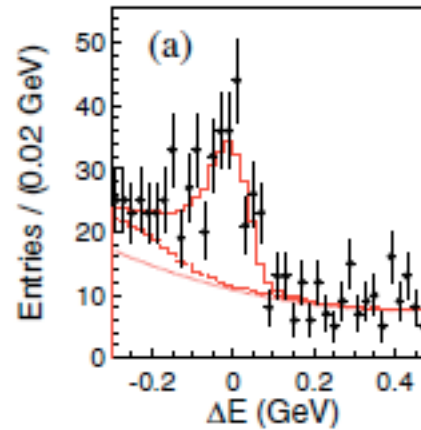
$$M_{bc} \equiv \sqrt{(E_{\text{beam}}^{\text{c.m.s.}})^2 - (p_B^{\text{c.m.s.}})^2}$$

Signal extraction :  $\Delta E$ - $M_{bc}$  2D fit

Signal region :

$$-0.2 \text{ GeV} < \Delta E < 0.1 \text{ GeV}$$

$$5.27 \text{ GeV}/c^2 < M_{bc} < 5.29 \text{ GeV}/c^2$$



..... qq BG

TCPV to the events in the signal-box

406 events in the signal-box



# TCPV in $B \rightarrow K_S \pi^0 \gamma$

535 M  $B\bar{B}$   
PRD 74, 1111(R) (2006)

==> Vertex is from  $K_S \rightarrow \pi^+ \pi^-$  (both pions are required to have enough hits in the silicon)

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

==> measurement for  $K_S \pi^0 \gamma$  :

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

$$\mathcal{S}_{K_S \pi^0 \gamma} = -0.10 \pm 0.31 \pm 0.07$$

$$\mathcal{A}_{K_S \pi^0 \gamma} = -0.20 \pm 0.20 \pm 0.06$$

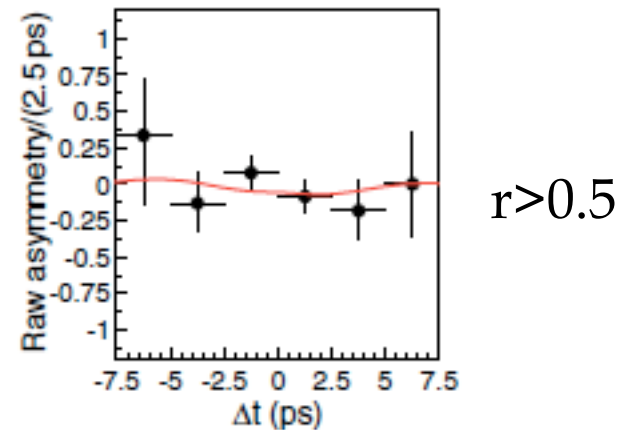
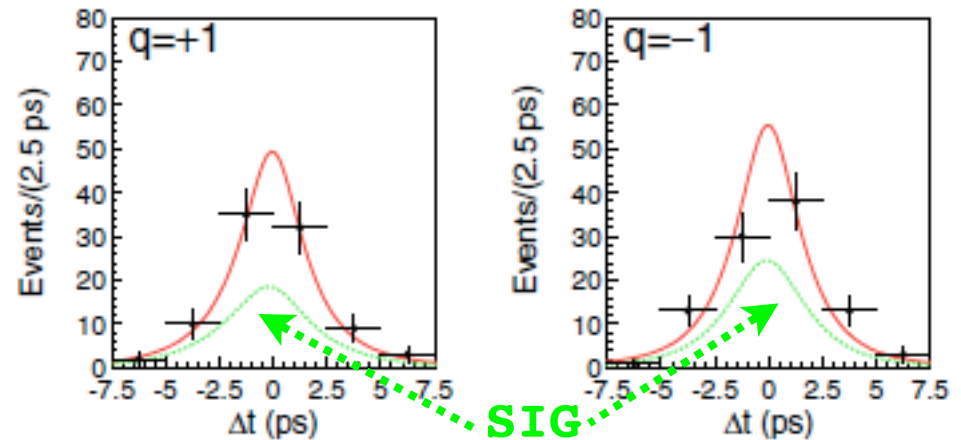
and also for  $B \rightarrow K^* (\rightarrow K_S \pi^0) \gamma$  :

$$[0.8 < M(K_S \pi^0) < 1.0 \text{ GeV}]$$

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

$$\mathcal{A}_{K^* \gamma} = -0.20 \pm 0.24 \pm 0.05$$

==> consistent with the SM expectation.





# TCPV in $B \rightarrow K_S \rho^0 \gamma$

657 M  $B\bar{B}$   
PRL 101, 251601 (2008)

=> Vertex is from  $\rho^0 \rightarrow \pi^+ \pi^-$  (no  $K_S$  vertex is needed)

$B \rightarrow K_S \rho^0 \gamma$  candidates are selected from  $K_S \pi^+ \pi^- \gamma$  sample :

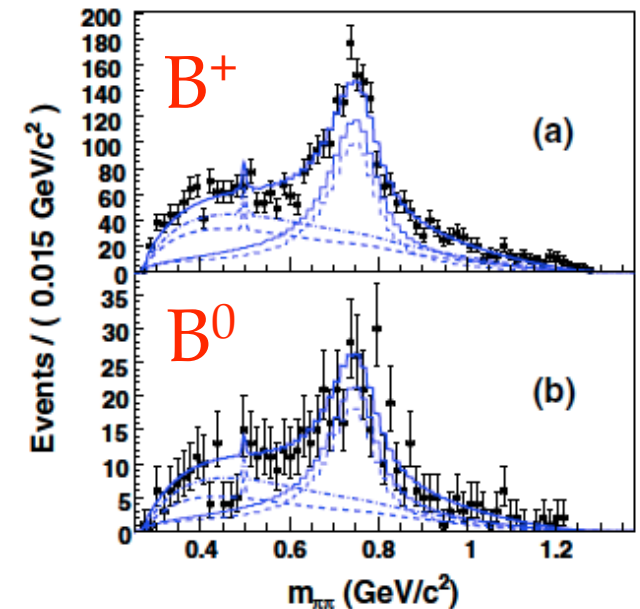
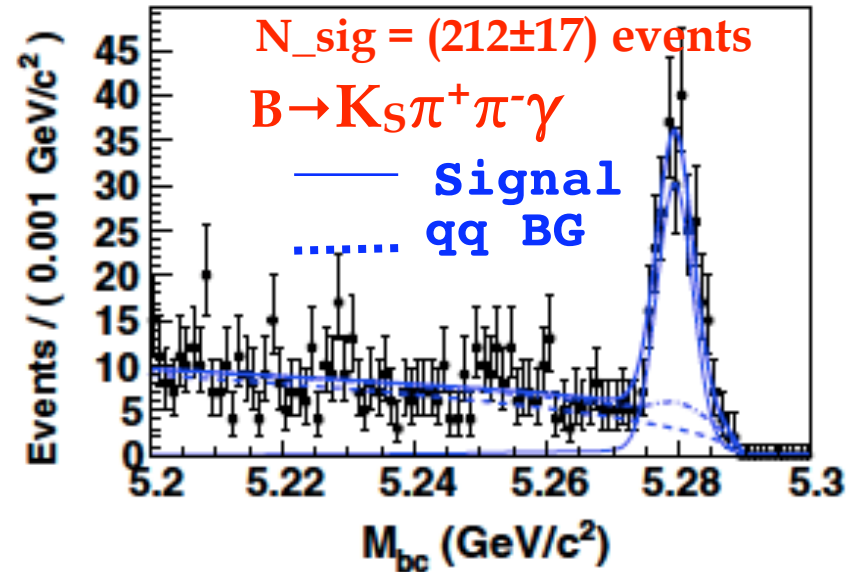
$M(\pi^+ \pi^-)$  invariant mass is required to be consistent with a  $\rho^0$  meson.

$$0.6 < M(\pi^+ \pi^-) < 0.9 \text{ GeV}/c^2$$

contributions from other modes :  $B \rightarrow K^{*+} \pi^- \gamma$

Signal Extraction : using  $M_{bc}$  distribution  
 $-0.1 < \Delta E < 0.08 \text{ GeV}$

Effective CP violation parameters are measured and corrected for the dilution.







# TCPV in $B \rightarrow K_S \rho^0 \gamma$

657 M  $B\bar{B}$   
PRL 101, 251601 (2008)

**Effective** CP violation parameters in the  $\rho^0$  region :  
for  $M(K_S \pi^+ \pi^-) < 1.8$  GeV and  $0.6 < M(\pi^+ \pi^-) < 0.9$  GeV/ $c^2$

$N_{\text{sig}} = (212 \pm 17)$  events

$$\mathcal{S}_{\text{eff}} = 0.09 \pm 0.27^{+0.04}_{-0.07}$$

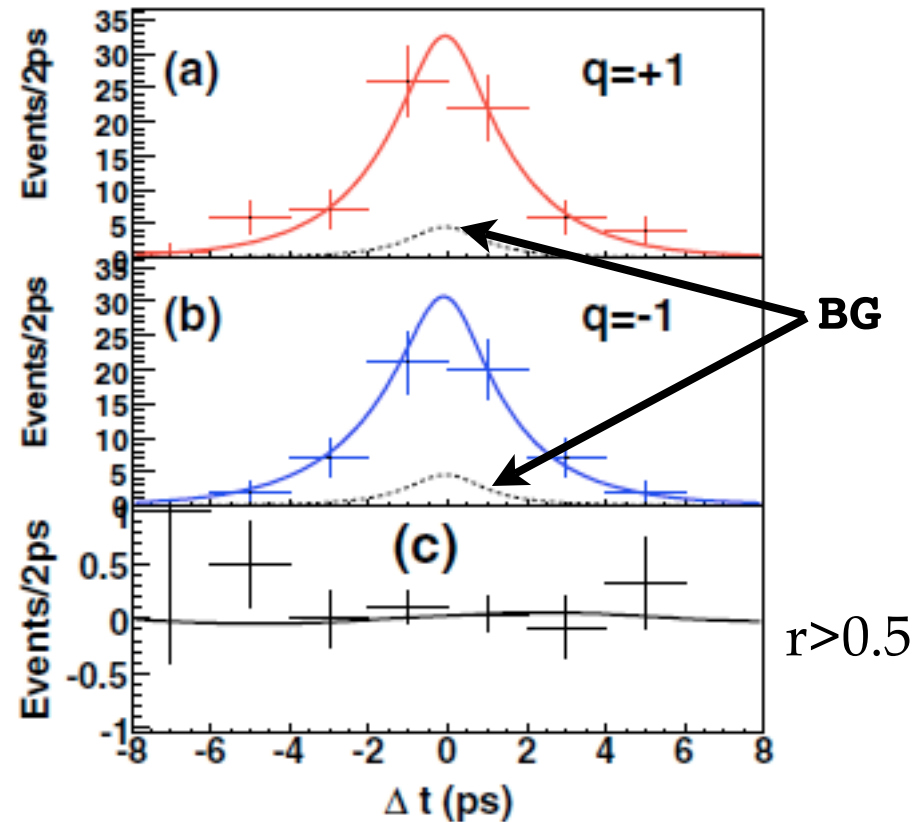
$$\mathcal{A}_{\text{eff}} = 0.05 \pm 0.18 \pm 0.06$$

dilution due to  $\mathcal{B}(B \rightarrow K^{*+} \pi^- \gamma)$  (not self-conjugate)

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

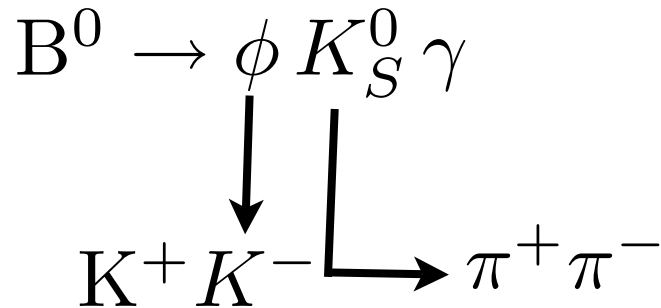
$$\mathcal{S}_{K_S \rho^0 \gamma} = 0.11 \pm 0.33(\text{stat})^{+0.05}_{-0.09}(\text{syst})$$

**==> consistent with the SM expectation.**





$$B \rightarrow \phi K \gamma$$

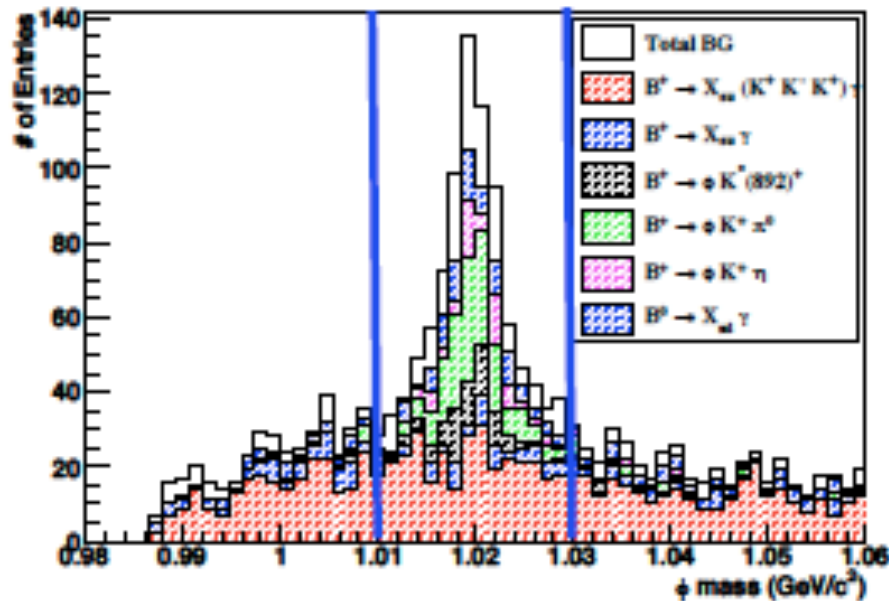


Previous measurement by  
Belle with 96 M BB PRL92, 051801 (2004)  
Observation of  $\phi K^+ \gamma$   
UL on  $\phi K_S \gamma$

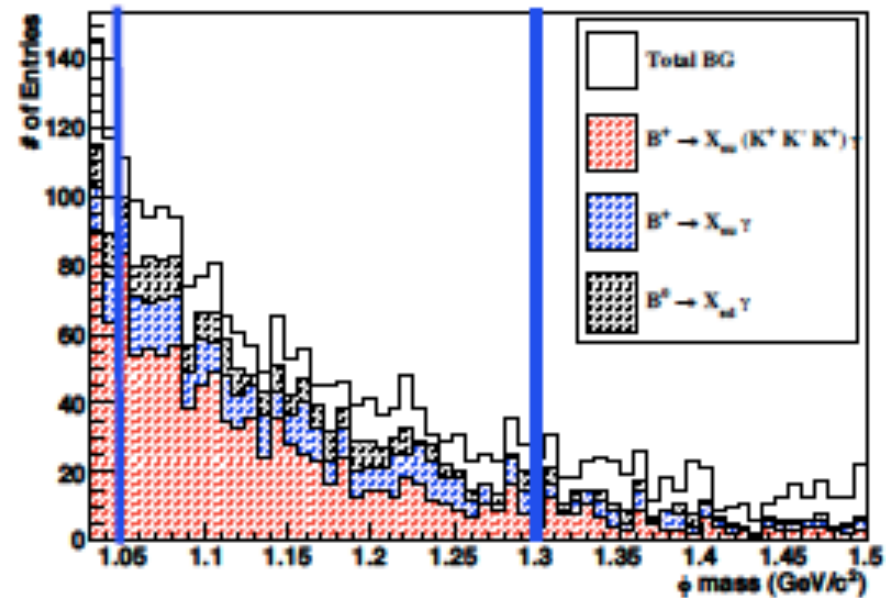
=> Vertex is from  $\phi \rightarrow K^+ K^-$  (no  $K_S$  vertex is needed)

- Signal extraction :  $\Delta E$ - $M_{bc}$  2D fit (unbinned extended maximum likelihood).
- $b \rightarrow c$  backgrounds are removed by  $D^0$  veto (neutral mode) ( $1.842 < M(\phi K_S) < 1.878$  GeV)
- Non-resonant  $K^+ K^- K \gamma$  is subtracted using  $\phi$  mass sideband.

# $\phi$ mass sideband

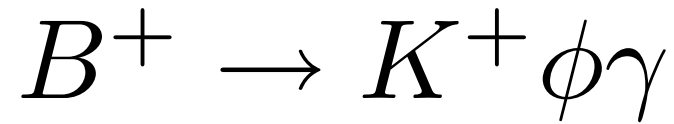


**signal region :** [1.01-1.03]



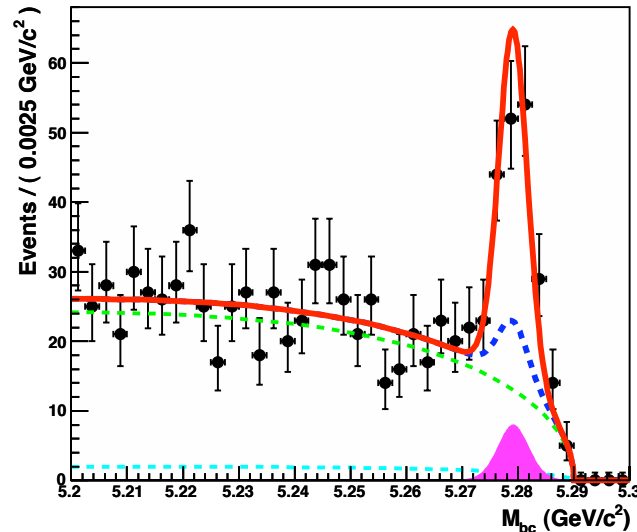
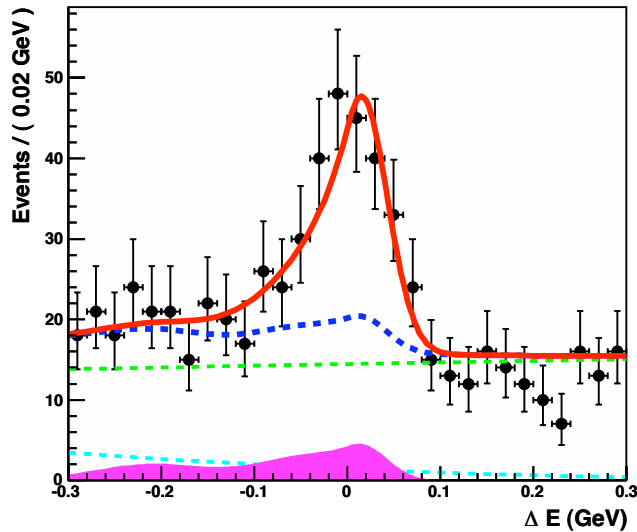
**sideband :** [1.05-1.3]

- The non-resonant  $K^+K^-K\gamma$  peaks in both  $\Delta E$  and  $M_{bc}$  signal region, but flat in  $\phi$  mass.
- This component is estimated to be 13% using  $\phi$  sideband in data [1.05-1.3 GeV].
- and subtracted from the  $\phi K\gamma$  signal.



772 M  $B\bar{B}$

Preliminary!

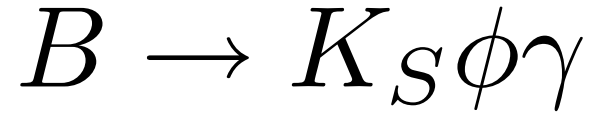


136±17 Events

- Signal
- qq BG
- b→c BG
- non-res+ charmless BG

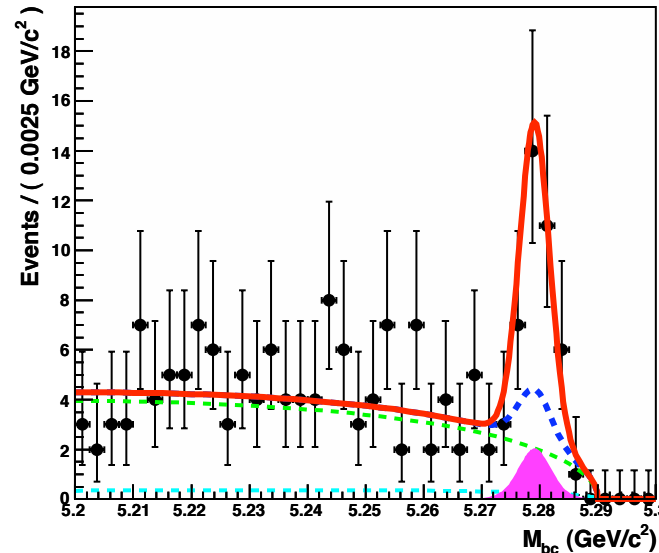
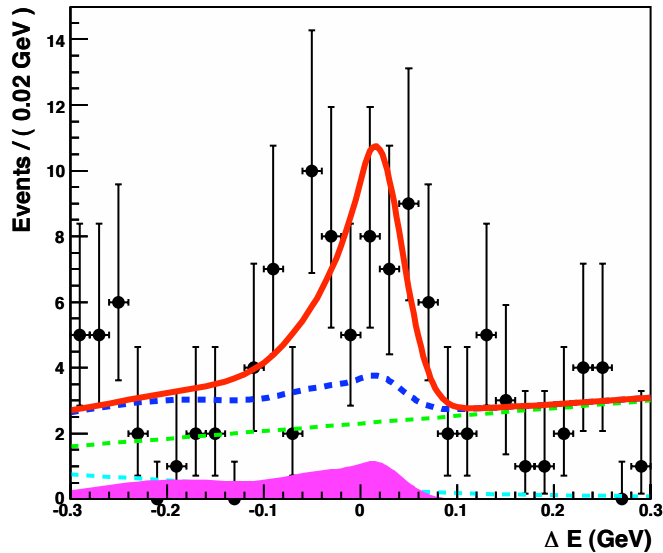
Significance :  $10.5\sigma$  (statistical only)

$$\mathcal{B}(B^+ \rightarrow \phi K^+ \gamma) = (2.34 \pm 0.29 \pm 0.23) \times 10^{-6}$$



772 M  $B\bar{B}$

**Preliminary!**



$35 \pm 8$  Events

Significance :  $5.8\sigma$  (statistical only)

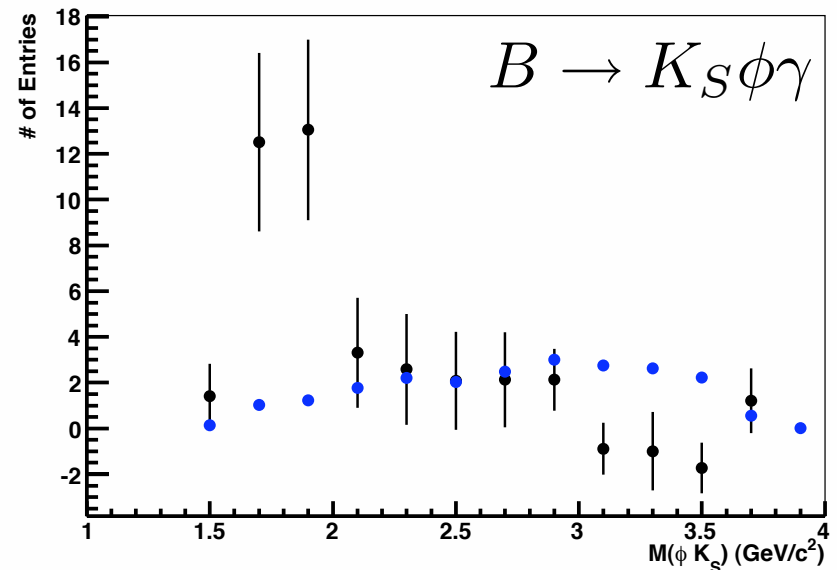
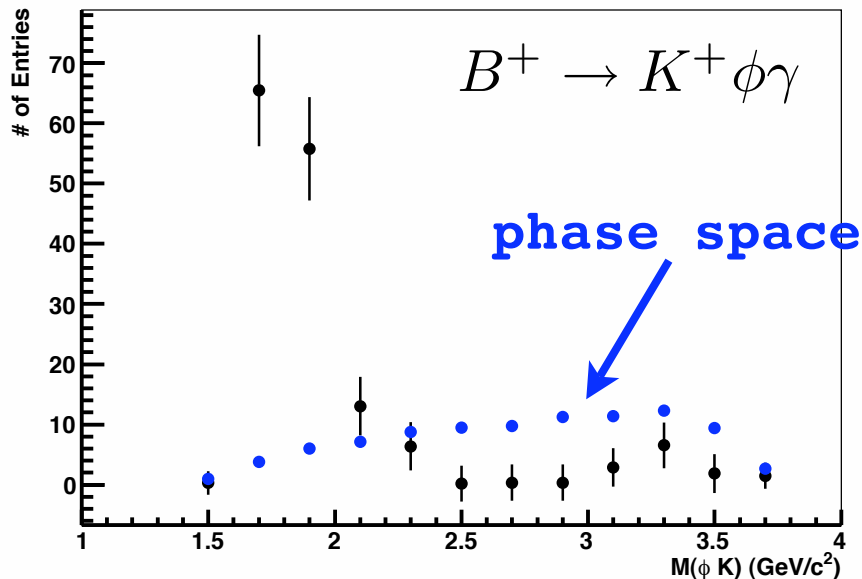
$$\mathcal{B}(B^0 \rightarrow \phi K^0 \gamma) = (2.66 \pm 0.60 \pm 0.32) \times 10^{-6}$$

The neutral mode will be used for time dependent CPV study.

# M(Xs) mass distribution

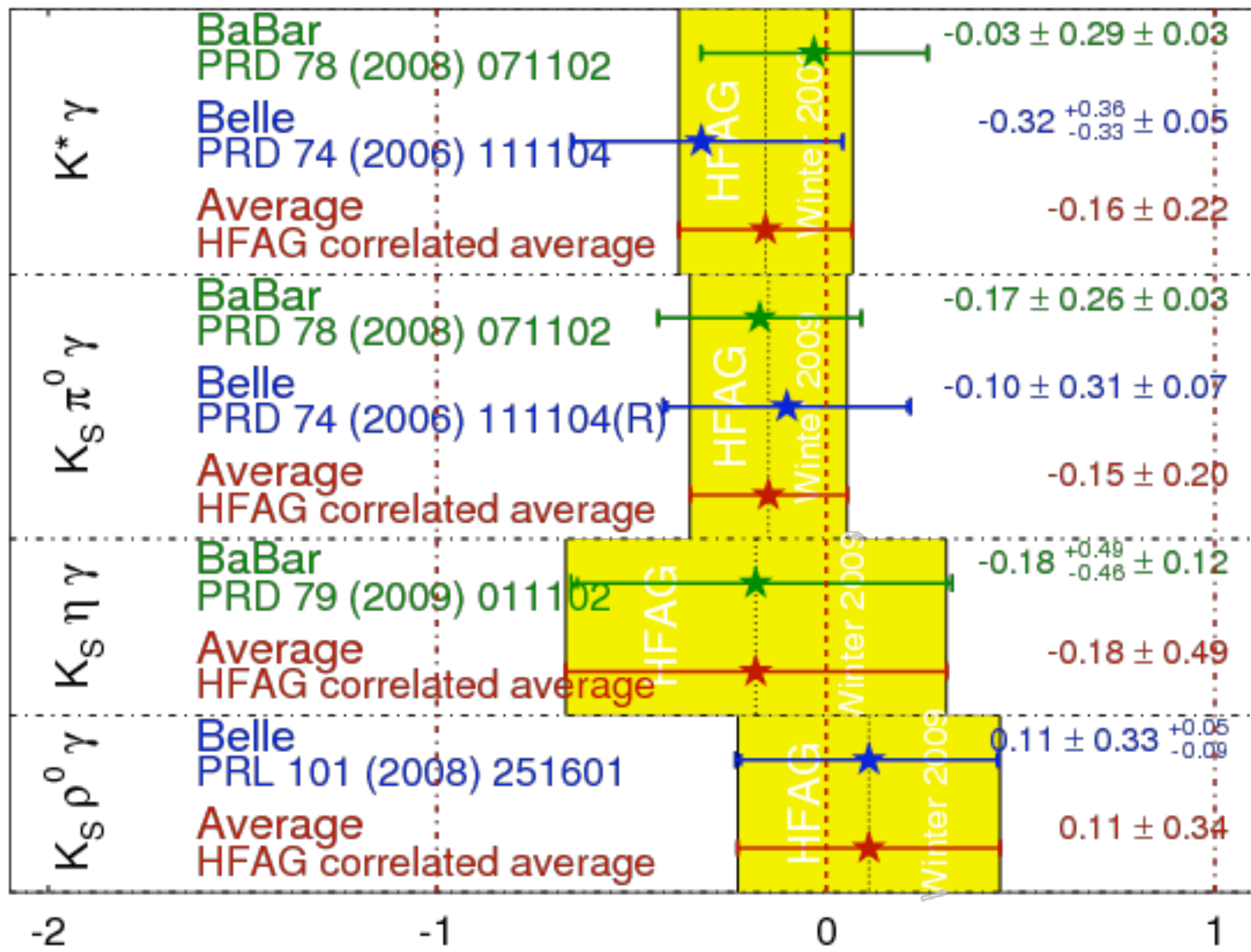
**Belle 772M BB  
Preliminary!**

- Background subtracted M(Xs) mass distribution.
- Each yield is from fit in bins of  $\phi K$  mass.
- The observed spectrum differs significantly from a three-body phase space.
- Re-weighted efficiency is used for branching fraction measurement.



# $b \rightarrow s \gamma S_{CP}$

**HFAG**  
Winter 2009  
PRELIMINARY



opposite CP

# Summary

- We observed the  $\varphi K^+ \gamma$  signal with  $10.5\sigma$  and  $\varphi K_S \gamma$  signal with  $5.8\sigma$ .
- The  $\varphi K_S \gamma$  mode will be used for mixing-induced CP violation study.
- The observed  $M(X_S)$  distribution significantly differs from a three body phase-space decay.
- Time-dependent CP asymmetry in  $B \rightarrow K_S \pi^0 \gamma$ ,  $B \rightarrow K_S \rho^0 \gamma$ .
- Results are consistent with SM expectation. No evidence of new physics from right handed currents with the current statistics.

**More luminosity is needed to test any NP scenario.**



# $b \rightarrow s \gamma$ $C_{CP}$

**HFAG**  
Winter 2009  
PRELIMINARY

