CP violation and related issues

Part 11: FCNC decays

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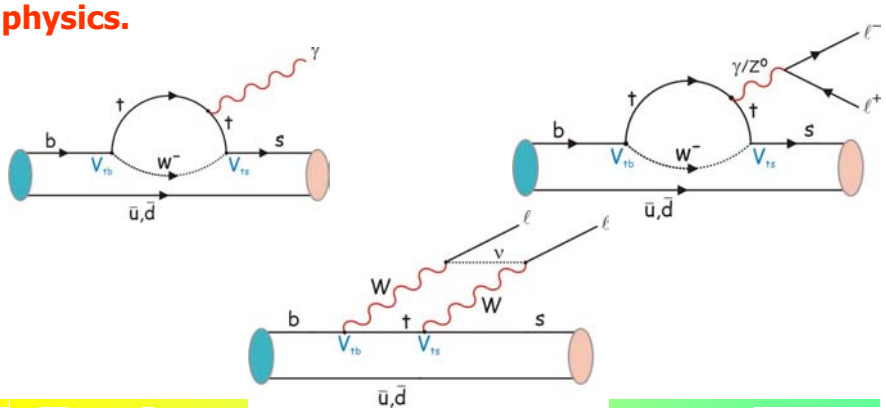
FCNC B decays

Flavour changing neutral current (FCNC) processes (like b→s, b→d) are fobidden at the tree level in the Standard Model. Proceed only at low rate via higher-order loop diagrams. Ideal place to search for new physics.



b → sγ inclusive

b → sγ rate: sensitive to deviations from the SM, world average in good agreement with SM predictions.

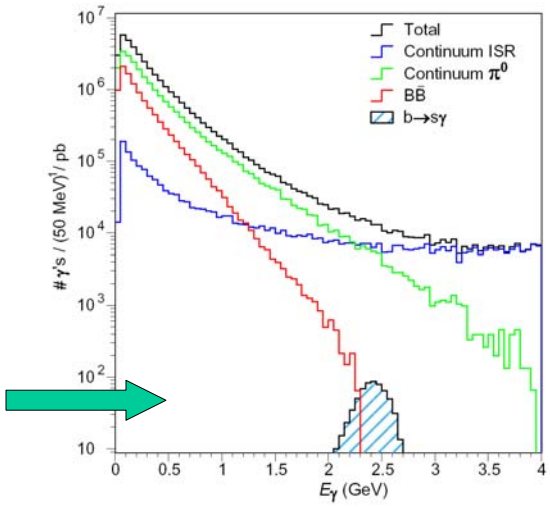
Photon energy E_g distribution: depends on m_b and Fermi motion parameter in the B system (parameters of HQE); also important for the determination of V_{ub} in semileptonic B decays.

Previous measurement by CLEO: $E_\gamma > 2.0$ GeV.

Belle: extend the energy range to $E_\gamma > 1.8$ GeV to cover >95% of the rate.

b → sγ inclusive

Very hard job!



b → sγ inclusive

- Consider all photons with $E_\gamma > 1.5$ GeV
- Reject candidates compatible with π^0, $\eta \rightarrow \gamma\gamma$
- Apply stringent continuum cuts (event shape and energy flow variables)
- Subtract the remaining continuum component as determined with off-resonance data
- Other sources: inferred from data-corrected MC and subtracted

- Signal selection optimisation: maximize the significance in the $1.8\text{GeV} < E_\gamma < 1.9$ GeV interval

data sample 140/fb

b → sg inclusive

Results

Branching ratio:

$BR(b\to s\gamma)=(3.55\pm0.32^{+0.30+0.11}_{-0.31\ -0.07})\cdot10^{-4}$

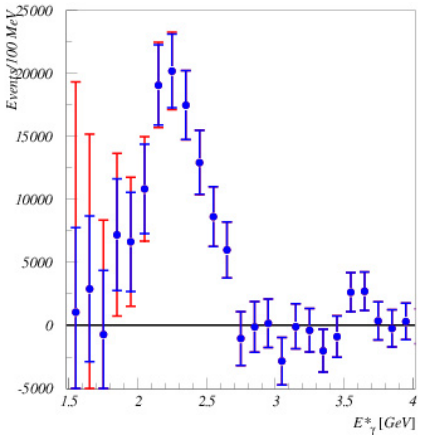
Photon energy E_γ distribution:

first moment:

$<E_\gamma>=(2.292\pm0.026\pm0.034)$ GeV

second moment: $<E_\gamma^2>-<E_\gamma>^2=$

$(0.0305\pm0.0074\pm0.0063)$ $(GeV)^2$



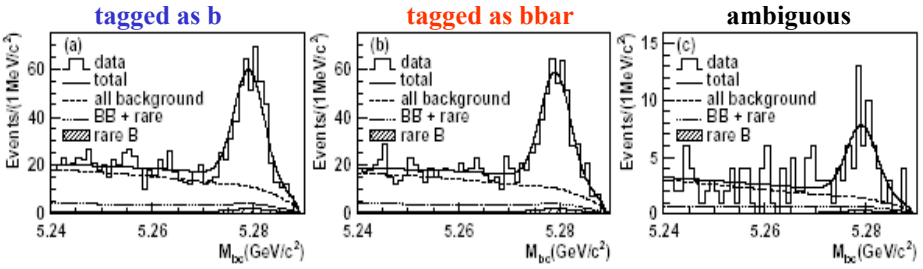
Two moments: parameters of the shape function (SF).

CP asymmetry in B → $X_s\gamma$

Inclusive measurement: pseudo-reconstruction of B→$X_s\gamma$.

For X_s use K^{+-} or K_S with 1-4 π (0 or 1 π^0), $K^{+-}K^{+-}K^{+-}(\pi^{+-})$, K_SK^{+-} $K^{+-}(\pi^{+-})$.

data sample 140/fb



Signal extraction: kinematic variable $M_{bc}=\sqrt{(E^{*2}_{beam}-|p^*_B|^2)}$

CP asymmetry in B → $X_s\gamma$

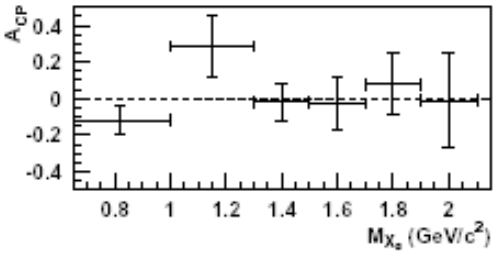
CP asymmetry

$A_{CP} = (\Gamma(b \to s\gamma)-\Gamma(\bar{b} \to \bar{s}\gamma))/(\Gamma(b \to s\gamma)+\Gamma(\bar{b} \to \bar{s}\gamma))$

SM expectation +0.5%

For events with X_s<2.1 GeV/c^2

$A_{CP} = -0.002 \pm 0.050(stat) \pm 0.030(syst)$



A_{CP} vs. X_s

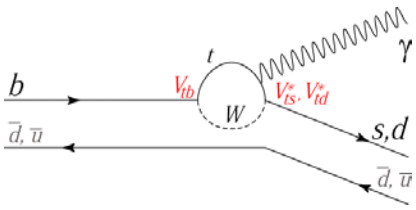
b → dγ exclusive: B → $\rho\gamma$, $\omega\gamma$

Supressed by $(V_{td}/V_{ts})^2$ vs b → sγ

SM prediction for $B^+ \to \rho^+\gamma$

BR around 1×10^{-6}

Not yet observed.



Potentially interesting:

Measurement of V_{td}/V_{ts}

CP violation could be sizeable in SM (order 10%)

B → ργ, ωγ

Exclusive B→ρ⁰/ρ⁺/ωγ (ρ⁰→π⁺π⁻, ρ⁺→π⁰π⁺, ω→π⁺π⁻π⁰) measurements on a data sample of 140/fb

BG : B→K*γ missid., B→ρ/ωπ⁰, continuum

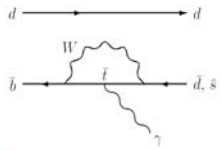
Continuum rejection: by Fisher event shape variable, vertexing, flavor-tag

Signal yield: Use 2-D unbinned maximum likelihood fit in two variables $M_{bc} = \sqrt{(E^{*2}_{beam} - |p^*_B|^2)}$ and $\Delta E = E^*_B - E^*_{beam}$

Simultaneous fit to 3 signals + 2 K*γ assuming isospin relations:

$Br(B^+ \to \rho^+\gamma) = 2(\tau(B^+)/\tau(B^0))Br(B^0 \to \rho^0\gamma) = 2(\tau(B^+)/\tau(B^0))Br(B^0 \to \omega\gamma)$

B → ργ, ωγ



(253 fb⁻¹)
1.9σ significance
$B < 1.4 \times 10^{-6}$ (90% C.L.)
$\Rightarrow |V_{td}/V_{ts}| < 0.21$

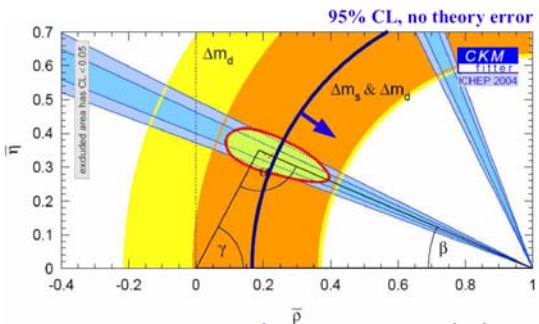
(191 fb⁻¹)
2.1σ significance
$B < 1.2 \times 10^{-6}$ (90% C.L.)
$\Rightarrow |V_{td}/V_{ts}| < 0.19$

Ali et al., PLB 595, 0323 (2004):

$$\frac{B(B0 \to (\rho,\omega)\gamma)}{B(B^0 \to K^*\gamma)} = \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1 - m^2_{(\rho,\omega)}/m^2_B}{1 - m^2_{K^*}/m^2_B}\right)^3 \xi^2 (1 + \Delta R)$$

$\xi = 0.85 \pm 0.10$ $SU(3)$−breaking form factor
$\Delta R = 0.1 \pm 0.1$ correction from annihilation

95% CL, no theory error



In agreement with SM
SM predictions ($B^+ \to \rho^+\gamma$):
$(0.90 \pm 0.34) \times 10^{-6}$ Ali, Parkhomenko
$(1.58\ {}^{+0.53}_{-0.46}) \times 10^{-6}$ Bosch, Buchalla

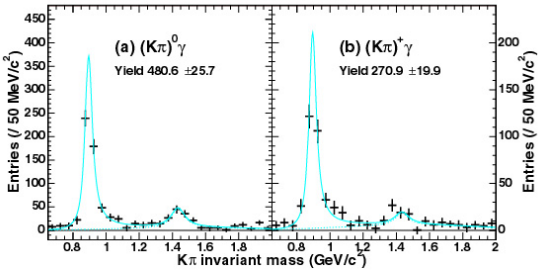
Blue contour: excludes half of the sin2β region.

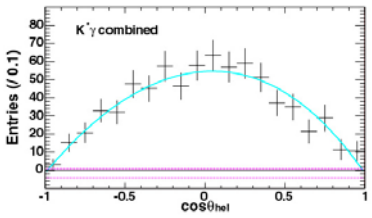
$B \to K^*\gamma$

- Photon candidates with π^0/h veto
- K*(892) reconstructed in 4 final states:

$K^+\pi^-$, $K^0_S\pi^0$, $K^+\pi^0$, $K^0_S\pi^+$ with $|M(K\pi) - M(K^*)_r| < 75$ MeV/c^2

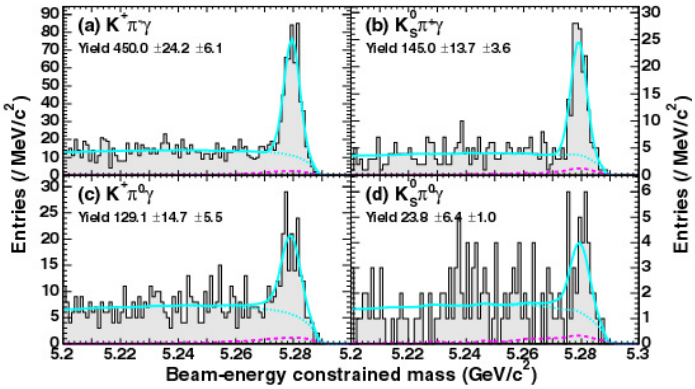
- BKG suppression against $e^+e^- \to qq(\gamma)$ by event shape var.





data sample 78/fb

$B \to K^*\gamma$ braching fractions



$M_{bc} = \sqrt{(E^{*2}_{beam} - |p^*_B|^2)}$

$BR(B^0 \to K^{*0}\gamma) = (4.01 \pm 0.21 \pm 0.17) \cdot 10^{-5}$ SM ≈ $(6.9 \pm 2.1) \cdot 10^{-5}$

$BR(B^+ \to K^{*+}\gamma) = (4.25 \pm 0.31 \pm 0.24) \cdot 10^{-5}$ SM ≈ $(7.4 \pm 2.3) \cdot 10^{-5}$

$B \to K^*\gamma$ asymmetries

Isospin asymmetry D_{0+} =

$$\frac{(\tau_{B^+} / \tau_{B^0})\, BR(B^0 \to K^{*0}\gamma) - BR(B^+ \to K^{*+}\gamma)}{(\tau_{B^+} / \tau_{B^0})\, BR(B^0 \to K^{*0}\gamma) + BR(B^+ \to K^{*+}\gamma)}$$

$\Delta_{0+} = +0.012 \pm 0.044(stat) \pm 0.026(syst)$ Belle — SM: 5-10%

$\Delta_{0+} = +0.051 \pm 0.044(stat) \pm 0.023(syst)$ BaBar

CP asymmetry — SM<<0.01

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

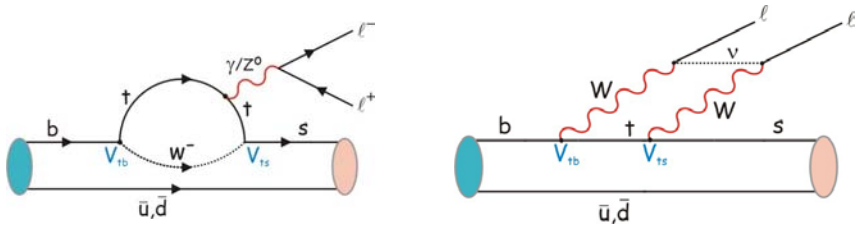
$$\frac{1}{(1-2w)} \quad \frac{N(\bar{B} \to \bar{K}^*\gamma) - N(B \to K^*\gamma)}{N(\bar{B} \to \bar{K}^*\gamma) + N(B \to K^*\gamma)}$$

$A_{CP} = -0.015 \pm 0.044(stat) \pm 0.012(syst)$ Belle

$A_{CP} = -0.015 \pm 0.036(stat) \pm 0.010(syst)$ BaBar

(w= dilution due to imperfect tagging)

$B \to K^* l^+ l^-$



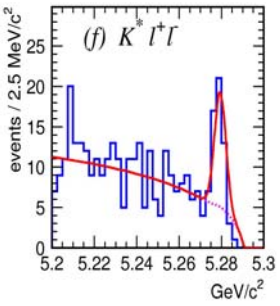
$b \to s\, l^+l^-$ was first measured in $B \to K\, l^+l^-$ by Belle.

With 140/fb of data, search for $K^*\, l^+l^-$ and update $K\, l^+l^-$.

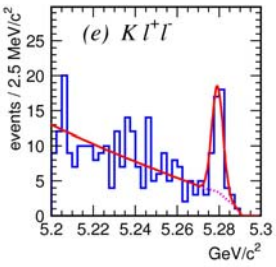
Important for further searches for the physics beyond SM: backward-forward asymmetry A_{FB} in $K^*\, l^+l^-$

B → K* l+ l-

- K*: $K^+\pi^-$, $K^0_s\pi^+$, $K^+\pi^0$ with $|M(K\pi)-M(K^*)|<75$ MeV/c^2
- K: charged or neutral
- Lepton pair: e or m, p(e)>0.4 GeV/c, p(μ)>0.7 GeV/c
  veto on J/Ψ, Ψ(2S)



first observation

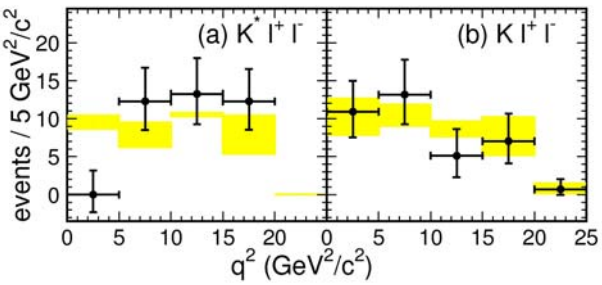


$M_{bc} = \sqrt{(E^{*2}_{beam} - |p^*_B|^2)}$

B → K* l+ l-

Results based on 140 fb^{-1}

- $BR(B \to K^* l^+ l^-) = (11.5^{+2.6}_{-2.4} \pm 0.8 \pm 0.2)\ 10^{-7}$ **observation**
- $BR(B \to K l^+ l^-) = (4.8^{+1.0}_{-0.9} \pm 0.3 \pm 0.1)\ 10^{-7}$ **update with more data**



$q^2 = M_{ll}^2 c^2$

yellow: SM expect.

$B \to K^* l^+ l^-, K l^+ l^-$

Results based on 123 fb^{-1}

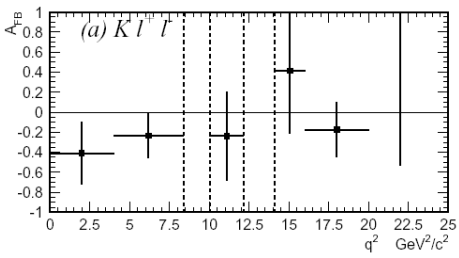
- $BR(B \to K^* l^+ l^-) = (8.8^{+3.3}_{-2.9} \pm 1.0)\ 10^{-7}$
- $BR(B \to K l^+ l^-) = (6.5^{+1.4}_{-1.3} \pm 0.4)\ 10^{-7}$

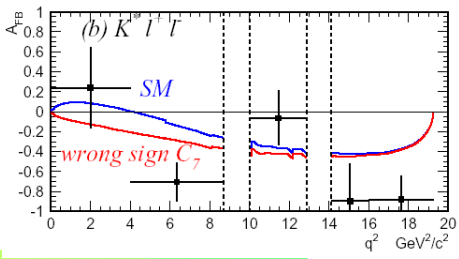
Belle+BaBar: All in good agreement with SM.

With more statistics: measure backward-forward asymmetry A_{FB} in $K^* l^+ l^-$ -> determine sign of C_7

A_{FB} for $B \to K^{(*)} l^+ l^-$

- Raw A_{FB} in each q^2 region is extracted from M_{bc} fit.
- Dotted lines indicate charmonium veto windows.
- Kll has no asymmetry, hence a good control sample.
- Curves (not fitted lines!) show theory including exp'tal efficiency.
- Both are in agreement with data.





A_{FB} for $B \to K^{(*)}l^+l^-$

- Long list of theoretical expectations for A_{FB} vs s