CKMfitter update: CP-violation in the Standard Model and beyond

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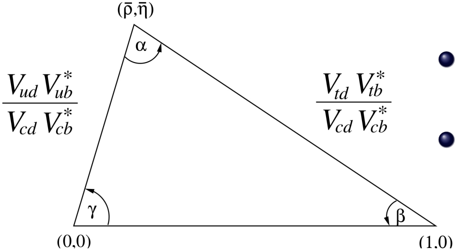
CP-violation : the four parameters

In SM weak charged transitions mix quarks of different generations

Encoded in unitary CKM matrix $V_{CKM} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$



- 3 generations $\Longrightarrow$ 1 phase, only source of CP-violation in SM
- Wolfenstein parametrisation, defined to hold to all orders in λ and rephasing invariant

$$\lambda^2 = \frac{|V_{us}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad A^2\lambda^4 = \frac{|V_{cb}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad \bar\rho + i\bar\eta = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$$

$\Longrightarrow$ 4 parameters describing the CKM matrix,
to extract from data under the SM hypothesis

The inputs

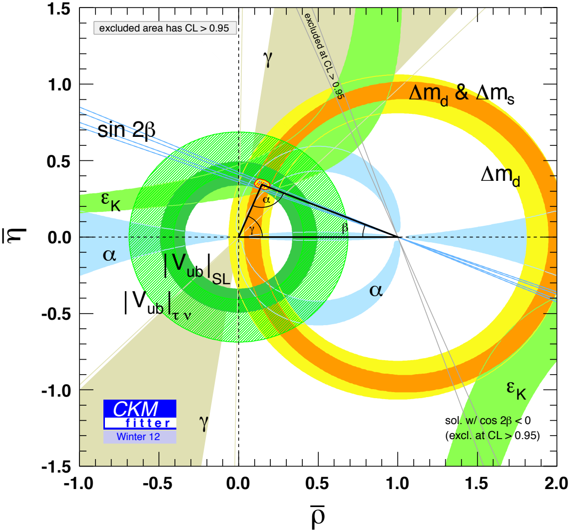
CKM fitter

CKM matrix within a frequentist framework ($\simeq \chi^2$ minimum)
+ specific scheme for theory errors (Rfit)

data = weak $\otimes$ QCD $\Longrightarrow$ Need for hadronic inputs (often lattice)

$\|V_{ud}\|$	superallowed β decays	PRC79, 055502 (2009)
$\|V_{us}\|$	$K_{\ell 3}$ (Flavianet)	$f_+(0) = 0.963 \pm 0.003 \pm 0.005$
	$K \to \ell\nu, \tau \to K\nu_\tau$	$f_K = 156.3 \pm 0.3 \pm 1.9$ GeV
$\|V_{us}/V_{ud}\|$	$K \to \ell\nu/\pi \to \ell\nu, \tau \to K\nu_\tau/\tau \to \pi\nu_\tau$	$f_K/f_\pi = 1.198 \pm 0.002 \pm 0.010$
ϵ_K	PDG 08	$\hat{B}_K = 0.733 \pm 0.003 \pm 0.036$
$\|V_{ub}\|$	inclusive and exclusive	$\|V_{ub}\| \cdot 10^3 = 3.92 \pm 0.09 \pm 0.45$
$\|V_{cb}\|$	inclusive and exclusive	$\|V_{cb}\| \cdot 10^3 = 40.89 \pm 0.38 \pm 0.59$
Δm_d	last WA B_d-$\bar{B}_d$ mixing	$B_{B_s}/B_{B_d} = 1.024 \pm 0.013 \pm 0.015$
Δm_s	last WA B_s-$\bar{B}_s$ mixing	$B_{B_s} = 1.291 \pm 0.025 \pm 0.035$
β	last WA $J/\psi K^{(*)}$	
α	last WA $\pi\pi, \rho\pi, \rho\rho$	isospin
γ	last WA $B \to D^{(*)}K^{(*)}$	GLW/ADS/GGSZ
$B \to \tau\nu$	$(1.68 \pm 0.31) \cdot 10^{-4}$	$f_{B_s}/f_{B_d} = 1.218 \pm 0.008 \pm 0.033$
		$f_{B_s} = 229 \pm 2 \pm 6$ MeV

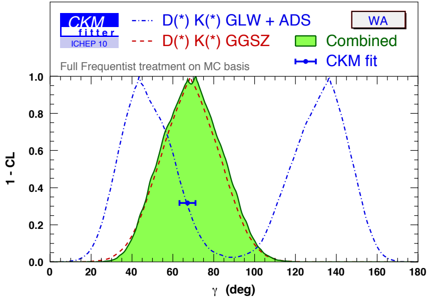
The global fit

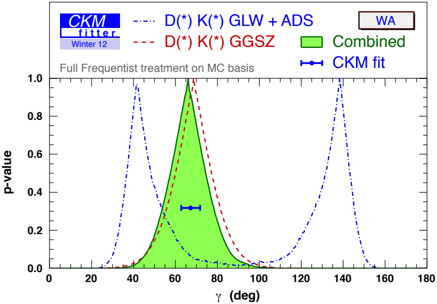


$|V_{ud}|, |V_{us}|$
$|V_{cb}|, |V_{ub}|_{SL}$
$B \to \tau\nu$
$\Delta m_d, \Delta m_s$
ϵ_K
$\sin 2\beta$
α
γ

$A = 0.812^{+0.015}_{-0.022}$
$\lambda = 0.2254^{+0.0006}_{-0.0010}$
$\bar{\rho} = 0.145^{+0.027}_{-0.027}$
$\bar{\eta} = 0.343^{+0.015}_{-0.015}$
(68% CL)

- Improved treatment of nuisance (hadronic) parameters
- Update in ADS inputs from Belle and CDF (2011)
- Inclusion of ADS from LHCb (2012)



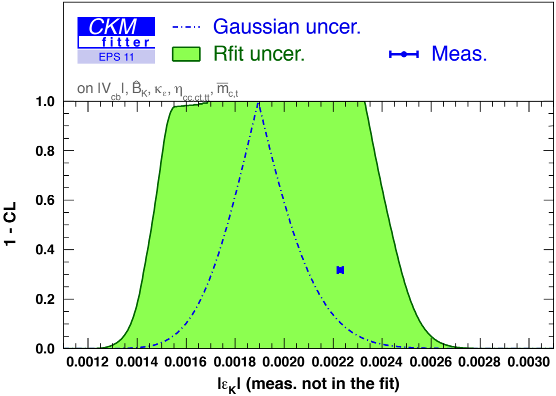


Summer 10	Summer 11	Winter 12
$\gamma[\text{comb}] = (71^{+21}_{-25})^\circ$	$\gamma[\text{comb}] = (68^{+10}_{-11})^\circ$	$\gamma[\text{comb}] = (66^{+12}_{-12})^\circ$
$\gamma[\text{fit}] = (67.2^{+3.9}_{-3.9})^\circ$	$\gamma[\text{fit}] = (67.3^{+4.2}_{-3.5})^\circ$	$\gamma[\text{fit}] = (67.1^{+4.3}_{-4.3})^\circ$

$K - \bar{K}$ mixing in the SM

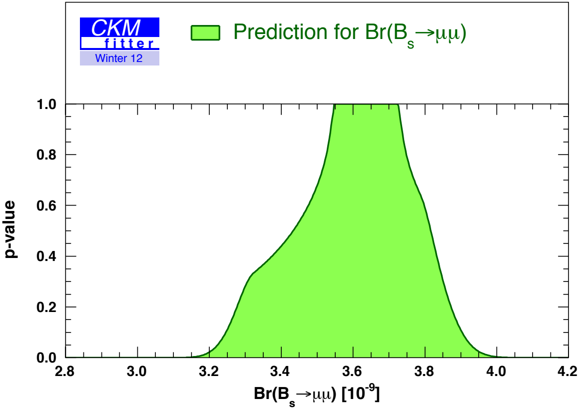
Impact of the statistical treatment of theoretical inputs on ϵ_K

$$\kappa_\epsilon,\ |V_{cb}|,\ \hat{B}_K,\ \eta_{ct,cc,tt},\ \bar{m}_{c,t}$$



- Gaussian error: 1.6 σ discrepancy
- Rfit error: no discrepancy

$B_s \to \mu\mu$ in SM



- Prediction: $Br(B_s \to \mu\mu) = (3.64^{+0.21}_{-0.32}) \cdot 10^{-9}$
- 95% CL bounds: $< 4.5 \cdot 10^{-9}$ [LHCb] and $7.7 \cdot 10^{-9}$ [CMS]

[see R. Fleischer's talk]

Predictions for $Br(B_s \to \mu\mu)$

$$Br(B_s \to \mu^+\mu^-) = \tau_{B_s} \frac{G_F^2}{\pi} \left(\frac{\alpha}{4\pi \sin^2\theta_W}\right)^2 f_{B_s}^2 m_{B_s} m_\mu^2 \sqrt{1 - \frac{4m_\mu^2}{m_{B_s}^2}} |V_{tb}^* V_{ts}|^2 \eta_Y^2 Y^2(x_t)$$

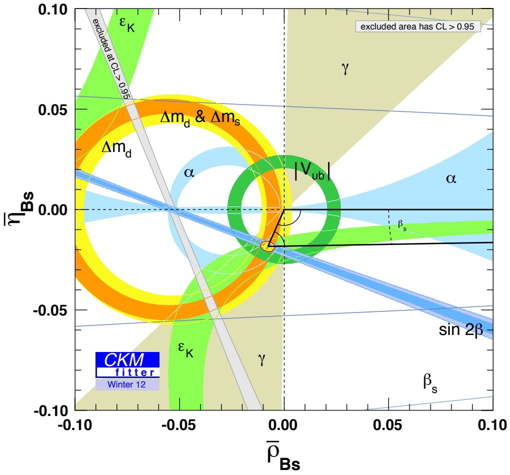
f_{B_s} constrained indirectly by Δm_s and B_{B_s} (both precisely known)

$$\frac{Br(B_s \to \mu^+\mu^-)}{\Delta m_s} = \eta_Y^2 \frac{6\pi}{\eta_B} \left(\frac{\alpha}{4\pi \sin^2\theta_W}\right)^2 \frac{m_\mu^2}{m_W^2} \frac{\tau_{B_s}}{\hat{B}_{B_s}} \frac{Y^2(x_t)}{S(x_t)} \Delta M_s$$

Inserting our Summer 11 best-fit values for the inputs
and comparing with [Buras et al 10]

Value	CKMfitter	Buras et al. 10
$\hat{B}_{B_s}$	1.248	1.33
$\bar{m}_t(\bar{m}_t)$ (GeV)	164.8	163.5
Δm_s (ps^{-1})	17.73	17.77
τ_{B_s} (ps)	1.472	1.425
$Br(B_s \to \mu\mu)$	$3.6 \cdot 10^{-9}$	$3.2 \cdot 10^{-9}$

Another unitarity triangle



$$\bar\rho_{B_s} + i\bar\eta_{B_s} = \arg\left(-\frac{V_{ub}V^*_{us}}{V_{cb}V^*_{cs}}\right)$$

SM mechanism for CP-violation encoded in CKM matrix describes efficiently B_d and B_s systems ?

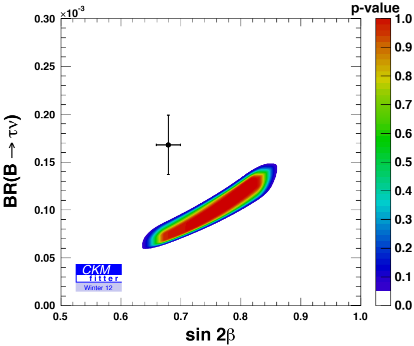
Not exactly:

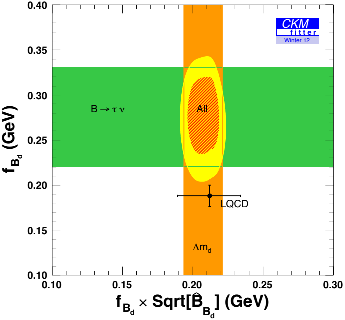
- $\sin(2\beta)$ vs $B \to \tau\nu$
- A_{SL}
- $(\beta_s, \Delta\Gamma_s)$ (?)

discrepancies which could be related to meson mixing

$\sin(2\beta)$ vs $B \to \tau\nu$

Global fit χ^2_{min} drops by 2.8σ if $\sin 2\beta_{c\bar{c}}$ or $B \to \tau\nu$ removed

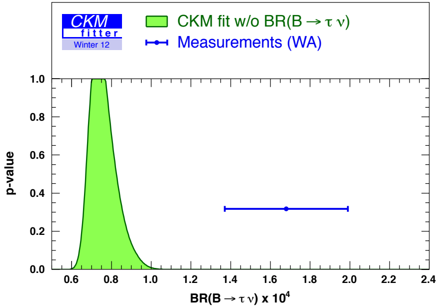


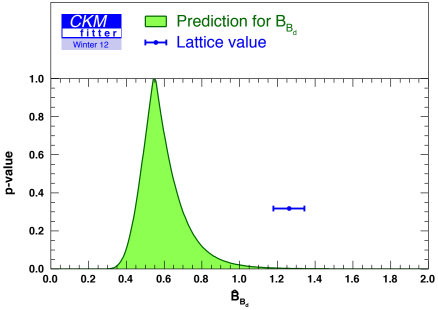


Issue *not only* the value of f_{B_d} since 2.9σ discrepancy from

$$\frac{Br(B \to \tau\nu)}{\Delta m_d} = \frac{3\pi}{4} \frac{m_\tau^2 \tau_B}{m_W^2 \eta_B S[x_t]} \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 \frac{\sin^2\beta}{\sin^2(\alpha+\beta)} \frac{1}{|V_{ud}|^2 B_{B_d}}$$

$\sin(2\beta)$ vs $B \to \tau\nu$

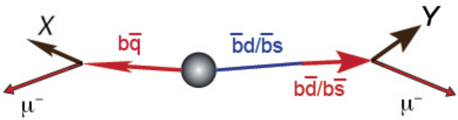


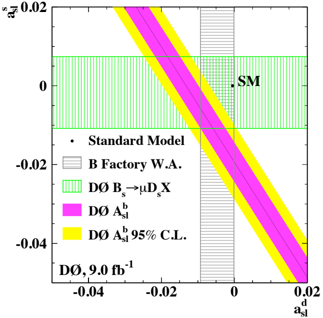


Possible explanations for this discrepancy

- $Br(B \to \tau\nu)$ measurement incorrect (2.6 σ) ?
- Correlated error in lattice values for f_{B_d} (2.6 σ) and B_{B_d} (2.7 σ) ?
- NP in decay (not 2HDMII [O. Deschamps et al. 10, Babar 12]) ?
- New physics in mixing ?

A_{SL}





- Same-sign dimuon charge asymmetry yields A_{SL} DØ, CDF

$$(-8.5 \pm 2.8) \cdot 10^{-3} \text{ [2010]} \to (-7.4 \pm 1.9) \cdot 10^{-3} \text{ [2011]}$$

- Linear comb. of semileptonic (flavour specific) asym. for $B_{d,s}$

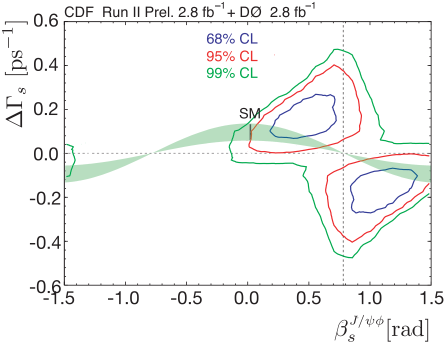
$$a^q_{SL} = \frac{\Gamma(\bar{B}_q(t)\to\ell^+\nu X)-\Gamma(B_q(t)\to\ell^-\nu X)}{\Gamma(\bar{B}_q(t)\to\ell^+\nu X)+\Gamma(B_q(t)\to\ell^-\nu X)} \neq 0 \Longrightarrow \text{CPV in mixing}$$

- Discrepancy from SM expectation $A_{SL} = -(0.20 \pm 0.03) \cdot 10^{-3}$

[Lenz, Nierste 11]

Angular analysis of $B_s \to J/\psi\phi$ to measure $(\phi_{Bs}, \Delta\Gamma_{Bs})$

In SM, $\phi_{Bs} \to -2\beta_s = 2 \cdot \arg(V_{cs} V_{cb}^* / V_{ts} V_{tb}^*) = -2.1^\circ \pm 0.1^\circ$



- 2010 CDF/DØ $\phi_{Bs} \in [-67.6^\circ, -30.9^\circ] U [-148.9^\circ, -111.1^\circ]$

ϕ_{Bs}

Angular analysis of $B_s \to J/\psi\phi$ to measure $(\phi_{Bs}, \Delta\Gamma_{Bs})$

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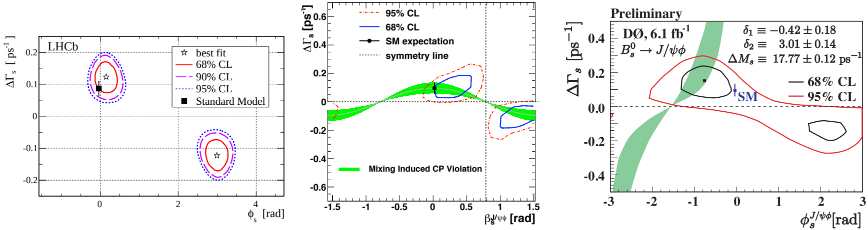

- 2011 a series of results dominated by LHCb
  - DØ (6.1 fb^{-1}): $\phi_{Bs} = -43.5^\circ{}^{+21.8^\circ}_{-20.6^\circ} \pm 1.2^\circ$
  - CDF (5.2 fb^{-1}): $\phi_{Bs} \in [-59.6^\circ, -2.3^\circ]$
  - LHCb $J/\psi f_0$ (0.4 fb^{-1}): $\phi_{Bs} = -25.2^\circ \pm 25.2^\circ \pm 1.2^\circ$
  - LHCb $J/\psi\phi$ (0.4 fb^{-1}): $\phi_{Bs} = 8.6^\circ \pm 10.3^\circ \pm 3.4^\circ$

ϕ_{Bs}

Angular analysis of $B_s \to J/\psi\phi$ to measure $(\phi_{Bs}, \Delta\Gamma_{Bs})$

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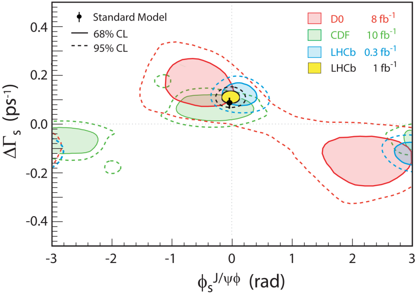


- 2012 updates
  - DØ (8.0 fb^{-1}): $\phi_{Bs} = -32^\circ{}^{+22^\circ}_{-21^\circ}$
  - CDF (9.6 fb^{-1}): $\phi_{Bs} \in [-34^\circ, -7^\circ]$
  - LHCb $J/\psi\phi$ (1 fb^{-1}): $\phi_{Bs} = -0.1^\circ \pm 5.8^\circ \pm 1.5^\circ$
  - LHCb $J/\psi K^+K^-$ (1 fb^{-1}): $\Delta\Gamma_s > 0$
- here: combine available LHCb and CDF $(\phi_{Bs}, \Delta\Gamma_s)$ likelihoods

  [LHCb: 0.4 fb^{-1} (2011) and 1 fb^{-1} (2012), CDF: 5.2 fb^{-1}]

$B - \bar{B}$ system

$$i\frac{d}{dt}\begin{pmatrix} |B_q(t)\rangle \\ |\bar{B}_q(t)\rangle \end{pmatrix} = \left(M^q - \frac{i}{2}\Gamma^q\right)\begin{pmatrix} |B_q(t)\rangle \\ |\bar{B}_q(t)\rangle \end{pmatrix}$$

- Non-hermitian Hamiltonian (only 2 states) but M and Γ hermitian
- Mixing due to non-diagonal terms $M^q_{12} - i\Gamma^q_{12}/2$

$\Longrightarrow$Diagonalisation: physical $|B^q_{H,L}\rangle = p|B_q\rangle \mp q|\bar{B}_q\rangle$

of masses $M^q_{H,L}$, widths $\Gamma^q_{H,L}$

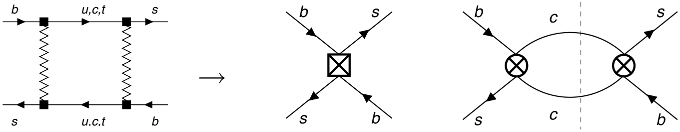
In terms of M^q_{12}, $|\Gamma^q_{12}|$ and $\phi_q = \arg\left(-\frac{M^q_{12}}{\Gamma^q_{12}}\right)$ [using $|\Gamma^q_{12}| \ll |M^q_{12}|$]

- Mass difference $\Delta m_q = M^q_H - M^q_L \simeq 2|M^q_{12}|$
- Width difference $\Delta\Gamma_q = \Gamma^q_L - \Gamma^q_H \simeq 2|\Gamma^q_{12}|\cos(\phi_q)$
- $a^q_{SL} = \frac{\Gamma(\bar{B}_q(t)\to\ell^+\nu X)-\Gamma(B_q(t)\to\ell^-\nu X)}{\Gamma(\bar{B}_q(t)\to\ell^+\nu X)+\Gamma(B_q(t)\to\ell^-\nu X)} \simeq \frac{|\Gamma^q_{12}|}{|M^q_{12}|}\sin\phi_q \simeq \frac{\Delta\Gamma_q}{\Delta m_q}\tan\phi_q$
- Phase from mixing in time-dep CP analyses

$$q/p \simeq -M^{q*}_{12}/|M^q_{12}| = -e^{-i\phi_{B_q}}$$

Computing neutral mixing in SM at NLO

Eff. Hamiltonian integrating out heavy W, Z, t

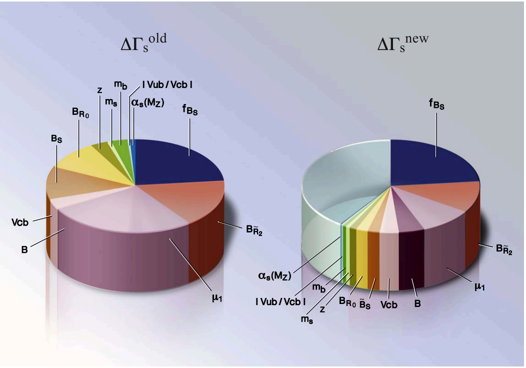


$$A_{\Delta B=2} = \langle \bar{B} | \mathcal{H}_{\rm eff}^{\Delta B=2} | B \rangle - \frac{1}{2} \int d^4x d^4y \langle \bar{B} | T \mathcal{H}_{\rm eff}^{\Delta B=1}(x) \mathcal{H}_{\rm eff}^{\Delta B=1}(y) | B \rangle$$

- M_{12}^q dominated by dispersive part of top boxes [Re[loops]]
  - related to heavy virtual states ($t\bar{t}\ldots$)
  - one operator at LO: $Q = \bar{q}_L \gamma_\mu b_L \bar{q}_L \gamma^\mu b_L$
  - $\arg(M_{12}^q)$ CKM phase: $\phi_{B_d} = 2\beta, \phi_{B_s} = -2\beta_s$
- Γ_{12}^q dominated by absorptive part of charm boxes [Im[loops]]
  [Beneke et al 1996-03, Ciuchini et al. 03]
  - common B and $\bar{B}$ decay channels into final states with $c\bar{c}$ pair
  - non local contribution, computed assuming quark-hadron duality and expanded in $1/m_b$ and α_s series of local operators
  - two operators at LO: Q and $\tilde{Q}_S = \bar{q}_L^\alpha b_R^\beta \bar{q}_L^\beta b_R^\alpha$

Uncertainties

Choice of operators Q and $\tilde{Q}_S$ important to compute Γ_{12}
depending mainly on Q, taming $1/m_b$-corrections



[Nierste and Lenz 2006]

- B and $\tilde{B}_S$ normalised contrib. from Q and $\tilde{Q}_S$ (bag params.)
- m_b^{pow}, B_{1/m_b} $1/m_b$-suppressed, unknown contrib.
- μ renormalisation scale $O(m_b)$

$$\Delta\Gamma_s = f[f_{Bs}, B, \tilde{B}_S; \mu, m_b^{pow}, B_{1/m_b}\ldots]$$

$$\Delta\Gamma_s/\Delta m_s = f[\tilde{B}_S/B; B_{1/m_b}, m_b^{pow}, \mu, \bar{m}_c\ldots]$$

$$a_{SL}^s = f[\tilde{B}_S/B; |V_{ub}/V_{cb}|, \gamma, \mu, \bar{m}_c, B_{1/m_b}\ldots]$$

New Physics in $\Delta F = 2$

- M_{12} dominated by (virtual) top boxes
  [affected by NP, e.g., if heavy new particles in the box]
- Γ_{12} dominated by tree decays into (real) charm states
  [affected by NP if changes in (constrained) tree-level decays]
- Tree level (4 diff flavours) processes not affected by New Physics

Model-independent parametrisation under the assumption that NP only changes modulus and phase of M_{12}^d and M_{12}^s

$$M_{12}^q = (M_{12}^q)_{SM} \times \Delta_q \qquad \Delta_q = |\Delta_q| e^{i\phi_q^\Delta}$$

affects Δm_q ($\leftrightarrow |\Delta_q|$), a_{SL}^q ($\leftrightarrow \Delta_q$), $\Delta\Gamma_q$ and ϕ_{B_q} ($\leftrightarrow \phi_q^\Delta$)

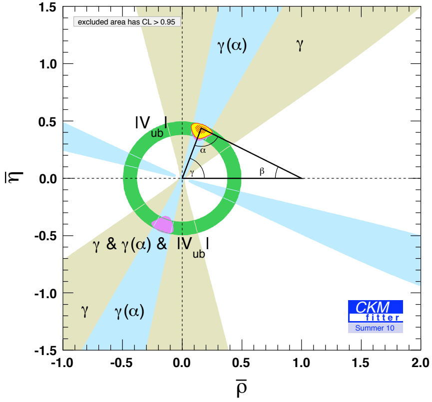
[A. Lenz et al., Phys.Rev. D83 (2011) 036004 and arXiv:1203.0238]

$\Longrightarrow$ 3 scenarios, focus on Sc. I where Δ_d and Δ_s independent

Fixing the CKM part

Observables not affected by NP, used to fix CKM :

$$|V_{ud}|,\ |V_{us}|,\ |V_{ub}|,\ |V_{cb}|,\ \gamma \text{ and } \gamma(\alpha) \equiv \pi - \alpha - \beta\ (\phi_{B_d} \text{ cancels})$$



Observables affected by NP, used to determine Δ_d, Δ_s

- Neutral-meson oscillation $\Delta m_{d,s}$
- Lifetime difference $\Delta\Gamma_{d,s}$
- Time-dep asymmetries related to $\phi_{B_d} = 2\beta + \phi_d^\Delta$, $\phi_{B_s} = -2\beta_s + \phi_s^\Delta$
- Semileptonic asymmetries a_{SL}^d, a_{SL}^s, A_{SL}
- $\alpha = \pi - \beta - \gamma - \phi_d^\Delta/2$ (interference between decay and mixing)

Some of the theoretical inputs

- B_d, B_s, f_{B_d}, f_{B_d} parameters
  our average of unquenched 2 and 2+1 lattice estimates
- Bag parameters for scalar operators from quenched lattice QCD
  [Becirevic et al. 02, updated expected from several lattice collaborations: preliminary results from HPQCD, ongoing work from MILC and ETMC]

$$\tilde{B}'^{s}_{S}(m_b)/\tilde{B}'^{d}_{S}(m_b) = 1.00 \pm 0.03 \quad \tilde{B}'^{s}_{S}(m_b) = 1.40 \pm 0.13$$

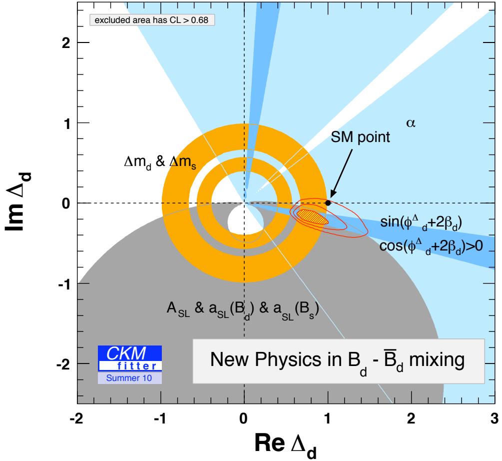
- $1/m_b$ suppressed operators: bag parameters (vacuum insertion approximation) and power correction scale

$$B_{Ri}(m_b) = 1.0 \pm 0.5 \qquad m_b^{\rm pow} = 4.70 \pm 0.10 \,\mathrm{GeV}$$

- charm mass from $\sigma(e^+e^- \to c\bar{c})$ sum rules to 3- and 4-loops
  [Steinhauser, Kühn 01-04, Jamin, Hoang 04, Dehnadi et al 11]

$$\bar{m}_c(\bar{m}_c) = 1.286 \pm 0.013 \pm 0.040 \,\mathrm{GeV}$$

B_d mixing (2010)

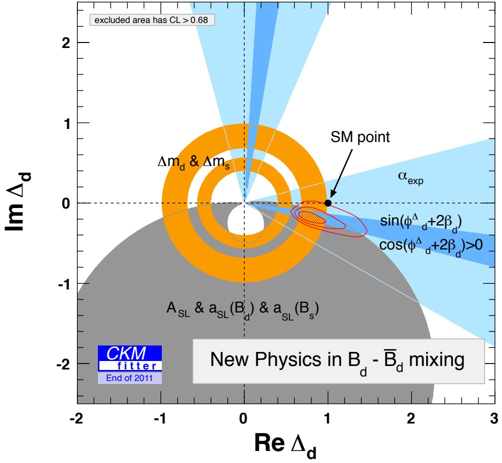


[Constraints @ 68% CL]

- Dominant constraint from β and Δm_d (2 rings from 2 sol for UT apex)
- Discrepancy from $Br(B \to \tau\nu)$ shifts β constraint from real axis
- Disagreement with SM driven in same dir by $Br(B \to \tau\nu)$ and A_{SL}

2D SM hypothesis ($\Delta_d = 1 + i \cdot 0$): 2.7 σ

B_d mixing (2011)

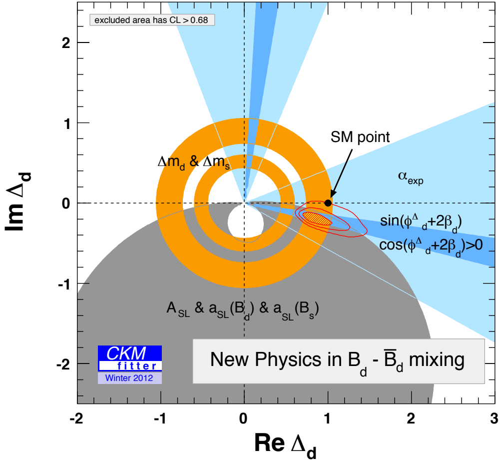


[Constraints @ 68% CL]

- Dominant constraint from β and Δm_d
- Discrepancy from $Br(B \to \tau\nu)$ shifts β constraint from real axis
- Disagreement with SM driven in same dir by $Br(B \to \tau\nu)$ and A_{SL}
- Improvement of γ, and thus contraint from $\alpha = \pi - \beta - \gamma - \phi_d^\Delta/2$

2D SM hypothesis ($\Delta_d = 1 + i \cdot 0$): 3.2 σ

B_d mixing (2012)

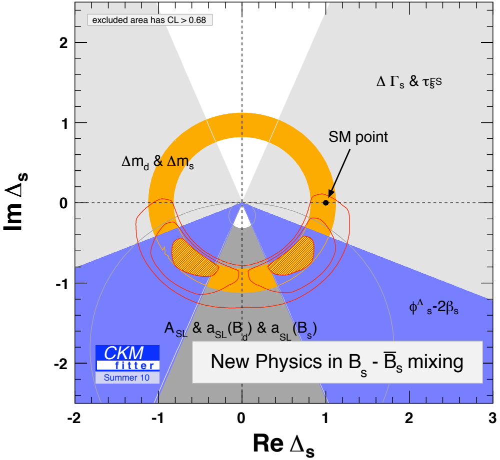


[Constraints @ 68% CL]

- Dominant constraint from β and Δm_d
- Discrepancy from $Br(B \to \tau\nu)$ shifts β constraint from real axis
- Disagreement with SM driven in same dir by $Br(B \to \tau\nu)$ and A_{SL}
- New results on γ and $\alpha = \pi - \beta - \gamma - \phi_d^{\Delta}/2$

2D SM hypothesis ($\Delta_d = 1 + i \cdot 0$): 3.0 σ

B_s mixing (2010)

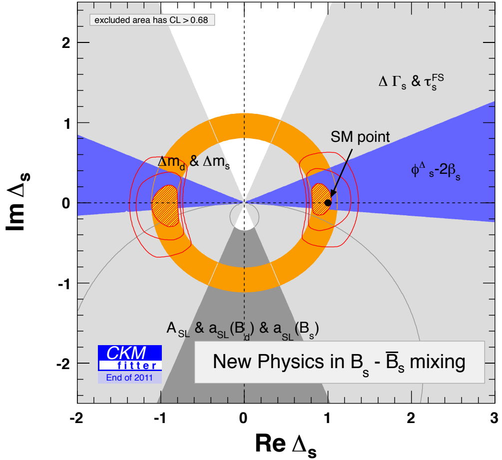


[Constraints @ 68% CL]

- Dominant constraints from Δm_s and ϕ_s
- Disagreement with SM driven by ϕ_s and A_{SL}
- In the same direction as for B_d mixing

2D SM hypothesis ($\Delta_s = 1 + i \cdot 0$): 2.7 σ

B_s mixing (2011)

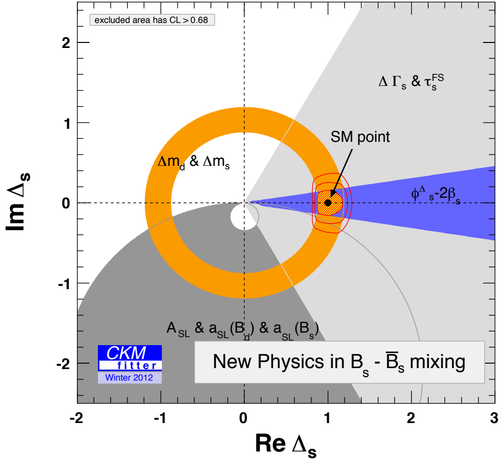


[Constraints @ 68% CL]

- Dominant constraints from Δm_s and ϕ_s
- Disagreement with SM driven by A_{SL} alone
- and in mild disagreement with ϕ_s, which favours SM situation

2D SM hypothesis ($\Delta_s = 1 + i \cdot 0$): 0.8σ

B_s mixing (2012)

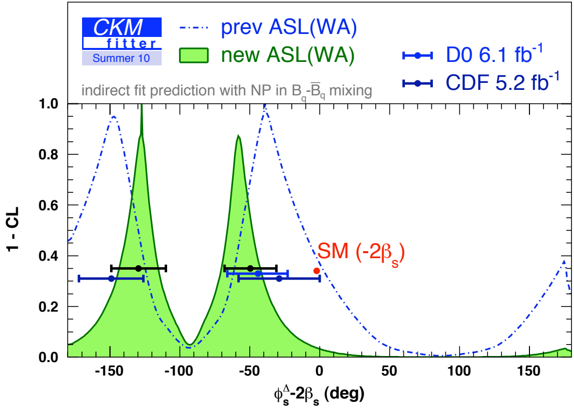


[Constraints @ 68% CL]

- Dominant constraints from Δm_s and ϕ_s
- Disagreement with SM driven by A_{SL} alone
- and in disagreement with ϕ_s, which favours SM situation
- but still room for NP $\phi_s^\Delta = (0^{+18}_{-18})^\circ$ at 3 σ
- $\Delta\Gamma_s > 0$ kills 2nd sol

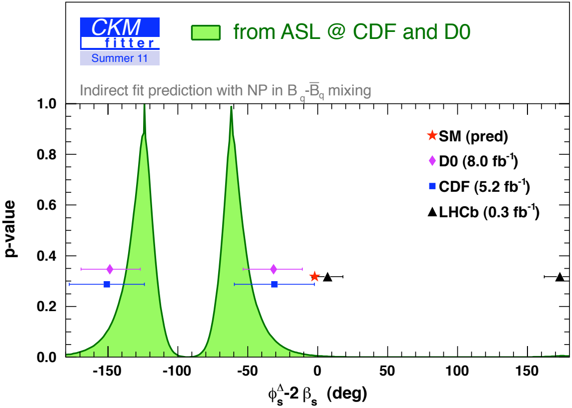
2D SM hypothesis ($\Delta_s = 1 + i \cdot 0$): 0.0 σ

Prediction for ϕ_s (2010)



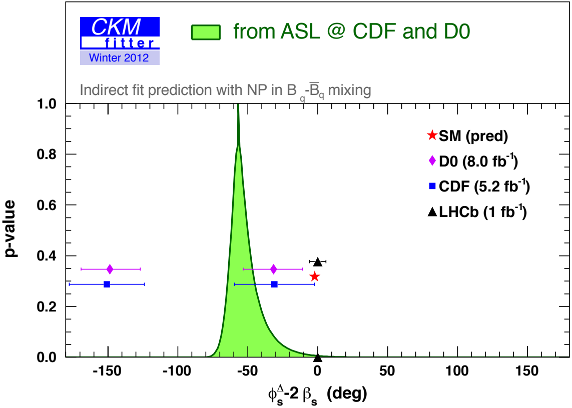
$$\phi_s^\Delta - 2\beta_s = (-127^{+13}_{-17})^\circ \qquad \text{or} \qquad (-58^{+17}_{-13})^\circ$$

Prediction for ϕ_s (2011)



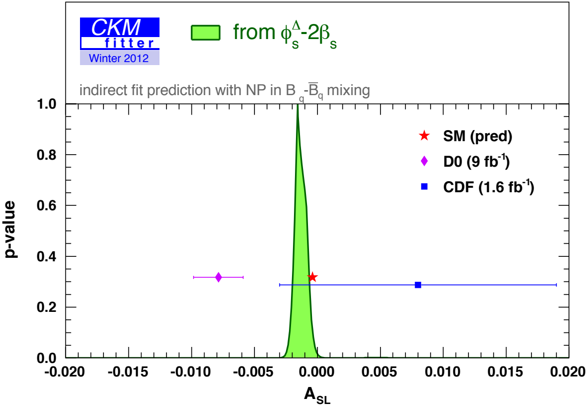
$$\phi_s^\Delta - 2\beta_s = (-124^{+9}_{-14})^\circ \qquad \text{or} \qquad (-62^{+14}_{-9})^\circ$$

Prediction for ϕ_s (2012)



$$\phi_s^\Delta - 2\beta_s = (-57^{+11}_{-7})^\circ$$

Prediction for $A_{SL}(2012)$



$$A_{SL} = (-15.6^{+9.2}_{-3.9}) \cdot 10^{-4}$$

A few predictions for Scenario I

Quantity	1σ	3σ
$\mathrm{Re}(\Delta_d)$	$0.823^{+0.143}_{-0.095}$	$0.82^{+0.54}_{-0.20}$
$\mathrm{Im}(\Delta_d)$	$-0.199^{+0.062}_{-0.048}$	$-0.20^{+0.18}_{-0.19}$
$\lvert\Delta_d\rvert$	$0.86^{+0.14}_{-0.11}$	$0.86^{+0.55}_{-0.22}$
ϕ_d^Δ [deg]	$-13.4^{+3.3}_{-2.0}$	$-13.4^{+12.1}_{-6.0}$
$\mathrm{Re}(\Delta_s)$	$0.965^{+0.133}_{-0.078}$	$0.97^{+0.30}_{-0.13}$
$\mathrm{Im}(\Delta_s)$	$-0.00^{+0.10}_{-0.10}$	$-0.00^{+0.32}_{-0.32}$
$\lvert\Delta_s\rvert$	$0.977^{+0.121}_{-0.090}$	$0.98^{+0.29}_{-0.15}$
ϕ_s^Δ [deg]	$-0.1^{+6.1}_{-6.1}$	$-0^{+18.}_{-18.}$
$\phi_d^\Delta + 2\beta$ [deg] (!)	$17^{+12.}_{-13.}$	$17^{+40.}_{-55.}$
$\phi_s^\Delta - 2\beta_s$ [deg] (!)	$-56.8^{+10.9}_{-7.0}$	$-57.^{+66.}_{-20.}$
A_{SL} $[10^{-4}]$ (!)	$-15.6^{+9.2}_{-3.9}$	-16^{+19}_{-12}
$a_{SL}^s - a_{SL}^d$ $[10^{-4}]$	$33.6^{+7.5}_{-8.2}$	34^{+24}_{-32}
a_{SL}^d $[10^{-4}]$ (!)	$-33.2^{+6.6}_{-4.1}$	-33^{+25}_{-13}
a_{SL}^s $[10^{-4}]$ (!)	$0.4^{+6.2}_{-6.3}$	0^{+20}_{-21}
$\Delta\Gamma_d[\mathrm{ps}^{-1}]$	$0.00480^{+0.00070}_{-0.00129}$	$0.0048^{+0.0020}_{-0.0031}$
$\Delta\Gamma_s[\mathrm{ps}^{-1}]$	$0.104^{+0.017}_{-0.016}$	$0.104^{+0.052}_{-0.041}$
$B \to \tau\nu$ $[10^{-4}]$ (!)	$1.341^{+0.064}_{-0.232}$	$1.34^{+0.20}_{-0.73}$

(!): prediction made without including measurement

Role of measurements

Pull: deviation between meas. and prediction (w/o meas.) in a model

Quantity	SM	Sc. I
$\phi_d^\Delta + 2\beta$	$2.7\ \sigma$	$2.1\ \sigma$
$\phi_s^\Delta - 2\beta_s$	$0.3\ \sigma$	$2.7\ \sigma$
A_{SL}	$3.7\ \sigma$	$3.0\ \sigma$
a_{SL}^d	$0.9\ \sigma$	$0.3\ \sigma$
a_{SL}^s	$0.2\ \sigma$	$0.2\ \sigma$
$\Delta\Gamma_s$	$0.0\ \sigma$	$0.4\ \sigma$
$Br(B \to \tau\nu)$	$2.8\ \sigma$	$1.1\ \sigma$
$Br(B \to \tau\nu), A_{SL}$	$4.3\ \sigma$	$2.8\ \sigma$
$\phi_s^\Delta - 2\beta_s, A_{SL}$	$3.3\ \sigma$	$2.7\ \sigma$
$Br(B \to \tau\nu), \phi_s^\Delta - 2\beta_s, A_{SL}$	$4.0\ \sigma$	$2.4\ \sigma$

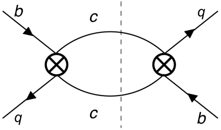
- If given the possibility, Sc. I tries to accomodate data by modifying ϕ_s or A_{SL}
- Sc. I not able to accomodate $\phi_s^\Delta - 2\beta_s$ and A_{SL} at the same time
- but can accomodate one of the two and $Br(B \to \tau\nu)$

4D SM hypothesis ($\Delta_d = \Delta_s = 1 + i \cdot 0$): $2.4\ \sigma$

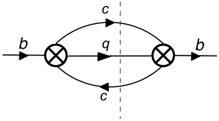
New physics also in Γ_{12}^s ?

$$\Delta m_s = 2|M_{12}^s| \qquad \Delta\Gamma_s = 2|\Gamma_{12}^s|\cos(\phi_s) \qquad a_{SL}^s = \frac{\Gamma_{12}^s}{M_{12}^s}\sin(\phi_s)$$

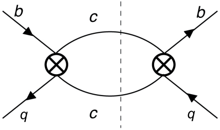
Could solve A_{SL}, but $\Delta\Gamma_s$ deviates w.r.t. SM and $\Delta B = 1$ modified



Γ_{12}^q, M_{12}^q



Inclusive



$\tau(B_s)/\tau(B_d)$

Change in Cabibbo Favoured $b \to c\bar{c}s$ or new decay mode affects

- Inclusive B_d and B^+ quantities
- Γ_s and thus $\tau(B_s)/\tau(B_d)$
- M_{12}^s (same box diagrams with same particles as Γ_{12}^s), thus Δm_s

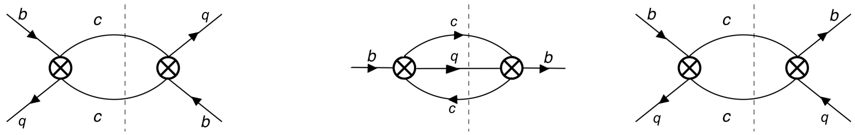
(all in agreement with SM)

No model-independent way of connecting $\Gamma_{12}^s, \Gamma_{11}^s, M_{12}^s$

New physics also in Γ_{12}^d ?

$$\Delta m_d = 2|M_{12}^d| \qquad \Delta\Gamma_d = 2|\Gamma_{12}^d|\cos(\phi_d) \qquad a_{SL}^d = \frac{\Gamma_{12}^d}{M_{12}^d}\sin(\phi_d)$$

Could solve A_{SL}, with deviation of $\Delta\Gamma_d$ w.r.t. SM (but not measured)



Γ_{12}^q, M_{12}^q — Inclusive — $\tau(B_s)/\tau(B_d)$

Change in Cabibbo Suppressed $b \to c\bar{c}d$ modes would

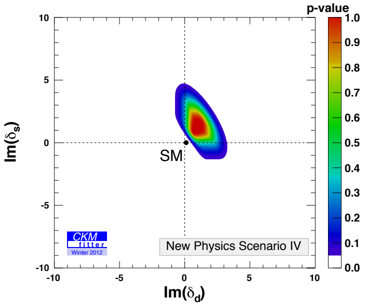
- barely affect inclusive B_d and B^+ quantities
- barely affect Γ_d and thus $\tau(B_s)/\tau(B_d)$
- impact M_{12}^d (same box diag with same particles as Γ_{12}^d), thus Δm_d
  $\Longrightarrow$evaded via chirality suppression (?)

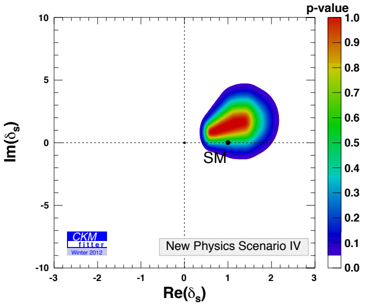
NP in $b \to c\bar{c}d$ interesting: to be checked through a_d^{SL}, non-lept ?

A fourth scenario

Extending Sc. I to allow NP in Γ_{12}^q parametrised by

$$\delta_q = \frac{\Gamma_{12}^q / M_{12}^q}{\mathrm{Re}(\Gamma_{12}^{SM,q} / M_{12}^{SM,q})} \qquad \mathrm{Re}\ \delta_q, \mathrm{Im}\ \delta_q \leftrightarrow \frac{\Delta\Gamma_q/\Delta m_q}{\Delta\Gamma_q^{SM}/\Delta M_q^{SM}}, \frac{-a_{SL}^q}{\Delta\Gamma_q^{SM}/\Delta M_q^{SM}}$$





8D SM hyp ($\Delta_{d,s} = 1 + i \cdot 0$, $\delta_d = 1 + 0.097i$, $\delta_s = 1 - 0.0057i$): 2.6σ

Sc. IV with $\delta_s = \delta_s^{SM}$ needs "too" large $\mathrm{Im}\delta_d = 1.60^{+1.02}_{-0.76}$ [$a_{SL}^d \simeq A_{SL}$]

Conclusions

Interesting recent data concerning neutral meson mixing

- Discrepancy in SM for $Br(B \to \tau\nu)$ vs $\sin 2\beta$ [new $B \to \tau\nu$ (Belle)]
- Discrepancy in SM for A_{SL} [separate a_{SL}^d and a_{SL}^s (LHCb)]
- $(\beta_s, \Delta\Gamma_s)$ [more from LHCb ?]

Scenarios of NP in $\Delta F = 2$

- Still room for sizeable NP contribution in B_s system at 3σ
- Conflict between current A_{SL} and ϕ_s not solved by NP in M_{12} only
- Could be solved by NP in Γ_{12}^q, however related also to $\Delta F = 1$
- NP in Γ_{12}^s affects other SM-compatible observables in mixing $(\Delta m_s, \Delta\Gamma_s, \Gamma_s)$ as well as in $b \to s$ decays
- NP in Γ_{12}^d more interesting since Cabibbo suppression helps for many constraints, to be checked with a_{SL}^d and non-leptonic decays

More

CKM fitter

- Home
- Plots & Results
- Specific Studies
- Talks & Writeups
- Publications
- CKMfitter Group

CKMfitter global fit results as of Moriond 12:

- Wolfenstein parameters
- UT angles and sides
- UT_s angle and apex
- CKM elements
- Theory parameters
- Rare branching fractions (B→lν, B→ll)

For a more extensive discussion, please read the summary of inputs and results.

Wolfenstein parameters and Jarlskog invariant:

Observable	Central ± 1 σ	± 2 σ	± 3 σ
A	0.812 [+0.015 -0.022]	0.812 [+0.025 -0.031]	0.812 [+0.035 -0.039]
λ	0.22543 [+0.00059 -0.00095]	0.2254 [+0.0010 -0.0019]	0.2254 [+0.0013 -0.0027]
ρbar	0.145 [+0.027 -0.027]	0.145 [+0.046 -0.040]	0.145 [+0.057 -0.050]
ηbar	0.343 [+0.015 -0.015]	0.343 [+0.030 -0.026]	0.343 [+0.044 -0.035]
J [10^{-5}]	2.96 [+0.18 -0.14]	2.96 [+0.32 -0.19]	2.96 [+0.46 -0.23]

UT angles and sides:

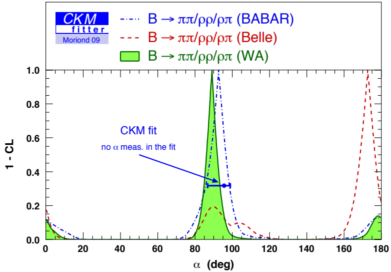
Observable	Central ± 1 σ	± 2 σ	± 3 σ
sin 2α	-0.04 [+0.15 -0.15]	-0.04 [+0.22 -0.24]	-0.04 [+0.27 -0.30]
sin 2α (meas. not in the fit)	-0.206 [+0.195 -0.074]	-0.21 [+0.38 -0.12]	-0.21 [+0.44 -0.17]
sin 2β	0.691 [+0.020 -0.020]	0.691 [+0.040 -0.034]	0.691 [+0.060 -0.047]
sin 2β (meas. not in the fit)	0.820 [+0.024 -0.028]	0.820 [+0.037 -0.086]	0.820 [+0.049 -0.159]
α [deg]	91.1 [+4.3 -4.3]	91.1 [+7.1 -6.2]	91.1 [+8.8 -7.8]
α [deg] (meas. not in the fit)	95.9 [+2.2 -5.6]	95.9 [+3.6 -10.9]	95.9 [+5.0 -12.8]
α [deg] (dir. meas.)	88.7 [+4.6 -4.2]	88.7 [+9.4 -8.5] ‖ 178.4 [+2.0 -5.7] ‖ -1.8 [+7.1 -5.5]	89 [+21 -13] ‖ 178.4 [+2.4 -14.0] ‖ -2 [+14 -14]
β [deg]	21.85 [+0.80 -0.77]	21.9 [+1.6 -1.3]	21.9 [+2.5 -1.8]
β [deg] (meas. not in the fit)	27.5 [+1.2 -1.4]	27.5 [+1.9 -3.9]	27.5 [+2.6 -6.8]
β [deg] (dir. meas.)	21.38 [+0.79 -0.77]	21.4 [+1.6 -1.5]	21.4 [+2.4 -2.3]
γ [deg]	67.1 [+4.3 -4.3]	67.1 [+6.1 -7.0]	67.1 [+7.6 -8.5]
γ [deg] (meas. not in the fit)	67.2 [+4.4 -4.6]	67.2 [+6.1 -7.2]	67.2 [+7.6 -8.7]

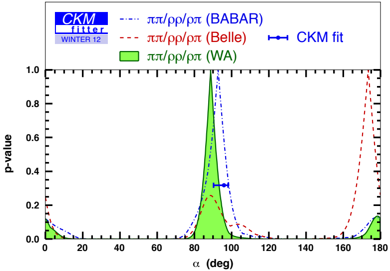
More plots and results available on
http://ckmfitter.in2p3.fr

J. Charles, Theory
O. Deschamps, LHCb
SDG, Theory
R. Itoh, Belle
H. Lacker, ATLAS/BaBar
A. Menzel, ATLAS
S. Monteil, LHCb
V. Niess, LHCb
J. Ocariz, ATLAS/BaBar
J. Orloff, Theory
S. T'Jampens, LHCb
V. Tisserand, BaBar/LHCb
K. Trabelsi, Belle

Back-up

- LHCb results for $C(\pi\pi)$ and $S(\pi\pi)$ presented at Moriond 2012
- Belle results for $Br(\pi\pi)$ and $Br(\pi^+\pi^0)$ presented at EPS2011





Summer 11

$$\alpha[\text{comb}] = (89.0^{+4.4}_{-4.2})^\circ$$

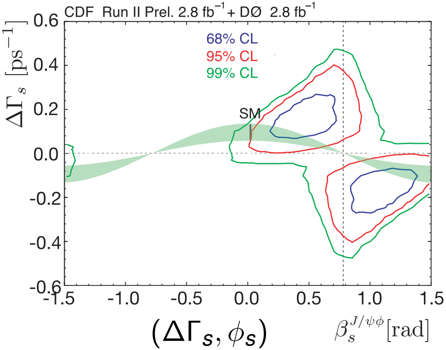
$$\alpha[\text{fit}] = (90.9^{+3.5}_{-4.1})^\circ$$

Winter 12

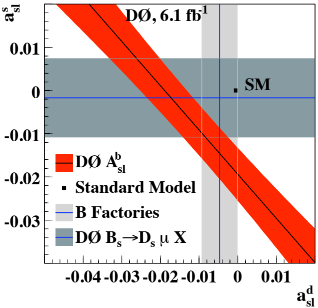
$$\alpha[\text{comb}] = (88.7^{+4.6}_{-4.2})^\circ$$

$$\alpha[\text{fit}] = (91.1^{+4.3}_{-4.3})^\circ$$

Three discrepancies in 2010



$(\Delta\Gamma_s, \phi_s)$

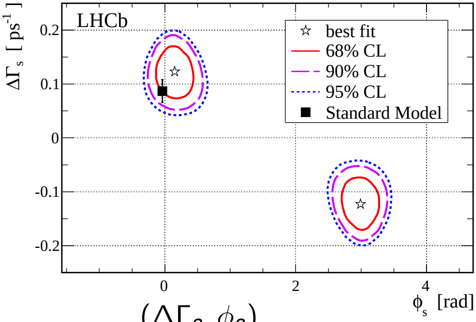


Linear comb of a^d_{SL} and a^s_{SL}

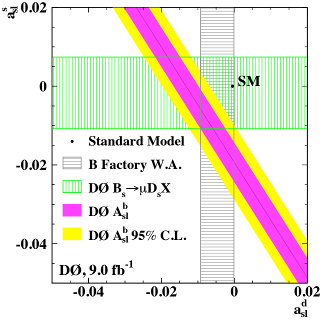
- $B \to \tau\nu$ vs $\sin 2\beta$ — 1D constraint : 2.6 σ
- β_s from $B_s \to J/\psi\phi$ and τ_{FS} (null test) — 1D constraint : 2.1 σ
- A_{SL} (null test) — 1D constraint : 2.9 σ

[pre-ICHEP10 $(\beta_s, \Delta\Gamma_s)$, since no CDF/DØ updated average]

Two discrepancies in 2011



$(\Delta\Gamma_s, \phi_s)$

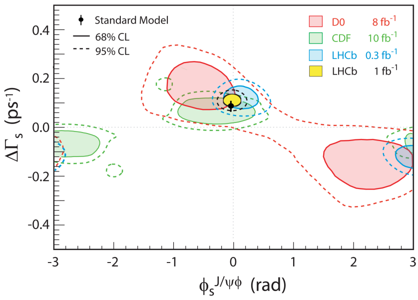


Linear comb of a^d_{SL} and a^s_{SL}

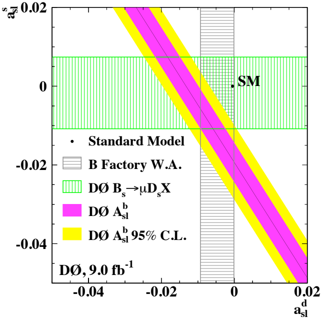
- $B \to \tau\nu$ vs $\sin 2\beta$ — 1D constraint : 2.8 σ
- β_s from $B_s \to J/\psi\phi$ and τ_{FS} (null test) — 1D constraint : 1.0 σ
- A_{SL} (null test) — 1D constraint : 3.7 σ

[CDF(5.2 fb^{-1})/LHCb(0.4 fb^{-1}) $(\beta_s, \Delta\Gamma_s)$ average from $B_s \to J/\psi\phi$]

Two discrepancies in 2012



$(\Delta\Gamma_s, \phi_s)$



Linear comb of a^d_{SL} and a^s_{SL}

- $B \to \tau\nu$ vs $\sin 2\beta$ — 1D constraint : 2.8 σ
- β_s from $B_s \to J/\psi\phi$ and τ_{FS} (null test) — 1D constraint : 0.3 σ
- A_{SL} (null test) — 1D constraint : 3.7 σ

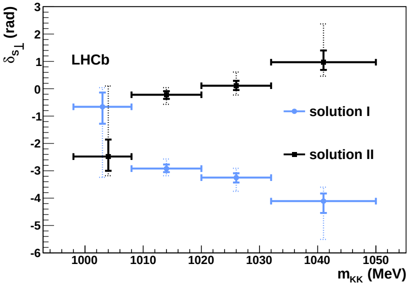
[CDF(5.2 fb^{-1})/LHCb(1 fb^{-1}) $(\beta_s, \Delta\Gamma_s)$ average from $B_s \to J/\psi\phi$]

Measurement of $\Delta\Gamma_s > 0$

Two solutions for $(\phi_s, \Delta\Gamma_s)$ from $B_s \to J\Psi\phi$

- Sol I: $\phi_s \simeq 0$, $|B_{sL(H)}\rangle$ almost aligned with $CP = +1(-1)$, $\Delta\Gamma_s > 0$
- Sol II: $\phi_s \simeq \pi$, $|B_{sL(H)}\rangle$ almost aligned with $CP = -1(+1)$, $\Delta\Gamma_s < 0$

$B_s^0 \to J/\Psi K^+ K^-$ [LHCb 12]



- P-wave final state superposition of $CP = +1$ and $CP = -1$
- S-wave final state $CP = -1$
- Interference between S- and P-wave, with $\delta_S - \delta_P$ expected to decrease rapidly around ϕ

$\Longrightarrow$ Sol I is preferred

Tagged vs untagged analyses for B_s decays

- Theoretical branching ratios computed at $t = 0$ (no B_s mixing)
- Untagged analyses with single decay time $t \in [0, \infty[$ [LHCb]

$$\langle \Gamma_{untagged}(t) \rangle_{CP} = \frac{1}{2}[\Gamma_{untagged}(B(t) \to f) + \Gamma_{untagged}(\bar{B}(t) \to f)]$$

$$\propto \frac{|A_f|^2 + |\bar{A}_f|^2}{2} e^{-\Gamma t} \times \left[\cosh \frac{\Delta\Gamma t}{2} + A_{\Delta\Gamma} \sinh \frac{\Delta\Gamma t}{2}\right]$$

- Entangled pairs with 2 decay times t_{CP} and $t_{\rm tag}$ [B-factories]

$\Gamma_{\rm tagged}(B(t) \to f)$ from $\Gamma_{\rm untagged}(B(t) \to f)$ with

$$\exp(-\Gamma t) \to \exp(-\Gamma |t|) \qquad t = t_{CP} - t_{\rm tag} \in]-\infty, \infty[$$

[BaBar Physics Book, SDG et al 11, De Bruyn et al 12]

$$\int_{-\infty}^{+\infty} \langle \Gamma_{tagged}(B(t) \to f) \rangle_{CP} = Br(B_s \to f)_{\rm theo} \frac{1}{1 - y_s^2} \qquad y_s = \frac{\Delta\Gamma_s}{2\Gamma_s}$$

$$\int_0^{\infty} \langle \Gamma_{untagged}(B(t) \to f)_{CP} \rangle = Br(B_s \to f)_{\rm theo} \frac{1 + y_s A_{\Delta\Gamma}}{1 - y_s^2}$$

What $Br(B_s \to f)$ means

- Theoretically: CP-average at fixed $t = 0$
- Experimentally: CP-average integrated over t (including mixing)

$O(\Delta\Gamma_s/\Gamma_s)$ difference [SDG et al 11, De Bruyn et al 12]

- Tagged analyses with entangled pairs @ B-factories

$$Br(B_s \to f)_{\rm theo} = (1 - y_s^2) Br(B_s \to f)_{\rm exp,tag} \qquad y_s = \frac{\Delta\Gamma_s}{2\Gamma_s}$$

- Untagged analyses @ LHCb

$$Br(B_s \to f)_{\rm theo} = \frac{1 - y_s^2}{1 + A^f_{\Delta\Gamma} y_s} Br(B_s \to f)_{\rm exp,untag}$$

$$\Gamma(B_s(t) \to f) + \Gamma(\bar{B}_s(t) \to f) = e^{-\Gamma_H t/2}(1 + A^f_{\Delta\Gamma}) + e^{-\Gamma_L t/2}(1 - A^f_{\Delta\Gamma})$$

For SM $B_s \to \mu\mu$, $A^f_{\Delta\Gamma} = 1$ enhances the effect [De Bruyn et al 12]

$$Br(B_s \to \mu\mu)_{\rm theo} \simeq 0.91 \cdot Br(B_s \to \mu\mu)_{\rm exp,untag}$$

bringing exp. bounds on $Br(B_s \to \mu\mu)$ closer to theoretical predictions

Three different NP scenarios for eff. Hamiltonian

- Minimal Flavour Violat. with small bottom Yukawa coupling (sc II)

$$H^{|\Delta B|=2} = (V_{tq}^* V_{tb})^2 CQ + h.c. \qquad C \text{ real}$$

$\Delta_d = \Delta_s$ real, related to K-meson mixing

- MFV with large bottom Yukawa coupling (sc III)

$$H^{|\Delta B|=2} = (V_{tq}^* V_{tb})^2 [CQ + C_S Q_S + \tilde{C}_S \tilde{Q}_S] + h.c.$$

$\Delta_d = \Delta_s$ complex, unrelated to K-meson mixing

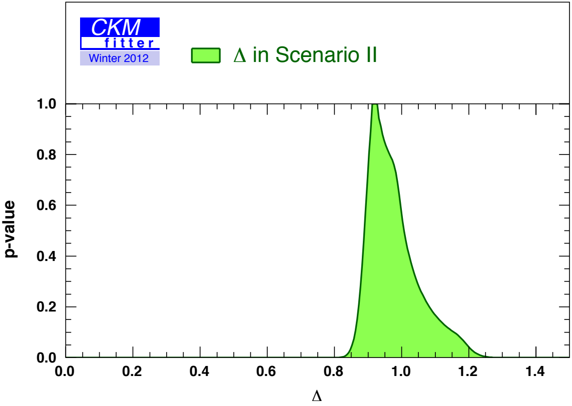
- Non Minimal Flavour Violation (sc I)

$$H^{|\Delta B|=2} = (V_{tq}^* V_{tb})^2 C_q Q + h.c.$$

Δ_d, Δ_s complex independent, unrelated to K-meson mixing

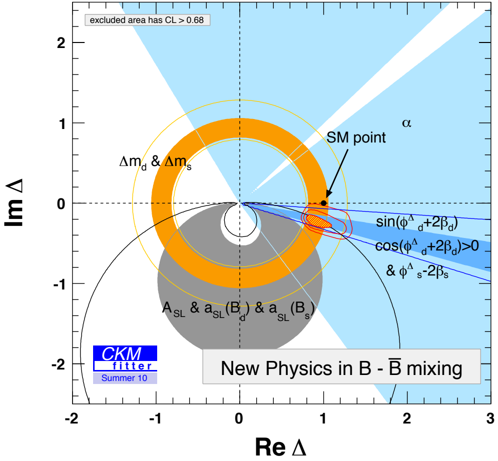
$\Longrightarrow$ Will focus mainly on the latter scenario in the following

Scenario II (2012)



$$\Delta = 0.920^{+0.120}_{-0.039}$$

Scenario III (in 2010)

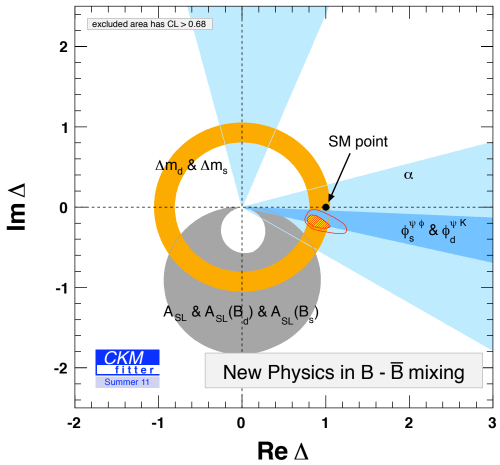


[Constraints @ 68% CL]

- Minimal Flavour Violation with large bottom Yukawa coupling
- $\Delta_d = \Delta_s = \Delta$ complex
- All three discrepancies in the same direction

2D SM hypothesis ($\Delta = 1 + i \cdot 0$): 3.3σ

Scenario III (in 2011)

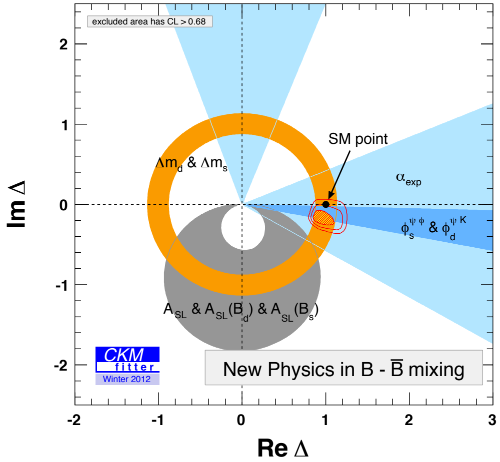


[Constraints @ 68% CL]

- Minimal Flavour Violation with large bottom Yukawa coupling
- $\Delta_d = \Delta_s = \Delta$ complex
- discrepancy among data more acute in this scenario: A_{SL} in one direction, $B_s \to J/\psi\phi$ in another, with $\sin(2\beta)$ standing in the middle

2D SM hypothesis ($\Delta = 1 + i \cdot 0$): 2.7σ

Scenario III (in 2012)



[Constraints @ 68% CL]

- Minimal Flavour Violation with large bottom Yukawa coupling
- $\Delta_d = \Delta_s = \Delta$ complex
- discrepancy among data more acute in this scenario: A_{SL} in one direction, $B_s \to J/\psi\phi$ in another, with $\sin(2\beta)$ standing in the middle

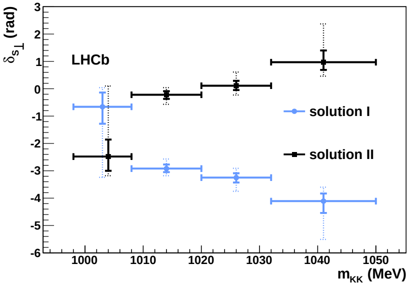
2D SM hypothesis ($\Delta = 1 + i \cdot 0$): 2.1σ

Measurement of $\Delta\Gamma_s > 0$

Two solutions for $(\phi_s, \Delta\Gamma_s)$ from $B_s \to J\Psi\phi$

- Sol I: $\phi_s \simeq 0$, $|B_{sL(H)}\rangle$ almost aligned with $CP = +1(-1)$, $\Delta\Gamma_s > 0$
- Sol II: $\phi_s \simeq \pi$, $|B_{sL(H)}\rangle$ almost aligned with $CP = -1(+1)$, $\Delta\Gamma_s < 0$

$B_s^0 \to J/\Psi K^+ K^-$ [LHCb 12]

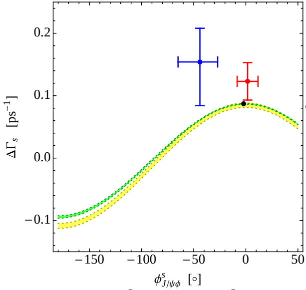


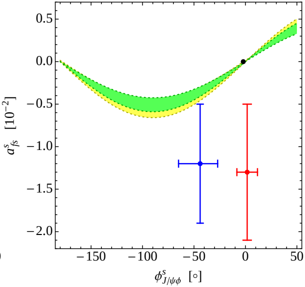
- P-wave final state superposition of $CP = +1$ and $CP = -1$
- S-wave final state $CP = -1$
- Interference between S- and P-wave, with $\delta_S - \delta_P$ expected to decrease rapidly around ϕ

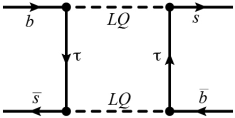
$\Longrightarrow$ Sol I is preferred

Example of NP in Γ_{12}^s

- $\tau\bar\tau$ intermediate states due to NP $(\bar b s)(\bar\tau\tau)$ operators, chirality suppression to tame contribution to M_{12}^s
- Eff. Hamiltonian analysis of $b \to s\gamma$, $b \to s\ell^+\ell^-$, $b \to s\gamma\gamma$ room for scalar or vector ops. able to enhance $|\Gamma_{12}^s|$ by 30-40%







[Haisch, Bobeth 11]

- But M_{12}^s and Γ_{12}^s correlated in specific models (e.g., $SU(2)$ singlet scalar leptoquark) making it difficult to accomodate all data
- General problem for $(M_{12}^s)_{NP}/(\Gamma_{12}^s)_{NP}$ real, linking Δm_s, $\Delta\Gamma_s$, a_{SL}^s [weakest Δm_s constraint if light NP scale or GIM-like mechanism]

Lattice : Averages

Consistent averages of lattice results for hadronic quantities needed
$\Longrightarrow$ we perform our own averages

- Collecting lattice results
  - only unquenched results with 2 or 2+1 dynamical fermions
  - papers and proceedings (but not preliminary results)
- Splitting error estimates into stat and syst
  - Stat : essentially related to size of gauge conf
  - Syst : fermion action, $a \to 0$, $L \to \infty$, mass extrapolations...
    added linearly when error budget available
- Potential problems
  - proceedings not always followed by peer-reviewed papers
  - some syst estimates controversial within lattice community (staggered action, extrapolations...)

Lattice : Averaging procedure

"Educated Rfit" used to combine the results, with different treament of statistical and systematic errors

- product of (Gaussian + Rfit) likelihoods for central value
- product of Gaussian (stat) likelihoods for stat uncertainty
- syst uncertainty of the combination
  = the one of the most precise method

Conservative, algorithmic procedure with internal logic for syst

- the present state of art cannot allow us to reach a better theoretical accuracy than the best of all estimates
  (combining 2 methods with similar syst does not reduce the intrinsic uncertainty encoded as a systematic)
- best estimate should not be penalized by less precise methods
  (opposed, e.g., to combined syst = dispersion of central values)

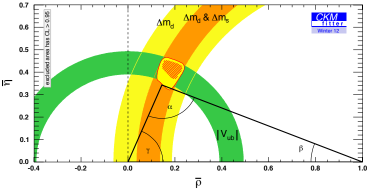
Lattice : Our average for $B_K^{\bar{M}S}(2\text{ GeV})$

Reference	N_f	Mean	Stat	Syst
JLQCD08	2	0.537	0.004	0.072
ETMC10	2	0.532	0.019	0.026
HPQCD/UKQCD06	2+1	0.618	0.018	0.179
ALVdW09	2+1	0.527	0.006	0.035
RBC/UKQCD10	2+1	0.549	0.005	0.038
SWME11	2+1	0.530	0.003	0.052
Our average		0.534	0.002	0.026
Our average for $\hat{B}_K$		0.732	0.003	0.036

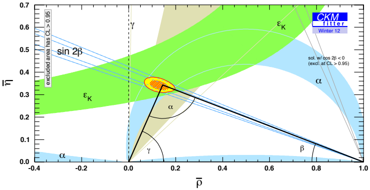
- Other values proposed: 0.767 ± 0.010 (latticeaverages.org) 0.738 ± 0.020 (FLAG), 0.731 ± 0.035 (UTfit)...
- Method used for B_d and B_s decay constants, bag parameters, form factors...

Lattice : Our average for $\hat{B}_s$

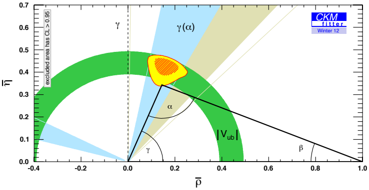
Reference	N_f	Mean	Stat	Syst
JLQCD03	2	1.299	0.034	$^{+0.122}_{-0.087}$
HPQCD06	2+1	1.187	0.086	0.108
HPQCD09	2+1	1.322	0.040	0.035
Our average		1.291	0.025	0.035



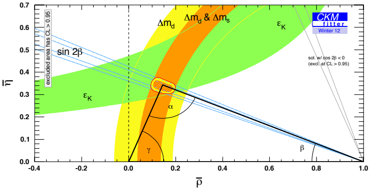
CP allowed only



CP violating only



Tree only



Loop only

Validity of Kobayashi-Maskawa picture of *CP* violation

$|V_{ub}|$ inclusive and exclusive

Two ways of getting $|V_{ub}|$:

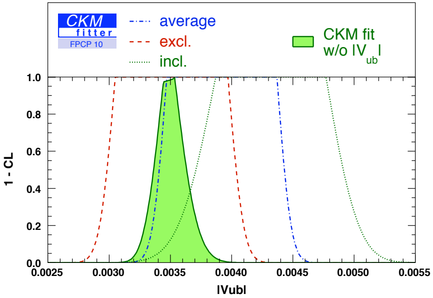
- Inclusive : $b \to u\ell\nu$ + Operator Product Expansion
- Exclusive : $B \to \pi\ell\nu$ + Form factors

$$|V_{ub}|_{inc} = 4.32^{+0.21}_{-0.24} \pm 0.45$$

$$|V_{ub}|_{exc} = 3.51 \pm 0.10 \pm 0.46$$

$$|V_{ub}|_{ave} = 3.92 \pm 0.09 \pm 0.45$$

with all values $\times 10^{-3}$



Discrepancy depends on statistical treatment:

- discrepancy solved once systematics combined in Educated Rfit
- same problem for $|V_{cb}|$

Interesting penguin-mediated decays

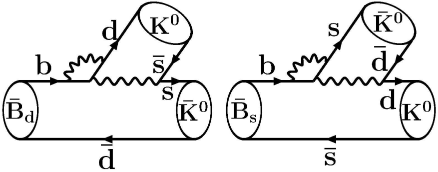
Penguin-mediated decays provide way to check "NP in $\Delta F = 2$" hyp.

[SDG, Matias, Virto 2011]

Consider tree and penguin decomposition of $B_Q \to K^0 \bar{K}^0$ $(Q = d, s)$

$$\bar{A} \equiv A(\bar{B}_Q \to K^0 \bar{K}^0) = V_{ub} V_{uq}^* T + V_{cb} V_{cq}^* P$$

$$A \equiv A(B_Q \to K^0 \bar{K}^0) = V_{ub}^* V_{uq} T + V_{cb}^* V_{cq} P \qquad b \to q(= Q)$$



Only penguin diagrams

no contrib. from W-exch. $(O_{1,2})$

Difference between tree and penguin from u, c, t quarks in loop

$\Longrightarrow \delta = T - P$ dominated by short-distance physics computed fairly accurately within QCD factorisation (exp. in α_s, $1/m_b$)

$$\delta(B_d \to K^0 \bar{K}^0) = (1.09 \pm 0.43) \cdot 10^{-7} + i(-3.02 \pm 0.97) \cdot 10^{-7} \mathrm{GeV}$$

$$\delta(B_s \to K^0 \bar{K}^0) = (1.03 \pm 0.41) \cdot 10^{-7} + i(-2.85 \pm 0.93) \cdot 10^{-7} \mathrm{GeV}$$

Various penguin-mediated modes of interest

Channel	$\lvert\delta\rvert$ $(10^{-7}\,\mathrm{GeV})$
$B_d \to K\bar{K}$	(3.23 ± 1.16)
$B_s \to \bar{K}K$	(3.05 ± 1.11)
$B_d \to K\phi$	(2.32 ± 1.00)
$B_d \to K\bar{K}^*$	(2.29 ± 0.93)
$B_d \to K^*\bar{K}$	(0.41 ± 0.60)
$B_s \to \bar{K}K^*$	(2.16 ± 0.89)
$B_s \to \bar{K}^*K$	(0.36 ± 0.53)
$B_d \to K^*\bar{K}^*$	(1.85 ± 0.93)
$B_s \to \bar{K}^*K^*$	(1.62 ± 0.81)
$B_d \to K^*\phi$	(1.92 ± 1.03)
$B_s \to \phi K^*$	(1.87 ± 0.94)
$B_s \to \phi\phi$	(3.86 ± 2.09)

- Penguin modes for B_Q decaying through $b \to q$ transition ($Q, q = d, s$)
- For VV modes, only observables for a longitudinally polarised final states (transverse polar. are $1/m_b$-suppressed, only modelled in QCD factorisation)
- Which requires one to translate measurements into “longitudinal observables” (BR, asymmetries)

Relating $\delta = T - P$ and observables

In terms of $A \equiv A(B_Q \to M_1 M_2)$ and $\bar{A} \equiv A(\bar{B}_Q \to M_1 M_2)$

- $b \to q$ penguin mediated decay into state of CP-parity η_f
- $BR = g_{ps}(|A|^2 + |\bar{A}|^2)/2$ with g_{ps} phase space factor
- 3 CP asymmetries with $A^2_{\rm dir} + A^2_{\rm mix} + A^2_{\Delta\Gamma} = 1$

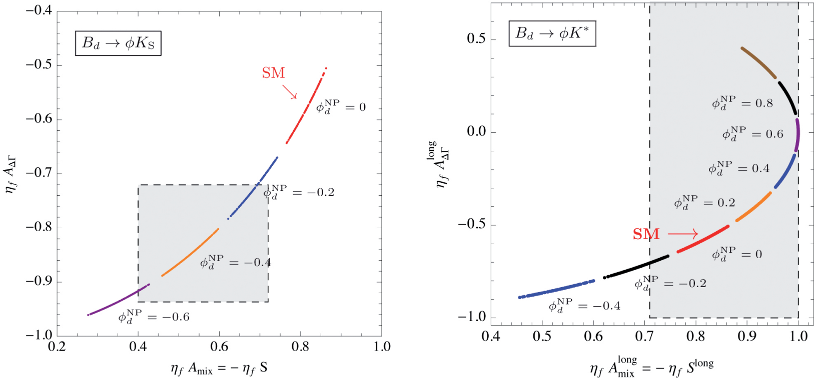
$$A_{\rm dir} \equiv \frac{|A|^2 - |\bar{A}|^2}{|A|^2 + |\bar{A}|^2} \qquad A_{\rm mix} + iA_{\Delta\Gamma} \equiv -2\eta_f \frac{e^{-i\phi_{B_Q}} A^* \bar{A}}{|A|^2 + |\bar{A}|^2}$$

Assuming NP affects only phase in B_Q mixing ($\Delta_Q = e^{i\phi^\Delta_Q}$)

$$2g_{ps}|\delta|^2 |V_{cb}V^*_{cq}|^2 \sin^2\beta_q = BR(1 - \eta_f \sin\Phi_{Qq} A_{\rm mix} + \eta_f \cos\Phi_{Qq} A_{\Delta\Gamma})$$

- $\Phi_{Qq} = 2\beta_Q - 2\beta_q + \phi^{\rm NP}_Q$ $\qquad (\phi^{\rm NP}_d = \phi^\Delta_d,\ \phi^{\rm NP}_s = -\phi^\Delta_s)$,
- Constraint on $A_{\rm dir}$ (near zero) for a solution $\phi^{\rm NP}_Q$ to exist
- Determine $\phi^{\rm NP}_Q$ from $|\delta|$, BR, $A_{\rm mix}$ (and CKM from tree decays)

Illustration for two measured modes



$B_d \to \phi K_s$ $\qquad$ $B_d \to \phi K^*$

- 1σ range for $(A_{\rm mix}, A_{\Delta\Gamma} = \pm\sqrt{1 - A_{\rm mix}^2 - A_{\rm dir}^2})$ in grey box
- $\phi_d^{NP}(\phi K_S) = -0.36 \pm 0.22$ rad, $\phi_d^{NP}(\phi K^*) = 0.33 \pm 0.90$ rad