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Flavour Physics at B-factories and Hadron Colliders

Part 11: FCNC decays

Peter Križan

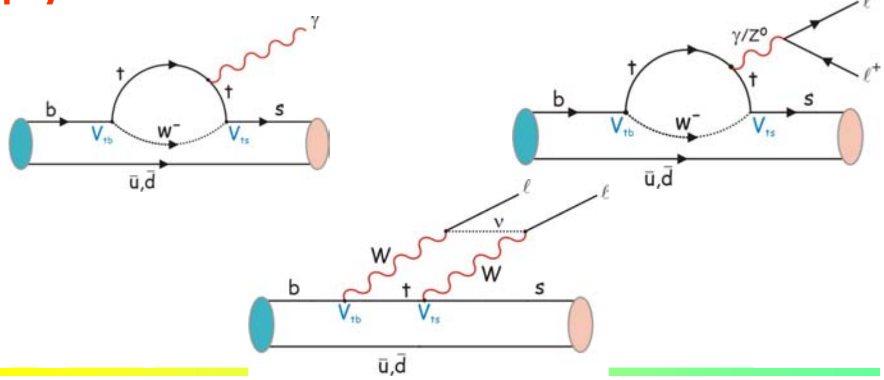
University of Ljubljana and J. Stefan Institute

Contents

- Radiative B decays
- b->s l^-l^+ decays
- Measurements of A_{FB}

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.

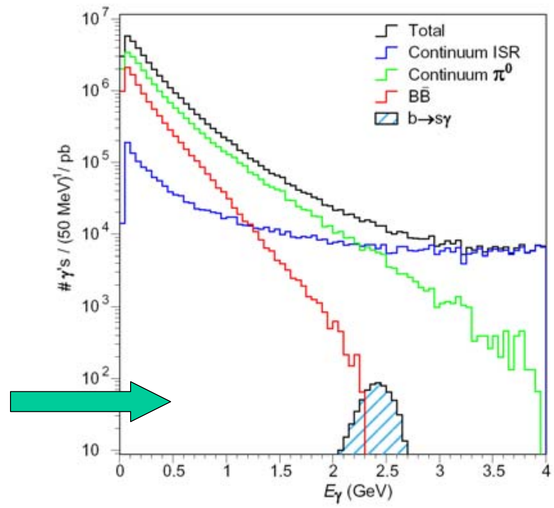
Photon energy E_γ distribution: depends on m_b and Fermi motion parameter in the B system (parameters of HQE); also important for the determination of V_{ub} in semileptonic B decays.

Previous measurement by CLEO: E_γ > 2.0 GeV.

Belle: extend the energy range to E_γ > 1.8 GeV to cover >95% of the rate.

b → sγ inclusive

Very hard job!



b → sγ inclusive

- Consider all photons with E_γ > 1.5 GeV
- Reject candidates compatible with π^0, $\eta \to \gamma\gamma$
- 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 1.8GeV<E_γ<1.9 GeV interval

data sample 140/fb

b → sg inclusive

Results

Branching ratio:

$BR(b\to s\gamma)=(3.55\pm0.32^{+0.30+0.11}_{-0.31-0.07})\cdot 10^{-4}$

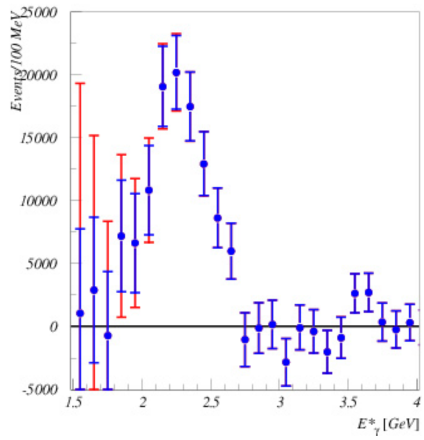
Photon energy E_γ distribution:

first moment:

$<E_\gamma> = (2.292 \pm 0.026 \pm 0.034)$ GeV

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

$(0.0305 \pm 0.0074 \pm 0.0063)\ (\mathrm{GeV})^2$



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

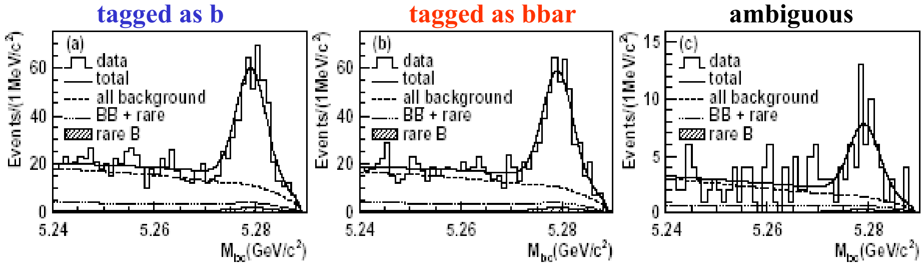
CP asymmetry in B → $X_s\gamma$

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

tagged as b | tagged as bbar | ambiguous



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

CP asymmetry in $B \to X_s \gamma$

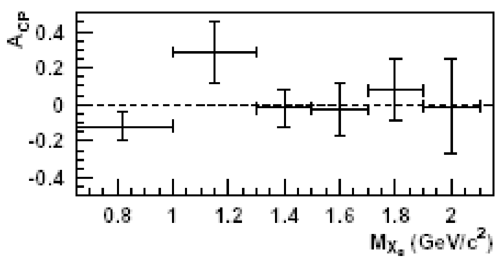
CP asymmetry

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

SM expectation +0.5%

For events with $X_s < 2.1$ GeV/c^2

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



A_{CP} vs. X_s mass

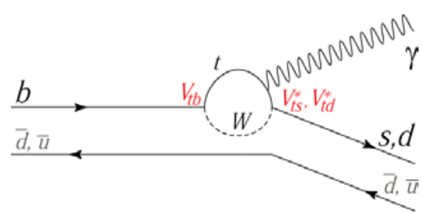
$b \to d\gamma$ exclusive: $B \to \rho\gamma, \omega\gamma$

Supressed by $(V_{td}/V_{ts})^2$ vs $b \to s\gamma$

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

BR around 1×10^{-6}

Not yet observed.



Potentially interesting:

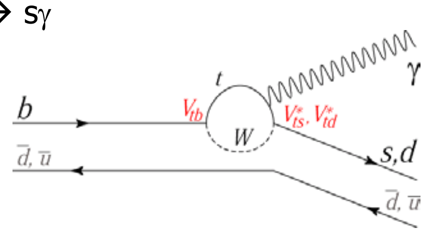
Measurement of V_{td}/V_{ts}

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

A large number of b→s modes are known, where are the b→d penguins ?

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

→BR around 1×10^{-6}



Interesting:

Measurement of $|V_{td}/V_{ts}|$

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

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

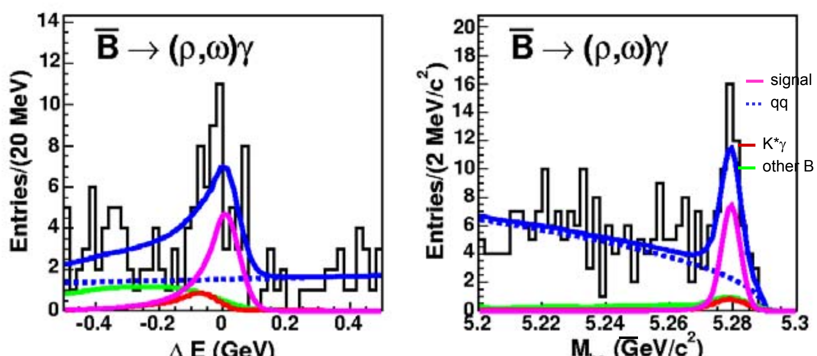
Addresses the same physics issue as B_s- B_s mixing (Tevatron + LHCb goal).

V_{td}/V_{ts} from B → ργ, ωγ

The measured branching fraction, $\mathcal{B}(B \to (\rho\omega)\gamma) = (1.34^{+0.34}_{-0.31}\ ^{+0.14}_{-0.10}) \times 10^{-6}$, translates to

$$|V_{td}/V_{ts}| = 0.200^{+0.026}_{-0.025}(\text{exp.})^{+0.038}_{-0.029}(\text{theo.}),$$

which is compatible with SM constraints based on fits using measurements of other CKM parameters.



hep-ex/0506079

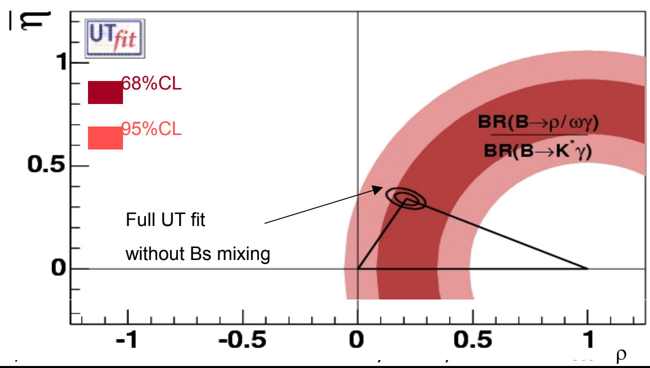
First observation of b→d γ

Implications of Belle's observation of b→d γ

Together with the evidence of B→K^0 K modes, Belle has demonstrated the existence of a new quark level transition: b→d γ + measurement of $|V_{td}/V_{ts}|$

$$\frac{\mathrm{BR}(B \to (\rho/\omega)\gamma)}{\mathrm{BR}(B \to K^{*}\gamma)} \propto \left|\frac{V_{td}}{V_{ts}}\right|^{2}$$

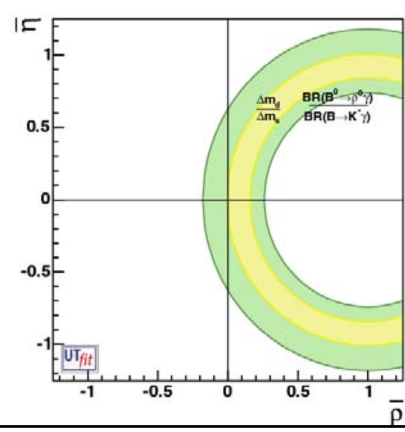
SU(3) breaking correction
weak annihilation diagram for $BR(B \to \rho/\omega\, \gamma)$



Implications of Belle's observation of b→d γ

Comparison with the recent observation of B_s mixing at Tevatron:

- green: Belle measurement of $|V_{td}/V_{ts}|$ in b→d γ
- yellow: CDF measurement of $|V_{td}/V_{ts}|$ from B_s mixing

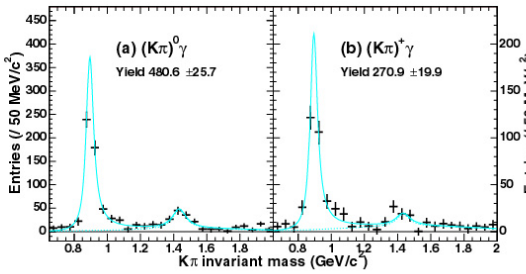


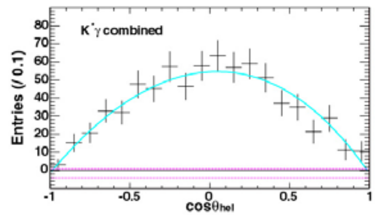
$B \to K^{*}\gamma$

- **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

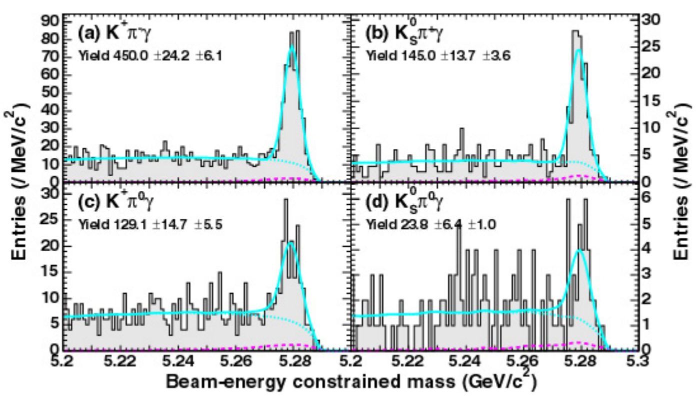
- **BKG suppression against $e^+e^- \to qq(\gamma)$ by event shape var.**





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 $\approx (6.9 \pm 2.1) \cdot 10^{-5}$**

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

$B \to K^* \gamma$ asymmetries

Isospin asymmetry D_{0+} =

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

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

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

CP asymmetry — SM<<0.01

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

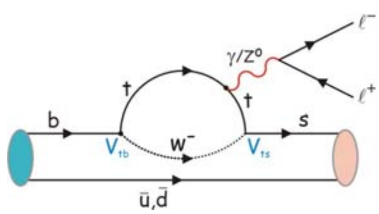
$$\frac{1}{(1-2w)} \; \frac{N(\bar{B} \to \bar{K}^*\gamma) - N(B \to K^*\gamma)}{N(\bar{B} \to \bar{K}^*\gamma) + N(B \to K^*\gamma)}$$

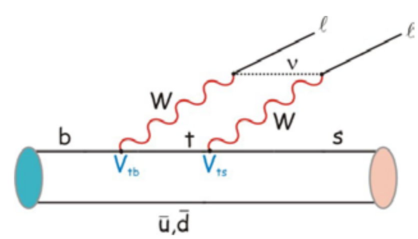
A_{CP} = -0.015 $\pm$ 0.044(stat) $\pm$ 0.012(syst) Belle

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

(w= dilution due to imperfect tagging)

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





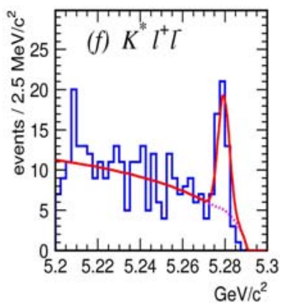
$b \to s\, l^+l^-$ was first measured in $B \to K\, l^+l^-$ by Belle.

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

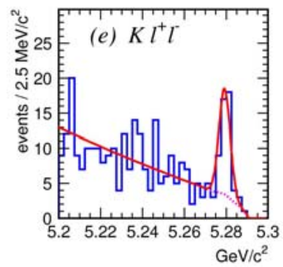
Important for further searches for the physics beyond SM: backward-forward asymmetry A_{FB} in $K^*\, l^+l^-$

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

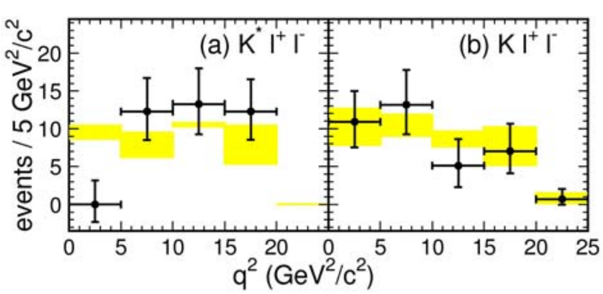


$M_{bc} = \sqrt{(E^{*2}_{beam} - |p^*_B|^2)}$

B → K* l+ l-

Results based on 140 fb^{-1}

- BR(B → K*l+l-) = $(11.5^{+2.6}_{-2.4} \pm 0.8 \pm 0.2)\ 10^{-7}$ **observation**
- BR(B → 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}

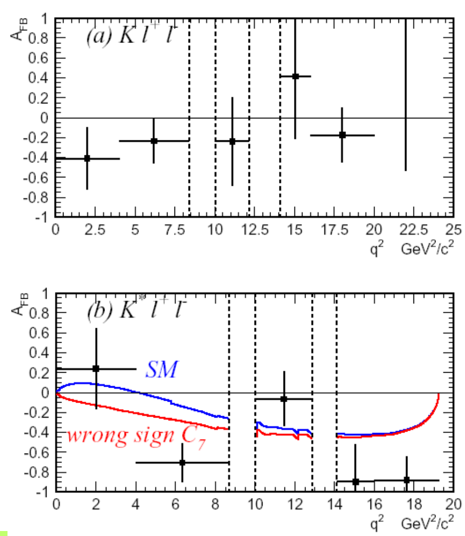
- $BR(B \to K^* l^+ l^-) = (8.8^{+3.3}_{-2.9} \pm 1.0)\ 10^{-7}$
- $BR(B \to K\, l^+ l^-) = (6.5^{+1.4}_{-1.3} \pm 0.4)\ 10^{-7}$

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

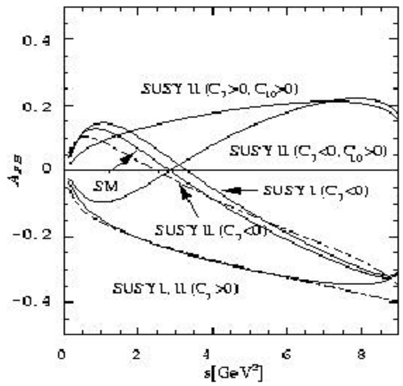
A_{FB} for $B \to K^{(*)} l^+ l^-$

- 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.

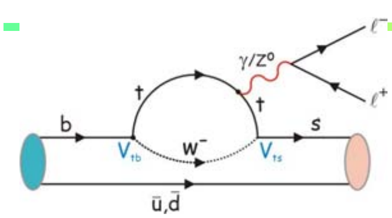


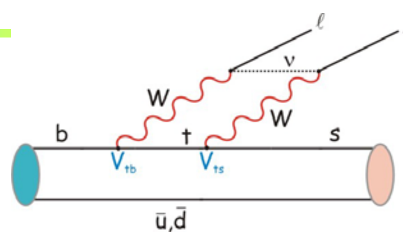
A_{FB} for $B \to K^{(*)}l^+l^-$

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



Another FCNC decay: $B \to K^* l^+ l^-$





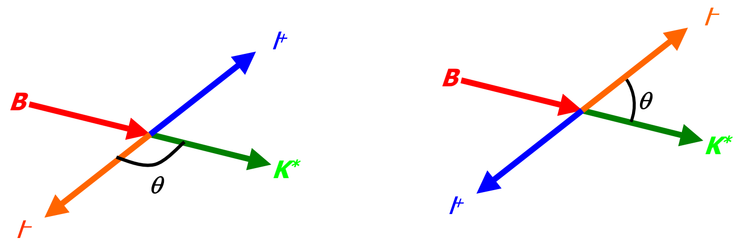
$b \to s\, l^+l^-$ was first measured in $B \to K\, l^+l^-$ by Belle (2001).

Important for further searches for the physics beyond SM

$$\frac{d\Gamma\left(b\to s\ell^+\ell^-\right)}{d\hat{s}} = \left(\frac{\alpha_{em}}{4\pi}\right)^2 \frac{G_F^2 m_b^5 \left|V_{ts}^* V_{tb}\right|^2}{48\pi^3}(1-\hat{s})^2 \times\left[(1+2\hat{s})\left(\left|C_9^{eff}\right|^2+\left|C_{10}^{eff}\right|^2\right)+4\left(1+\frac{2}{\hat{s}}\right)\left|C_7^{eff}\right|^2+12\,\mathrm{Re}\left(C_7^{eff}C_9^{eff*}\right)\right]$$

Particularly sensitive: backward-forward asymmetry in $K^*\, l^+l$

$$A_{\rm FB}(q^2) = \frac{\int_0^1 \frac{d^2\Gamma}{dq^2 d\cos\theta} d\cos\theta - \int_{-1}^0 \frac{d^2\Gamma}{dq^2 d\cos\theta} d\cos\theta}{\int_0^1 \frac{d^2\Gamma}{dq^2 d\cos\theta} d\cos\theta + \int_{-1}^0 \frac{d^2\Gamma}{dq^2 d\cos\theta} d\cos\theta}.$$



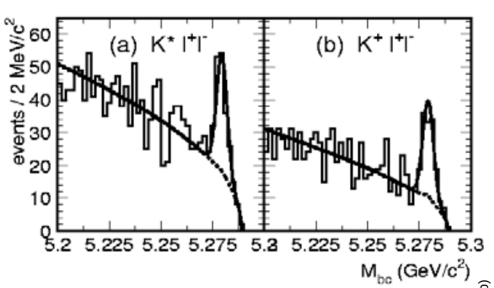
Backward event Forward event

[γ* and Z* contributions in B→K* l l interfere and give rise to forward-backward asymmetries c.f. $e^+e^- \to \mu^+ \mu^-$]

Unbinned fit to the variables q^2 (di-lepton invariant mass) and cos(θ) for B→K* l l data

2005: Sample used for $A_{FB}(B\to K^*ll)(q^2)$

hep-ex/0508009



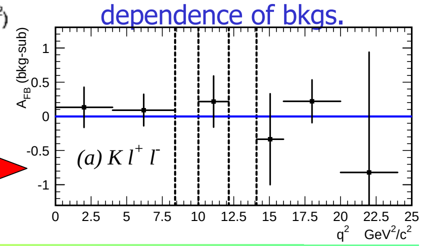
$$\begin{aligned} & P(q^2,\cos\theta; A_9/A_7, A_{10}/A_7) \\ = \; & f_{\rm sig}\epsilon_{\rm sig}(q^2,\cos\theta)\frac{d^2\Gamma}{dq^2 d\cos\theta}(q^2,\cos\theta)/N_{\rm sig} \\ + \; & f_{\rm cfcf}\epsilon_{\rm cfcf}(q^2,\cos\theta)\frac{d^2\Gamma}{dq^2 d\cos\theta}(q^2,\cos\theta)/N_{\rm cfcf} \\ + \; & f_{\rm ifcf}\epsilon_{\rm ifcf}(q^2,\cos\theta)\frac{d^2\Gamma}{dq^2 d\cos\theta}(q^2,-\cos\theta)/N_{\rm ifcf} \\ + \; & f_{X_s\ell\ell}\mathcal{P}_{X_s\ell\ell}(q^2,\cos\theta) \\ + \; & f_{\rm dilep}\Big\{(1-f_{K^*\ell h})\mathcal{P}_{\rm dilep}(q^2,\cos\theta) \\ & +f_{K^*\ell h}\mathcal{P}_{K^*\ell h}(q^2,\cos\theta)\Big\} \\ + \; & f_{K^*hh}\mathcal{P}_{K^*hh}(q^2,\cos\theta) + f_\psi\mathcal{P}_\psi(q^2,\cos\theta), \qquad (\end{aligned}$$

Treat q^2, cos(θ) dependence of bkgs.

Sample for B→K* l l events 113±13

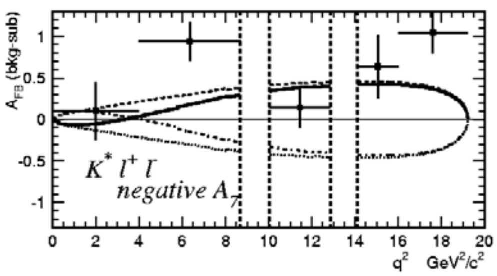
B→K l l control sample 96±12

Consistent with flat



Constraints on Wilson coefficients from $A_{FB}(B \to K^* l\, l)(q^2)$

Projections of the full fit to q^2, cos(θ)



Integrated FB asymmetry

$$A_{FB}(B \to K^* l^- l^+) = 0.50 \pm 0.12 \pm 0.02; (3.4\sigma)$$

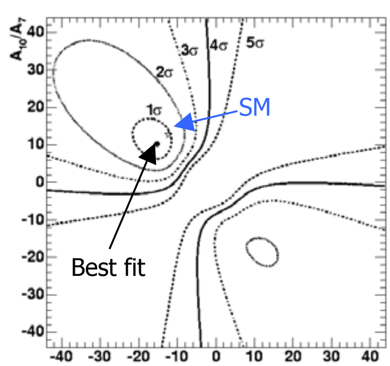
control sample:

$$A_{FB}(B \to K^+ l^- l^+) = 0.10 \pm 0.14 \pm 0.01$$

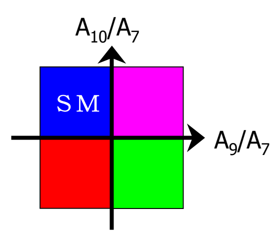
Observed integrated A_{FB} rules out some radical New Physics Models with incorrect signs/magnitudes of C_9 and C_{10}

Results of the unbinned fit to q^2 and cos(θ) distributions for ratios of Wilson coefficients.

A_{10}/A_7



A_9/A_7



$|A_7|$ constrained from $b \to s\,\gamma$ to be close to SM

Ref: hep-ex/0508009

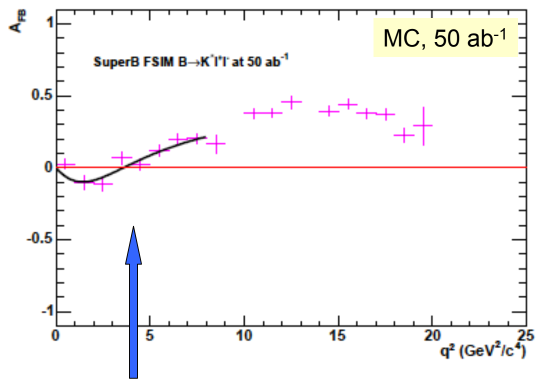
	negative A_7	positive A_7
A_9/A_7	$-15.3^{+3.4}_{-4.8} \pm 1.1$	$-16.3^{+3.7}_{-5.7} \pm 1.4$
A_{10}/A_7	$10.3^{+5.2}_{-3.5} \pm 1.8$	$11.1^{+6.0}_{-3.9} \pm 2.4$

$$-1401 < A_9 A_{10}/A_7^2 < -26.4.$$

at 95% C.L.

$A_{FB}(B \rightarrow K^* l^+ l^-)[q^2]$ at Super B Factory

Sensitivity at Super KEKB with 100x bigger data sample



- Zero-crossing q^2 for A_{FB} will be determined with 5% error with $50ab^{-1}$.