

# Radiative $B$ Meson Decay

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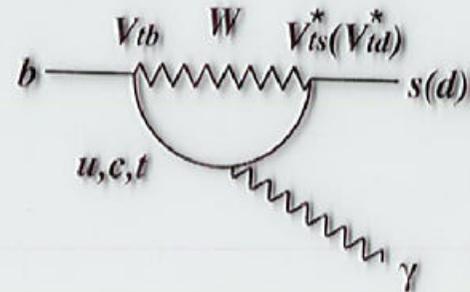
Kyoto University

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BCP4

## Interest in Radiative $B$ Decay

FCNC is forbidden at tree level in SM. Lowest order diagram is EW penguin.

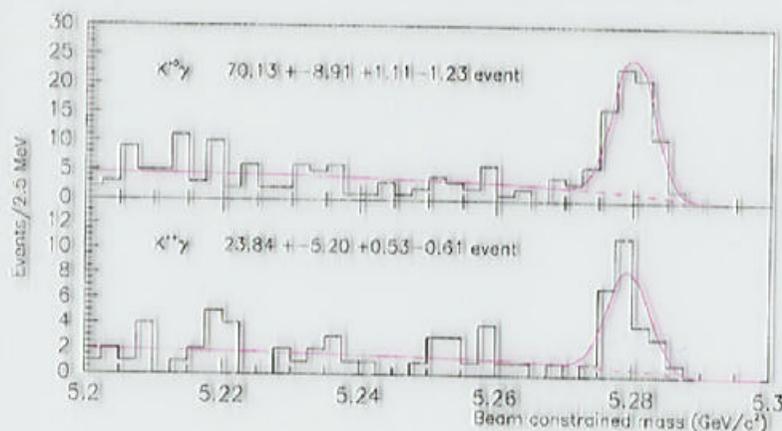


- Good probe for non-SM physics
  - IF non-SM contribution ( charged Higgs, SUSY, ... ) to the loop
    - Branching Fraction may deviate from SM prediction.
    - CP Asymmetry ( very small in SM ) may appear.

$B \rightarrow K^*(892)\gamma$

$\mathcal{B}(B \rightarrow K^*(892)\gamma)$

- 11M  $B\bar{B}$  events
- Exclusive reconstruction  
 $K^\pm\pi^\pm, K_S^0\pi^0, K_S^0\pi^\pm, K^\pm\pi^0$   
 $|M_{K\pi} - M_{K^*(892)}| < 75 \text{ MeV}/c^2$
- Likelihood Ratio cut



Signal Yield

$$K^{*0}(892)\gamma \quad 70.1 \pm 9.0 \begin{matrix} +1.1 \\ -1.2 \end{matrix}$$
$$K^{*+}(892)\gamma \quad 23.8 \pm 5.2 \begin{matrix} +0.5 \\ -0.6 \end{matrix}$$

Branching Fraction

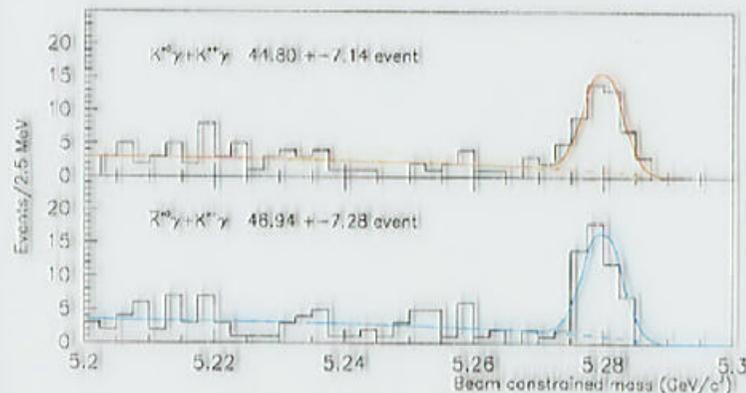
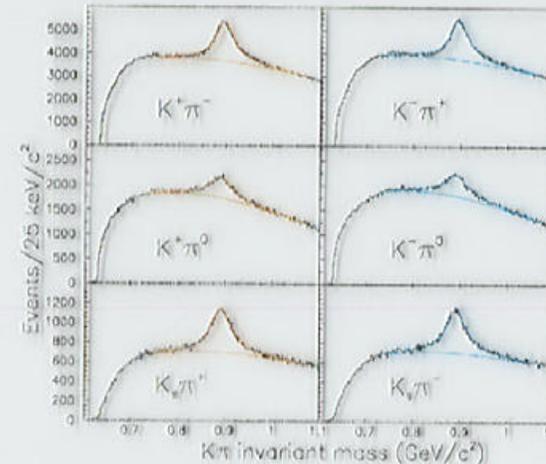
$$\mathcal{B}(K^{*0}\gamma) = (49.6 \pm 6.7 \pm 4.5) \times 10^{-6}$$
$$\mathcal{B}(K^{*+}\gamma) = (38.9 \pm 9.3 \pm 4.1) \times 10^{-6}$$

$B \rightarrow K^*(892)\gamma$

$A_{CP}$

$$A_{CP} = \frac{1}{1 - 2\eta} \cdot \frac{\mathcal{N}(\bar{K}^{*0}\gamma + K^{*-}\gamma) - \mathcal{N}(K^{*0}\gamma + K^{*+}\gamma)}{\mathcal{N}(\bar{K}^{*0}\gamma + K^{*-}\gamma) + \mathcal{N}(K^{*0}\gamma + K^{*+}\gamma)}$$

- $A_{CP}$  is very small in SM ( $< 1\%$ )
- Self-tagging modes ( $K_S^0\pi^0\gamma$  is excluded)
- Small wrong tag fraction  $\eta = 1.2\%$
- Null asymmetry in reconstruction : checked with inclusive  $K^*(892)$ .  $A = 0.003 \pm 0.011$



Yield

$$\mathcal{N}(K^{*0}\gamma + K^{*+}\gamma) = 44.8 \pm 7.1$$

$$\mathcal{N}(\bar{K}^{*0}\gamma + K^{*-}\gamma) = 46.9 \pm 7.3$$

Result

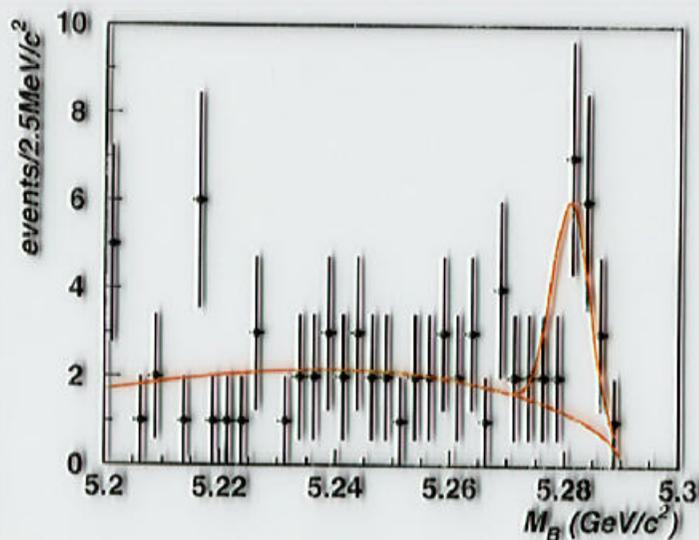
$$A_{CP} = +0.02 \pm 0.11 \pm 0.01$$

Preliminary

$B \rightarrow K_2^*(1430)\gamma$

$\mathcal{B}(B \rightarrow K_2^*(1430)\gamma)$

- 11M  $B\bar{B}$  events
- Exclusive reconstruction  
 $K^\pm\pi^\pm, K_S^0\pi^0, K_S^0\pi^\pm, K^\pm\pi^0$   
 $||M_{K\pi} - M_{K_2^*(1430)}|| < 100 \text{ MeV}/c^2$



Signal Yield

$$15.6 \pm 4.6 \begin{matrix} +0.6 \\ -0.7 \end{matrix} \text{ events}$$

Assuming all are  $K_2^*(1430)\gamma$ , Branching Fraction

$$\mathcal{B}("K_2^*(1430)"\gamma) = (18.9 \pm 5.6 \pm 1.8) \times 10^{-6}$$

Preliminary

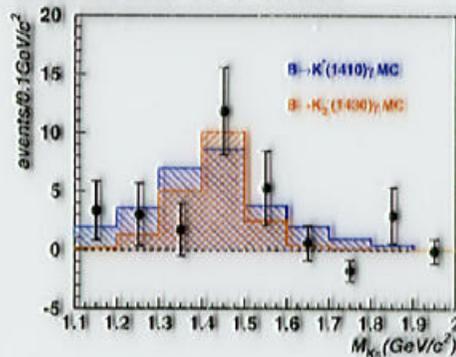
$B \rightarrow K_2^*(1430)\gamma$

$K_2^*(1430)$  vs.  $K^*(1410)$

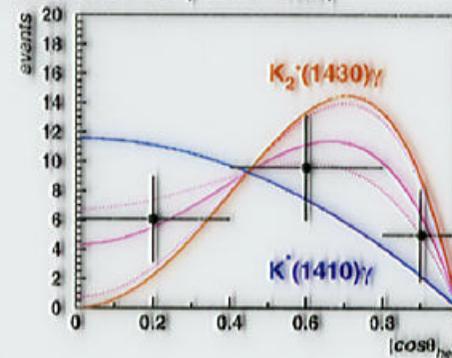
- $K^*(1410)$ : Spin 1, wider mass width, smaller branching fraction to  $K\pi$  final state
- NR cannot be ruled out (not very large)

|               | $J$ | $\Gamma$       | $\mathcal{B}(K\pi)$ |
|---------------|-----|----------------|---------------------|
| $K_2^*(1430)$ | 2   | $\sim 100$ MeV | $\sim 50\%$         |
| $K^*(1410)$   | 1   | $\sim 230$ MeV | $\sim 7\%$          |

Extracted  $K\pi$  mass



Extracted  $|\cos \theta_{hel}|$



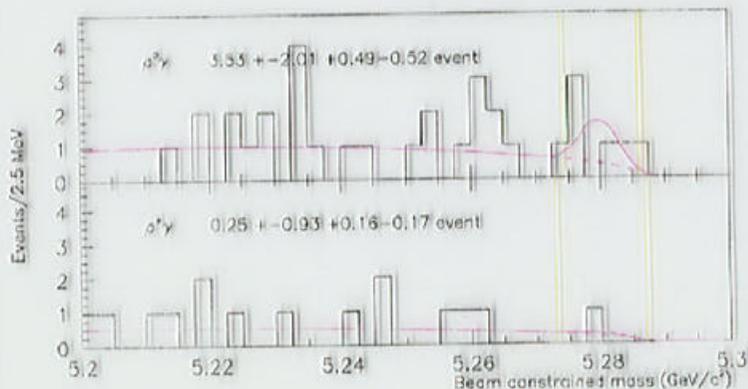
Yield Fraction – helicity fit result

$$\mathcal{N}(K_2^*(1430)\gamma)/\mathcal{N} : (63 \pm 31)\% \quad (\text{stat. only})$$

Not disentangled yet.

## Search for $B \rightarrow \rho\gamma$

- 11M  $B\bar{B}$  events
- $|M_{\pi\pi} - M_{\rho}| < 150 \text{ MeV}/c^2$
- $K^*(892)$  veto :  $|M_{K\pi} - M_{K^*(892)}| > 50 \text{ MeV}/c^2$
- $K^*(892)\gamma$  BKG is very small  
0.4 (0.02) event for  $\rho^0\gamma$  ( $\rho^+\gamma$ )



### Yield

|                | candidate | excess        |
|----------------|-----------|---------------|
| $\rho^0\gamma$ | 6         | $3.5 \pm 2.1$ |
| $\rho^+\gamma$ | 1         | $0.3 \pm 0.9$ |

### Upper Limits

$$\mathcal{B}(B \rightarrow \rho^0\gamma) < 10.6 \times 10^{-6} \quad @90\%CL$$

$$\mathcal{B}(B \rightarrow \rho^+\gamma) < 9.9 \times 10^{-6} \quad @90\%CL$$

$$\frac{\mathcal{B}(B \rightarrow \rho\gamma)}{\mathcal{B}(B \rightarrow K^*(892)\gamma)} < 0.19 \quad @90\%CL$$

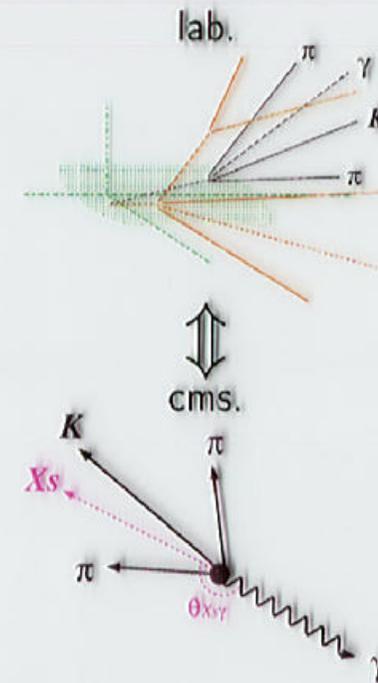
Preliminary

$B \rightarrow X_s \gamma$

## Semi-inclusive approach

- Exclusive  $\mathcal{B}$  : easy to measure, difficult to predict  
Inclusive  $\mathcal{B}$  : difficult to measure, easy to predict
- SM prediction (QCD-NLO)  
 $\mathcal{B}(B \rightarrow X_s \gamma) = (3.29 \pm 0.33) \times 10^{-4}$

- A kaon ( $K^\pm$  or  $K_S^0 \rightarrow \pi^+ \pi^-$ ) + 1 ~ 4 pions ( upto 1  $\pi^0$  allowed ) to form an  $X_s$
- an  $X_s$  + the hardest  $\gamma$  to form  $B$
- Form a vertex of  $X_s$  w/ beam profile constraint ( Except for  $K_S^0 \pi^0 \gamma$  mode )
- Choose the candidate w/ best vertex ( Largest  $\theta_{X_s \gamma}$  for  $K_S^0$  and/or  $\pi^0$  ambiguities )



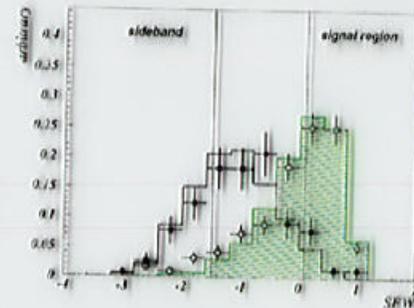
$B \rightarrow X_s \gamma$

## SFW

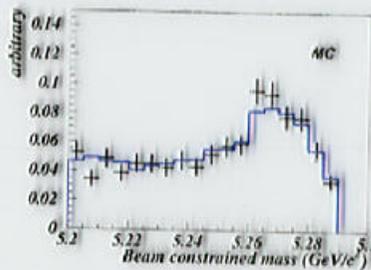
$$SFW = \sum_{l=2,4} \alpha_l R_l^{maj} + \sum_{l=1,2,3,4} \beta_l R_l^{min}$$

$$R_l^{maj} = \frac{\sum_{\gamma,j} |\vec{p}_\gamma| |\vec{p}_j| P_l(\cos \theta_{\gamma j})}{\sum_{\gamma,j} |\vec{p}_\gamma| |\vec{p}_j|}, \quad R_l^{min} = \frac{\sum_{i,j} |\vec{p}_i| |\vec{p}_j| P_l(\cos \theta_{ij})}{\sum_{i,j} |\vec{p}_i| |\vec{p}_j|}$$

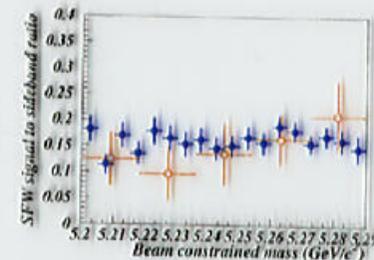
- Fisher Discriminant of Fox-Wolfram moments
- Tailored not to have correlation with kinematic variables ( $M_B$ )
- Good signal-to-background separation power ( $SFW > 0.1$  as signal region)
- SFW sideband ( $SFW < -1.5$ ) provides a large  $q\bar{q}$  BKG sample
- Beam constrained mass distribution for  $q\bar{q}$  BKG can be obtained from SFW sideband



Signal Box  
Sideband

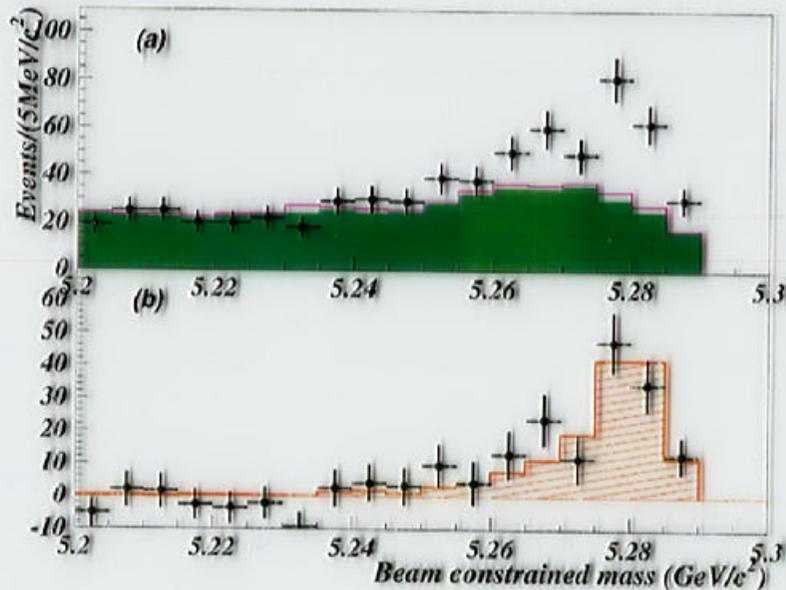


off- $\gamma$   
MC



$B \rightarrow X_s \gamma$

## Signal Yield



(a) Before BKG subtraction

Sideband

$B\bar{B}$  MC

(b) After BKG subtraction

Signal MC

- 6.1M  $B\bar{B}$  events
- $B\bar{B}$  BKG is subtracted by MC
- Fit by SFW sideband data + signal MC

In  $M_B > 5.27 \text{ GeV}/c^2$ ,

$$N^{\text{observed}} = 222$$

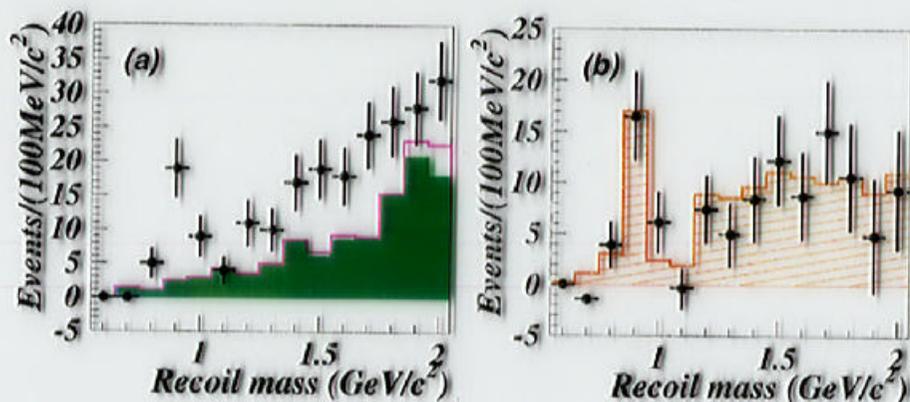
$$r \cdot N^{\text{sideband}} = 106.4 \pm 7.5$$

$$N^{B\bar{B}} = 9.1 \pm 1.8$$

$$\mathcal{N}(X_s \gamma) = 106.5 \pm 16.8 \pm 5.0$$

$B \rightarrow X_s \gamma$

## $M_{X_s}$ , Efficiency and Branching Fraction



- Clear  $K^*(892)$  peak + Continuum  $X_s$
- Model the recoil mass as  $K^*(892)$   
+ Kagan-Neubert [Eur. Phys. J. **C7**, 5 (1999)] w/ input  $m_b = 4.75 \pm 0.1 \text{ GeV}/c^2$

$$\epsilon = (2.58 \pm 0.29_{\text{stat}} \pm 0.42_{\text{syst}} \pm 0.39_{\text{model}}) \%$$

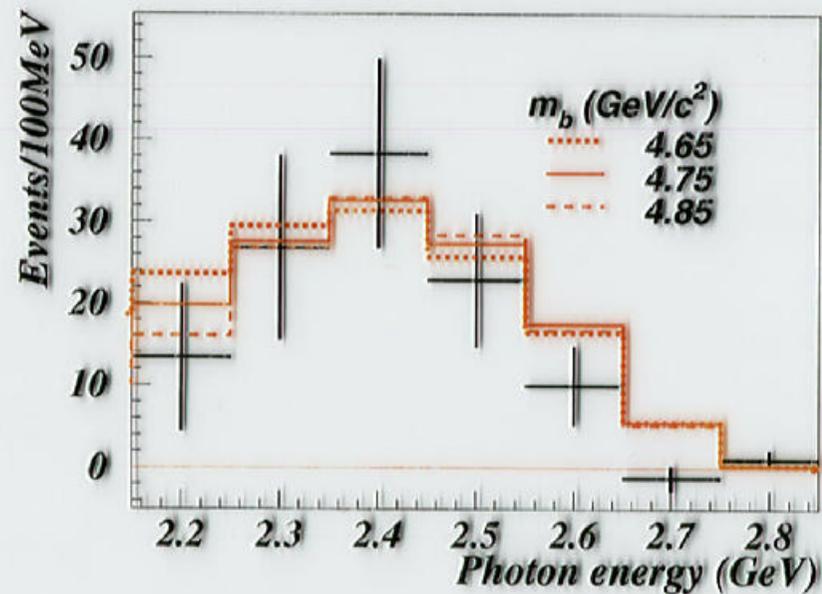
$$B(X_s \gamma) = (3.37 \pm 0.53_{\text{stat}} \pm 0.42_{\text{syst}} \pm 0.50_{\text{model}}) \times 10^{-4}$$

Preliminary

$B \rightarrow X_s \gamma$

## Photon Energy Spectrum

- $M_{X_s} < 2.05 \text{ GeV}/c^2$  cut  $\rightarrow$  Broad cut-off around  $E_\gamma \sim 2.25 \text{ GeV}$  (Correction applied)
- No significant model dependence in higher  $E_\gamma$  region with separate  $K^*(892)$  treatment



## Summary

- Exclusive Measurements for  $b \rightarrow s\gamma$  w/ 11M  $B\bar{B}$  events (Belle preliminary)

$$\mathcal{B}(B^0 \rightarrow K^{*0}(892)\gamma) = (49.6 \pm 6.7 \pm 4.5) \times 10^{-6}$$

$$\mathcal{B}(B^+ \rightarrow K^{*+}(892)\gamma) = (38.9 \pm 9.3 \pm 4.1) \times 10^{-6}$$

$$A_{CP}(B \rightarrow K^*\gamma) = +0.02 \pm 0.11 \pm 0.01$$

$$\mathcal{B}(B \rightarrow "K_2^*(1430)"\gamma) = (18.9 \pm 5.6 \pm 1.8) \times 10^{-6} \text{ w/ assumption}$$

- Upper limits are set for exclusive  $b \rightarrow d\gamma$  modes w/ 11M  $B\bar{B}$  events (Belle preliminary)

$$\mathcal{B}(B^0 \rightarrow \rho^0\gamma) < 10.6 \times 10^{-6} \text{ @90\% CL}$$

$$\mathcal{B}(B^+ \rightarrow \rho^+\gamma) < 9.9 \times 10^{-6} \text{ @90\% CL}$$

$$\mathcal{B}(B \rightarrow \rho\gamma)/\mathcal{B}(B \rightarrow K^*(892)\gamma) < 0.19 \text{ @90\% CL}$$

- $\mathcal{B}(B \rightarrow X_s\gamma)$  measured semi-inclusively w/ partial dataset (6.1M  $B\bar{B}$  events) (Belle preliminary)

$$\mathcal{B}(B \rightarrow X_s\gamma) = (3.37 \pm 0.53 \pm 0.42 \begin{smallmatrix} +0.50 \\ -0.54 \end{smallmatrix}) \times 10^{-4}$$

No longer off-resonance limited

inclusive  $\text{Br}(B \rightarrow X_s\gamma)$  results ( $\times 10^{-4}$ )

