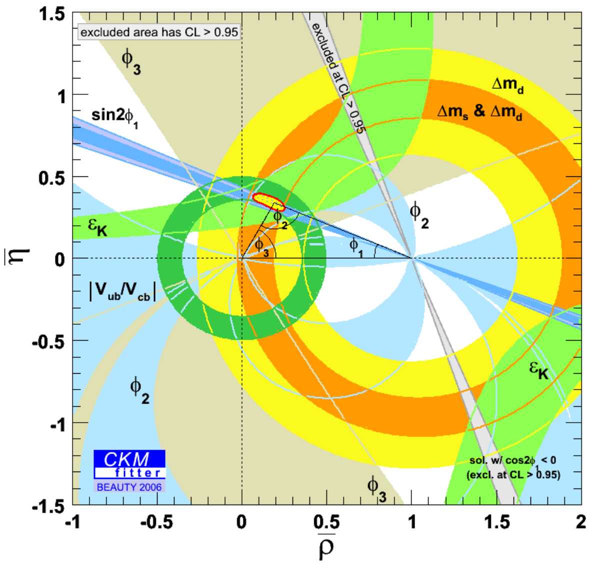
CKM fitter

PARTICLE PHYSICS JOINT LAB JAPAN - FRANCE

シーケーエムフィッター



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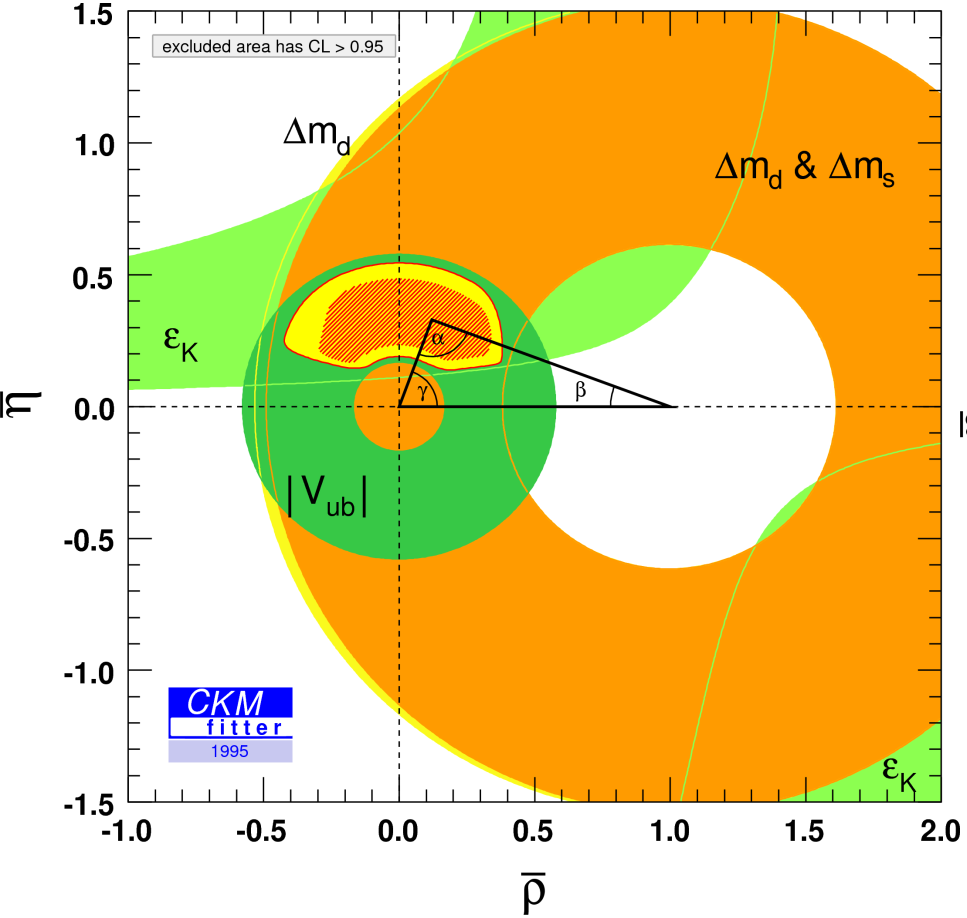
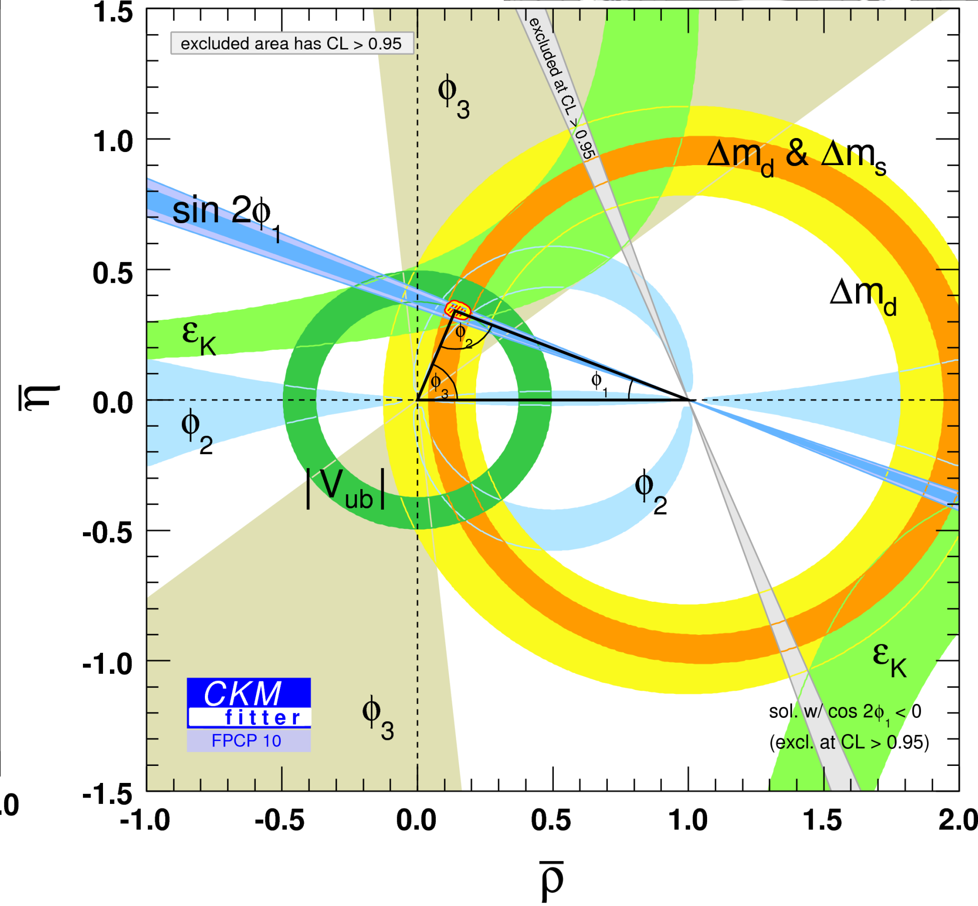
TYL'10 – LAPP – June 15-16 2010

Laboratoire d'Annecy-le-vieux de Physique des Particules

KM Mechanism: 1973 to the 2008 Nobel Prize





The great success of the B factories, Tevatron and LQCD (and the Standard Model): the KM mechanism is the dominant source of CPV at the EW scale.

➔Looking for corrections to the SM picture of flavor: NP

➔Precision measurements: from O(10%) to O(1%) [LHCb and Belle II] decreasing SM contrib. →

decreasing SM contrib. ↓

	$b \to s$ $(\sim\lambda^2)$	$b \to d$ $(\sim\lambda^3)$	$s \to d$ $(\sim\lambda^5)$
$\Delta F=2$ box	ΔM_{Bs} $A_{CP}(B_s \to \psi\phi)$	ΔM_{Bd} $A_{CP}(B_d \to \psi K)$	ΔM_K, ε_K
$\Delta F=1$ 4–quark box	$B_d \to \phi K$, $B_d \to K\pi$, ...	$B_d \to \pi\pi$, $B_d \to \rho\pi$, ...	ε'/ε, $K \to 3\pi$, ...
gluon penguin	$B_d \to X_s \gamma$, $B_d \to \phi K$, $B_d \to K\pi$, ...	$B_d \to X_d \gamma$, $B_d \to \pi\pi$, ...	ε'/ε, $K_L \to \pi^0 l^+ l^-$, ...
γ penguin	$B_d \to X_s l^+ l^-$, $B_d \to X_s \gamma$ $B_d \to \phi K$, $B_d \to K\pi$, ...	$B_d \to X_d l^+ l^-$, $B_d \to X_d \gamma$ $B_d \to \pi\pi$, ...	ε'/ε, $K_L \to \pi^0 l^+ l^-$, ...
Z^0 penguin	$B_d \to X_s l^+ l^-$, $B_s \to \mu\mu$ $B_d \to \phi K$, $B_d \to K\pi$, ...	$B_d \to X_d l^+ l^-$, $B_d \to \mu\mu$ $B_d \to \pi\pi$, ...	ε'/ε, $K_L \to \pi^0 l^+ l^-$, $K \to \pi\nu\nu$, $K \to \mu\mu$, ...
H^0 penguin	$B_s \to \mu\mu$	$B_d \to \mu\mu$	$K_{L,S} \to \mu\mu$

Theoretical errors $\lesssim 10\%$

There is much more to learn than just the UT consistency check

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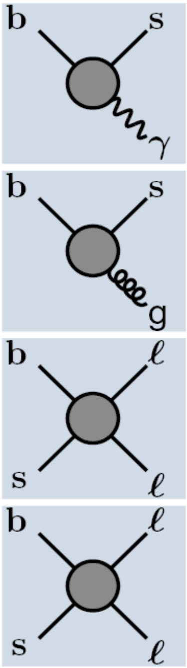
|ΔF|=1 FCNC b→s

i=1,2	tree
i=3-6,8	g penguin
i=7	**γ penguin**
i=9,10	**EW penguin**



Right handed part (suppressed in SM)

$$H_{\mathrm{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^{*} \sum_{i=1}^{10} \left(C_i(\mu) \times O_i(\mu) + \overbrace{C'_i(\mu) \times O'_i(\mu)} \right)$$

C_i : short distance Wilson coefficient (pert.)

O_i : long distance operator (non-pert.)

New physics shows up as modified C_i (or as new operators)

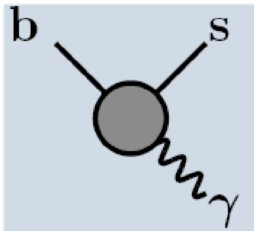
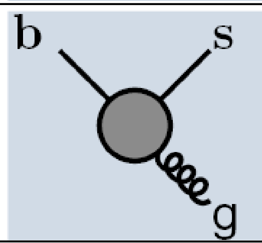
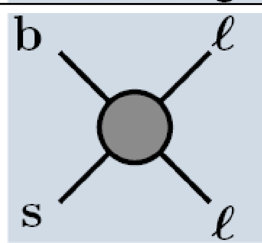
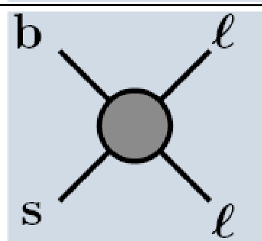
- In the framework of CKM fit, the NP effect is searched for in the $B_{d,s}$-$B_{d,s}$ mixing diagram, i.e., comparison of ρ-η constraints by (β/ϕ_1,α/ϕ_2,Δ $m_{d,s}$) and by (γ/ϕ_3, V_{ub})

- A complementary NP search can be performed by studying the FCNC transitions like $B \to X_s \gamma$ and $B \to X_s l^+ l^-$ which are governed by Wilson Coefficients C_7, C_9 and C_{10}.

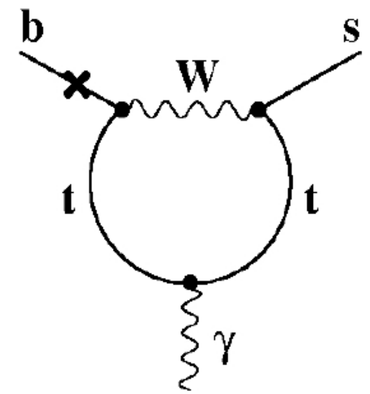
- The determination of Wilson Coefficients using various FCNC decays simultaneously in the similar manner as that in CKM fit (global fit) can be a sensitive probe to NP by comparing with the SM expectations.

Operators and Observables

G. Hiller - hep-ph/0308180

		magnitude	phase	helicity flip $\mathcal{O}_i'$
$\mathcal{O}_{7\gamma}$		$b \to s\gamma$	$a_{CP}(b \to s\gamma)$	$\Lambda_b \to \Lambda\gamma$ $B \to (K^* \to K\pi)\ell^+\ell^-$ $B \to (K^{**} \to K\pi\pi)\gamma$
$\mathcal{O}_{8g}$		$b \to s\gamma$ $B \to \not{X}_c$	$a_{CP}(b \to s\gamma)$ $B \to K\phi$	$\Lambda_b \to \Lambda\phi$ $B \to K^*\phi$
$\mathcal{O}_{9\ell,10\ell}$		$b \to se^+e^-$	$A_{FB}(b \to s\ell^+\ell^-)$	$B \to (K^* \to K\pi)\ell^+\ell^-$
$\mathcal{O}_{S,P}$		$B_{d,s} \to \mu^+\mu^-$	$B_{d,s} \to \tau^+\tau^-$	$b \to s\tau^+\tau^-$

Radiative decays



$b \to D\gamma^{(*)}$ with $D = d, s$

- access to $|V_{t(d,s)}|$ within SM
- cross-check of neutral B mixing (box/penguin)
- loop processes very sensitive to NP

In terms of effective Hamiltonian (integrating d.o.f above b quark)

$$\mathcal{H}^{b\to s} = -\frac{4G_F}{\sqrt{2}}\left(\sum_i V_{ts}^* V_{tb} C_i Q_i + V_{ub}^* V_{us}(C_1 Q_1^{c-u} + C_2 Q_2^{c-u})\right)$$

with main contributions to radiative decays from

- $Q_7 = \frac{e}{g^2} m_b \bar{D} \sigma^{\mu\nu}(1+\gamma_5) F_{\mu\nu}\, b$
- $Q_9 = \frac{e^2}{g^2} \bar{D} \gamma_\mu (1-\gamma_5) b\, \bar{\ell}\gamma_\mu \ell$
- $Q_{10} = \frac{e^2}{g^2} \bar{D} \gamma_\mu (1-\gamma_5) b\, \bar{\ell}\gamma_\mu \gamma_5 \ell$
- New physics changes Wilson coeffs C_i and/or new operators Q_i'

$b \to s\gamma$

For real photons, only Q_7 contributes (+ four-quark operators)

$$Q_7 = \frac{e}{g^2} m_b \, \bar{D} \sigma^{\mu\nu} (1 + \gamma_5) F_{\mu\nu} \, b$$

Exclusive: $B \to K^* \gamma$ and $B \to (\rho, \omega)\gamma$

- Measurements available from Babar & Belle
- Hadronic effects difficult to estimate theoretically (form factors)
- Naively : $A(B \to V\gamma) \propto V_{tD} V_{tb}^* C_7 T_1^{B \to V}$

Inclusive: $B \to X_s \gamma$

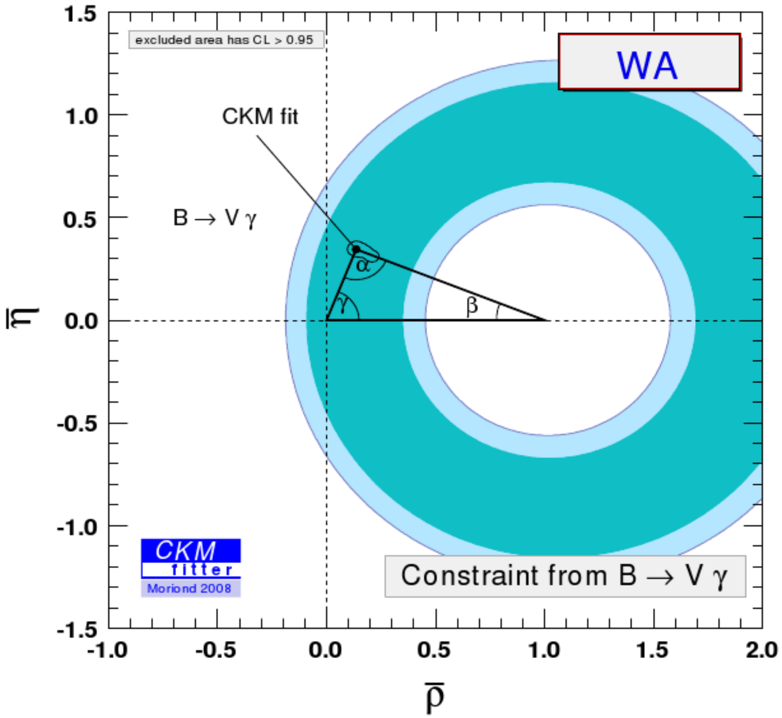
- accurately measured (but correlated with exclusive meas)
- computed perturbatively up to (N)NLO [Misiak et al.]

will be considered later...

$B \to \rho\gamma$ and $B \to K^*\gamma$

$b \to d, s\gamma$: loop processes, give access to $|V_{t(d,s)}|$, complement $\Delta m_{d,s}$

Early days : focus on magnetic op. $Q_7 = (e/8\pi^2) m_b \bar{D}\sigma^{\mu\nu}(1+\gamma_5)F_{\mu\nu}\, b$
and assume short-distance dominance



$$R_{\rho/\omega} = \frac{\overline{\mathcal{B}}(\rho^\pm\gamma) + \frac{\tau_{B^\pm}}{\tau_{B^0}}\left[\overline{\mathcal{B}}(\rho^0\gamma) + \overline{\mathcal{B}}(\omega\gamma)\right]}{\overline{\mathcal{B}}(K^{*\pm}\gamma) + \frac{\tau_{B^\pm}}{\tau_{B^0}}\left[\overline{\mathcal{B}}(K^{*0}\gamma)\right]}$$

$$= \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1 - m_\rho^2/m_B^2}{1 - m_{K^*}^2/m_B^2}\right)^3 \frac{1}{\xi^2}\,[1 + \Delta R]$$

- ξ ratio of form factors
- ΔR estimated as $\Delta R = 0.1 \pm 0.1$

Ali,Lunghi,Parkhomenko 02,04,06

Many open questions : dependence of ΔR on CKM matrix ? isopin breaking ? weak annihilation (tree for $(\rho, \omega)\gamma$) ?

A more sophisticated analysis

For each final state, estimate all contributions, expressed as factor to the leading amplitude (magnetic operator Q_7)

$$\bar{A} \equiv \frac{G_F}{\sqrt{2}} \left(\lambda_u^D a_7^u(V) + \lambda_c^D a_7^c(V) \right) \langle V\gamma | Q_7 | \bar{B} \rangle \qquad \lambda_U^D = V_{UD}^* V_{Ub}$$

$$a_7^U(V) = a_7^{U,\mathrm{QCDF}}(V) + a_7^{U,\mathrm{ann}}(V) + a_7^{U,\mathrm{soft}}(V) + \ldots$$

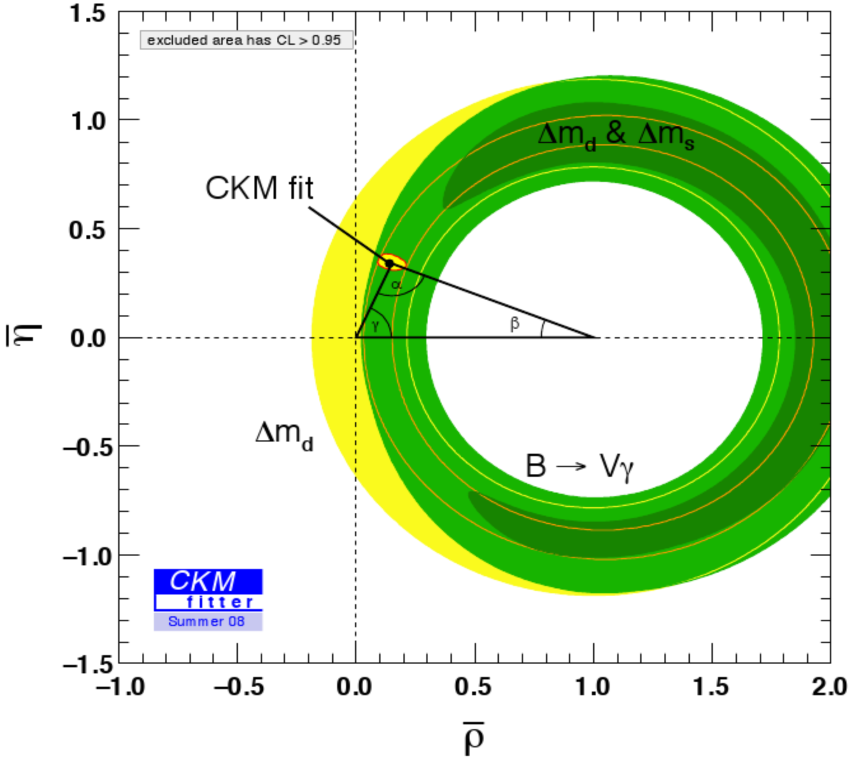
- QCDF : QCD factorisation for LO in $1/m_b$ up to $O(\alpha_s)$

  Bosch and Buchalla 02
- ann,soft : $1/m_b$-suppressed terms from light-cone sum rules

  Ball,Jones,Zwicky 06

- each decay described individually
- u and c internal loops (short and long dist), not “buried” into ΔR
- other operators than Q_7 taken into account

Package $B \to V\gamma$ (available)



- $C_i(m_b)$, form factor T_1
- $|V_{ud}|$, $|V_{us}|$, $|V_{cb}|$
- HFAG averages

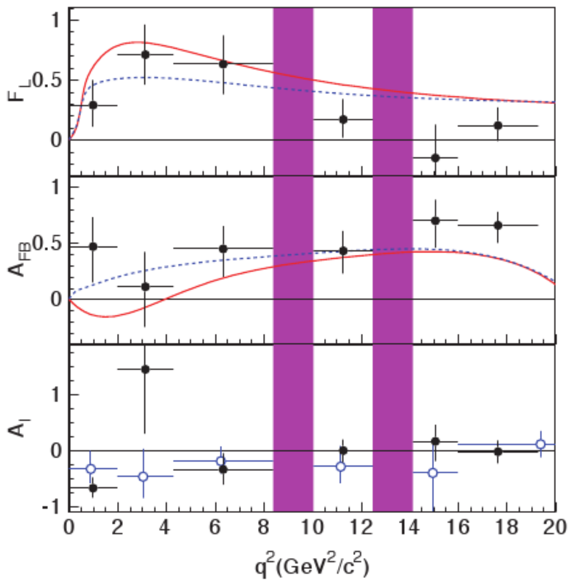
$K^{*-}\gamma$	45.7 ± 1.9
$K^{*0}\gamma$	44.0 ± 1.5
$\rho^{+}\gamma$	0.98 ± 0.25
$\rho^{0}\gamma$	0.86 ± 0.15
$\omega\gamma$	0.44 ± 0.17

- Belle 0804.4770, 0712.2659

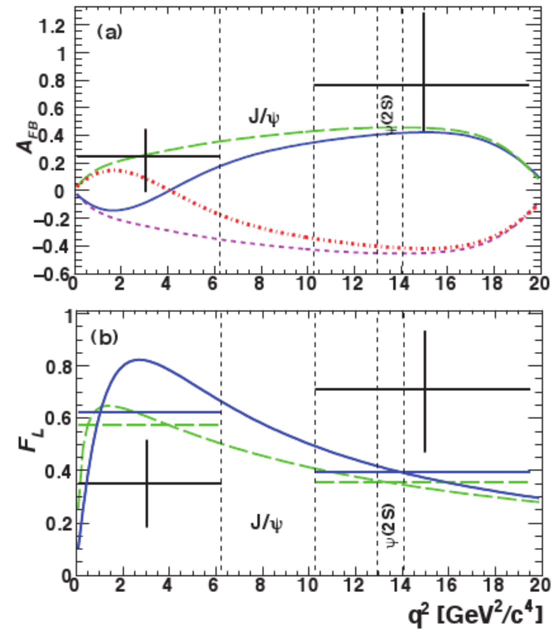
$B(B_s \to \phi\gamma)$	57 ± 22
$C(B^- \to \rho^-\gamma)$	$0.11 \pm 0.32 \pm 0.09$

$b \to s\gamma^{(*)}$

Focus on $B \to K^*(\to K\pi)\ell^+\ell^-$, prominent at LHCb and Belle II



Belle



Babar

Differential branching ratio, forward-backward asymmetry, polarisation (waiting for full angular analysis !)

Angular analysis

If no S-wave and all P-wave from narrow K^*, angular analysis:

$$\begin{aligned}
&\frac{d^4\Gamma}{dq^2\, d\cos\theta_l\, d\cos\theta_{K^*}\, d\phi} \\
&\propto I_1^s \sin^2\theta_{K^*} + I_1^c \cos^2\theta_{K^*} + (I_2^s \sin^2\theta_{K^*} + I_2^c \cos^2\theta_{K^*}) \cos 2\theta_l \\
&\quad + I_3 \sin^2\theta_{K^*} \sin^2\theta_l \cos 2\phi + I_4 \sin 2\theta_{K^*} \sin 2\theta_l \cos\phi \\
&\quad + I_5 \sin 2\theta_{K^*} \sin\theta_l \cos\phi \\
&\quad + (I_6^s \sin^2\theta_{K^*} + I_6^c \cos^2\theta_{K^*}) \cos\theta_l + I_7 \sin 2\theta_{K^*} \sin\theta_l \sin\phi \\
&\quad + I_8 \sin 2\theta_{K^*} \sin 2\theta_l \sin\phi + I_9 \sin^2\theta_{K^*} \sin^2\theta_l \sin 2\phi\,.
\end{aligned}$$

All observables can be expressed in terms of angular coeff I

$$\frac{d\Gamma}{dq^2} = \frac{3}{4}(2\,I_1^s + I_1^c) - \frac{1}{4}(2\,I_2^s + I_2^c). \qquad F_L \propto -I_2^c$$

$$A_{FB} = \left[\int_0^1 - \int_{-1}^0\right] d\cos\theta_l \frac{d^2\Gamma}{dq^2\, d\cos\theta_l} \Big/ \frac{d\Gamma}{dq^2} \propto \frac{3}{8}(2\,I_6^s + I_6^c).$$

Theoretical analysis

I_i interferences between eight transversity amplitudes $A_{\perp,L/R}$, $A_{||,L/R}$, $A_{0,L/R}$, A_s, A_t, depending on

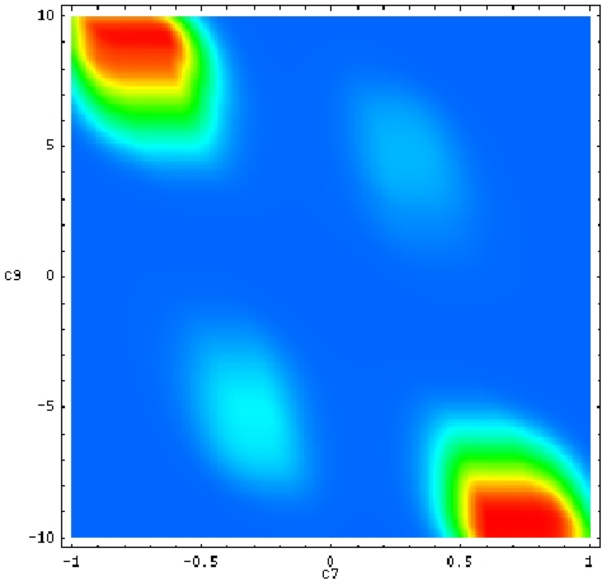
- q^2 (lepton pair invariant mass)
- Wilson coefficients C_7, C_9, C_{10} (known perturbatively in SM)
- $B \to K^*$ form factors $A_{0,1,2}$, V, $T_{1,2,3}$

Global fit of Wilson coefficients

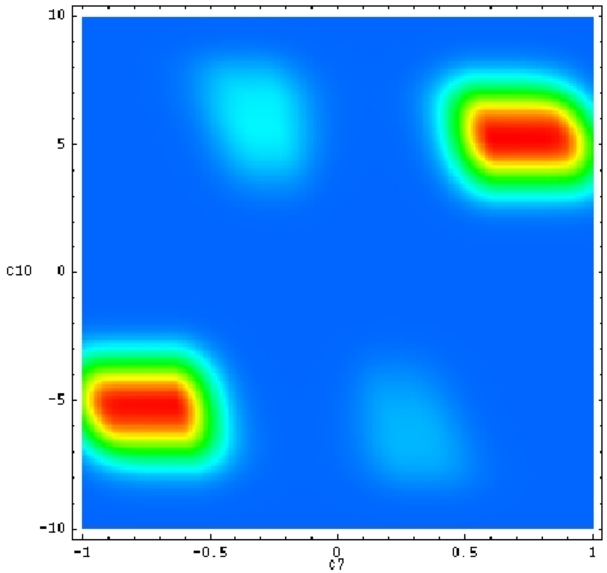
- Take a model for form factors [Ali et al. 00, Ball & Zwicky 05]
- Fit C_7, C_9, C_{10} from differential Γ, A_{FB}, f_L
- Compare with SM expectations

[Hurth et al. 2008, Altmannshofer et al. 2009]

Package $B \to V\ell\ell$ (under development)



C9 vs C7



C10 vs C7

With Belle only

Fair agreement with SM

$C_7(m_b) \simeq -0.342$
$C_9(m_b) \simeq 4.344$
$C_{10}(m_b) \simeq -4.699$

- Ghost solutions with flipped sign C_7 (f_L favours SM C_7 and A_{FB} slightly favours flipped sign C_7)

Programme

$B \to V\ell^+\ell^-$

- Analyse in detail the current data (sensitivity to hadronic inputs. . .)
- Finalise $B \to K^*\ell^+\ell^-$ package, with NNLL Wilson coeffs
- Study of low q^2-region where all form factors in terms of 2 soft form factors and corrections computed using QCD factorisation
- Impact of $c\bar{c}$ resonances (in collab with experimental analysis)
- Interface with $B \to V\gamma$: common packages for SM Wilson coefficients, form factors

Other radiative decays

- Inclusive decays $B \to X_s\gamma$, $B \to X_s\ell\ell$
- Exclusive decays $B \to K\ell\ell$, $B_s \to \phi\ell\ell$
- Interface together (with correlations) for a combined extraction of the Wilson Coefficients

Collaboration and discussions

Visit to KEK in April 09

- J. Charles, St. T'Jampens, S. Descotes-Genon
- Two seminars on CKMfitter for exp. group and discussions

Visit to KEK in February 10

- S. Descotes-Genon
- Lectures at Belle Analysis School, seminars for lattice group, and discussions

Visits in France/Germany in 2009-10

- K. Trabelsi and R. Itoh
- Collaboration meetings with CKMfitter members

Merci Thank you

ありがとうございます。