CKM fits and charm decays

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Introduction

End of the first B-factory era, Tevatron reign before LHC results

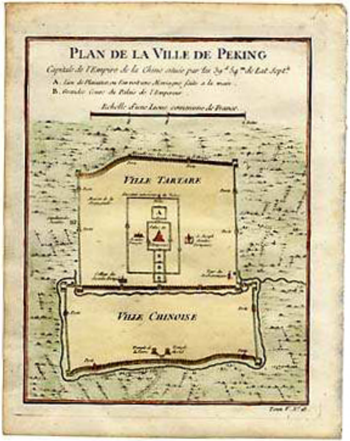
- High-precision data entangling electroweak and strong physics
- Stringent test of SM, and in particular of Kobayashi-Maskawa mechanism for CP violation
- Opportunity to test (and constrain) extensions of SM through flavour physics data

Global CKM fits relevant players in this game
both to check SM and provide directions for New Physics

What can we learn from the weak interactions of charm ?

- QCD : hard to compute analytically, but good prospects of improved accuracy from lattice
- SM : complementary K and D sectors ($V_{ud} \simeq V_{cs}$, $V_{us} \simeq V_{cd}$)
- New Physics : investigating u-type sector, as b-factories for d-type

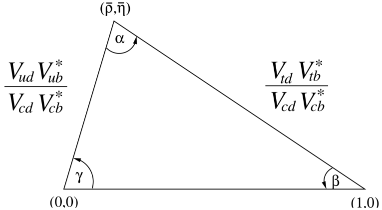
Mapping CP-violation



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

The inputs

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

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

$\lvert V_{ud}\rvert$	superallowed β decays	PRC79, 055502 (2009)
$\lvert V_{us}\rvert$	$K_{\ell 3}$ (Flavianet)	$f_+(0) = 0.963 \pm 0.003 \pm 0.005$
ϵ_K	PDG 08	$\hat{B}_K = 0.723 \pm 0.004 \pm 0.067$
$\lvert V_{ub}\rvert$	inclusive and exclusive	$\lvert V_{ub}\rvert \cdot 10^3 = 3.92 \pm 0.09 \pm 0.45$
$\lvert V_{cb}\rvert$	inclusive and exclusive	$\lvert V_{cb}\rvert \cdot 10^3 = 40.89 \pm 0.38 \pm 0.59$
Δm_d	last WA B_d-$\bar{B}_d$ mixing	$B_{B_s}/B_{B_d} = 1.05 \pm 0.01 \pm 0.03$
Δm_s	last WA B_s-$\bar{B}_s$ mixing	$B_{B_s} = 1.28 \pm 0.02 \pm 0.03$
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
$B \to \tau\nu$	$(1.68 \pm 0.31) \cdot 10^{-4}$	$f_{B_s}/f_{B_d} = 1.199 \pm 0.008 \pm 0.023$ $f_{B_s} = 228 \pm 3 \pm 17$ MeV

Lattice

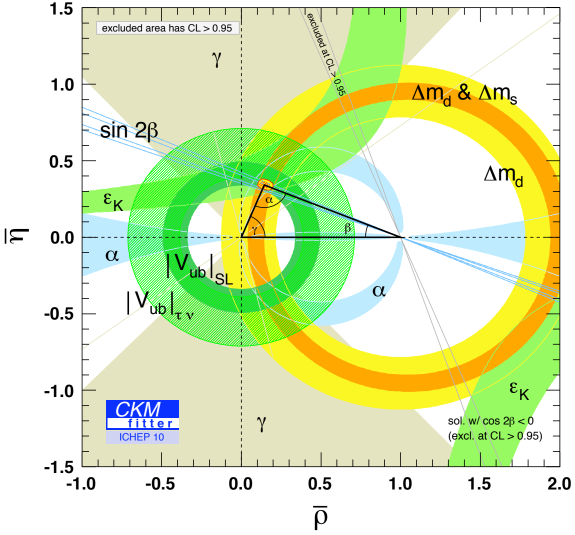
Consistent averages of lattice results for hadronic quantities needed
$\Longrightarrow$ we perform our own averages of published
$N_f = 2$ and 2+1 results using "Educated Rfit" procedure

- central value : product of Gaussian (stat) + Rfit (syst) likelihoods
- combined stat uncertainty : product of Gaussian (stat) likelihoods
- combined syst uncertainty : 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)

The global fit

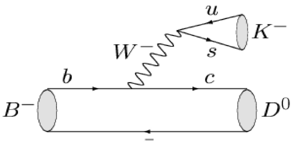


$|V_{ud}|, |V_{us}|$
$|V_{cb}|, |V_{ub}|$
$B \to \tau\nu$
$\Delta m_d, \Delta m_s$
ϵ_K
$\sin 2\beta$
α
γ

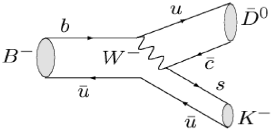
$$A = 0.8184^{+0.0094}_{-0.0311}$$
$$\lambda = 0.22512^{+0.00075}_{-0.00075}$$
$$\bar\rho = 0.139^{+0.027}_{-0.023}$$
$$\bar\eta = 0.342^{+0.016}_{-0.015}$$
(68% CL)

Focus on γ

γ angle from interference between $B^- \to D^0 K^-$ and $B^- \to \bar{D}^0 K^-$



colour allowed
$A\lambda^3$



colour suppressed
$A\lambda^3(\rho + i\eta)$

$$r_B = \frac{|A_{suppr}|}{|A_{favour}|} \simeq \frac{|V_{ub} V_{cs}^*|}{|V_{cb} V_{us}^*|} \times [1/N_c] \sim 0.1 - 0.2$$

- GLW : D into CP eigenstates (KK, $\pi\pi$, $K_S\pi^0$, $K_S\omega$, $K_S\phi$)
- ADS : $D^{(*)}$ into doubly Cabibbo suppressed states
- GGSZ : $D^{(*)}$ into 3-body state and Dalitz analysis

Combined results on γ

Increased statistics on GGSZ ($DK^{\pm}$, $D^*K^{\pm}$, $DK^{*\pm}$ with $D^* \to D\pi^0$, $D^0\gamma$ and $D \to K^0_S\pi^+\pi^-$) (Babar takes also neutral D into $K^0_S K^+ K^-$)

Belle [arXiv:1003.3360]
BaBar[arXiv:1005.1096]

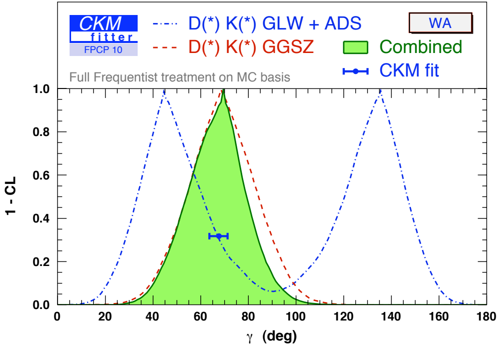
All methods combined :

$$\gamma = (70^{+14}_{-21})^\circ$$

From the global fit :

$$\gamma = (67.7^{+3.6}_{-4.1})^\circ$$

(68%CL)



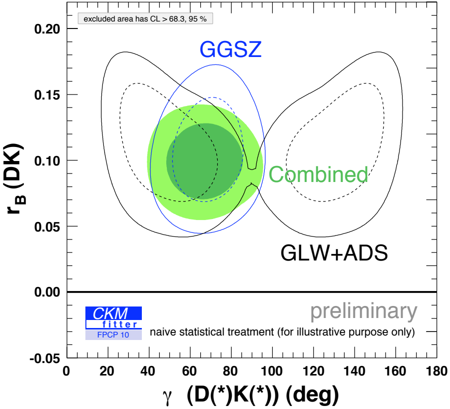
Far less precise than α and β,

$\Longrightarrow$and driven by one methode (GGSZ) : why is it so ?

Hadronic inputs for γ methods

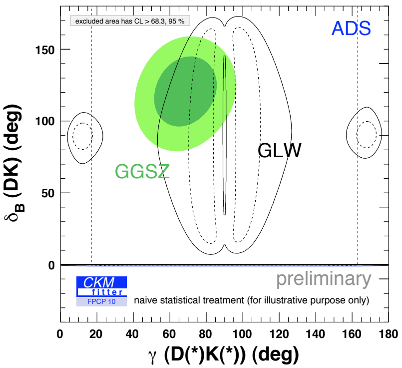
Not only γ in 3 methods, also $A(B^- \to \bar{D}K^-)/A(B^- \to DK^-) = r_B e^{i\delta_B}$

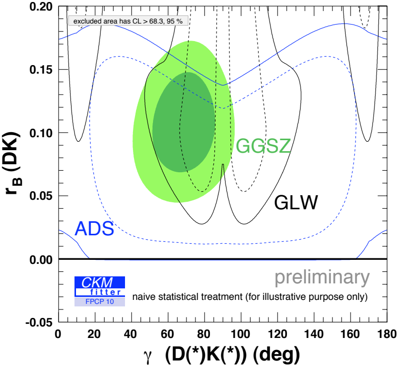
- GLW ($D_{CP}K, D^*_{CP}K, D_{CP}K^*$)
  $R_{CP\pm} = 1 \pm 2r_B \cos\delta_B \cos\gamma + r_B^2 \quad A_{CP\pm} = \pm 2r_B \sin\delta_B \sin\gamma / R_{CP\pm}$
- ADS (DK, D^*K, DK^* for $K\pi \ldots$)
  $R_{ADS} = r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D)\cos\gamma$
  $A_{ADS} = \frac{2r_B r_D \sin(\delta_B+\delta_D)\sin\gamma}{R_{ADS}}$
- GGSZ (DK, D^*K, DK^*)
  $x_\pm = r_B \cos(\delta_B \pm \gamma)$
  $y_\pm = r_B \sin(\delta_B \pm \gamma)$



Needs agreement on had. qties to increase accuracy on γ

The three methods w.r.t hadronic inputs



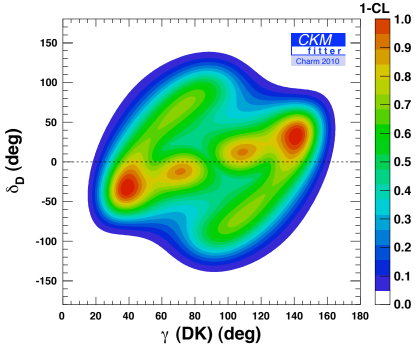


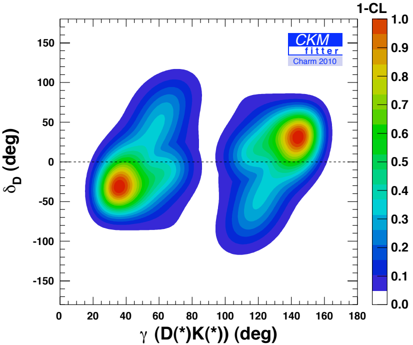
$$R_{GLW,CP\pm} = 1 \pm 2r_B \cos\delta_B \cos\gamma + r_B^2 \qquad A_{GLW,CP\pm} = \pm\frac{2r_B \sin\delta_B \sin\gamma}{R_{ADS,CP\pm}}$$

$$R_{ADS} = r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D)\cos\gamma \qquad A_{ADS} = \frac{2r_B r_D \sin(\delta_B+\delta_D)\sin\gamma}{R_{ADS}}$$

- Symmetry $(\delta_B, \delta_D, \gamma) \to (-\delta_B, -\delta_D, -\gamma)$
- For ADS: (r_B, δ_B) not enough, (r_D, δ_D) nuisance parameters

Impact of charm on ADS+GLW



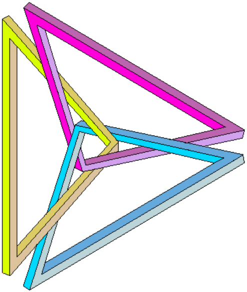


$$R_{GLW,CP\pm} = 1 \pm 2r_B \cos\delta_B \cos\gamma + r_B^2 \qquad A_{GLW,CP\pm} = \pm\frac{2r_B \sin\delta_B \sin\gamma}{R_{ADS,CP\pm}}$$

$$R_{ADS} = r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D)\cos\gamma \qquad A_{ADS} = \frac{2r_B r_D \sin(\delta_B+\delta_D)\sin\gamma}{R_{ADS}}$$

$r_D e^{i\delta_D} = A(D^0 \to K^+\pi^-)/A(D^0 \to K^-\pi^+)$ (and in particular δ_D)
needed to put GLW+ADS on a par with GGSZ

D-meson and the unitarity triangle(s)

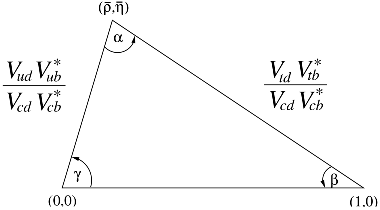


The D-meson unitarity triangle

Unitarity of the CKM matrix for (b, d)

$$\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} + 1 + \frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*} = 0$$

$$O(1) + 1 + O(1) = 0$$

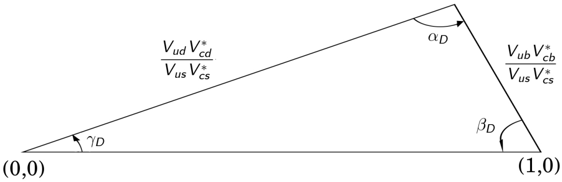


The D-meson unitarity triangle

Unitarity of the CKM matrix for (c, u)

$$\frac{V_{ud}V_{cd}^*}{V_{us}V_{cs}^*}+1+\frac{V_{ub}V_{cb}^*}{V_{us}V_{cs}^*}=0$$

$$O(1)+1+O(\lambda^4)=0$$

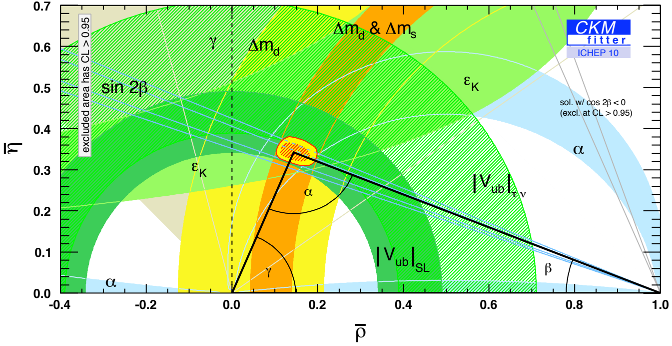


can be used to define a (squashed) D-meson unitarity triangle

- $\bar\rho_D + i\bar\eta_D = -\frac{V_{ud}V_{cd}^*}{V_{us}V_{cs}^*}$
- $\alpha_D = \arg\left(-\frac{V_{ub}V_{cb}^*}{V_{ud}V_{cd}^*}\right) = \arg\left(-\frac{V_{ub}V_{ud}^*}{V_{cb}V_{cd}^*}\right) = -\gamma$
- $\gamma_D = \arg\left(-\frac{V_{ud}V_{cd}^*}{V_{us}V_{cs}^*}\right) = O(\lambda^4)$
- $\beta_D = \arg\left(-\frac{V_{us}V_{cs}^*}{V_{ub}V_{cb}^*}\right) = \pi - \alpha_D - \gamma_D = \pi + \gamma + O(\lambda^4)$

Current constraints on *D* unitarity triangle

In the SM, kaon and *B*-processes constrain strongly *D*-UT,
squashed with two almost parallel sides



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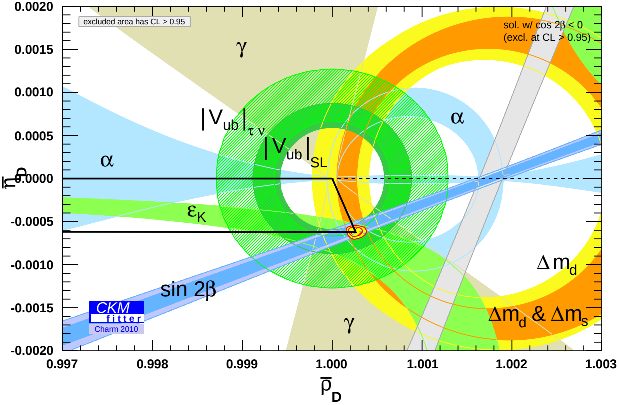


What on CKM from charm ?

CP-violating observables

- CP-violation very difficult to observe in D meson
- ...and hard to control theoretically
- Diffcult to extract information from D_0-$\bar{D}_0$ mixing
- Constraining loop NP effects $\Delta C = 2$ but issue of long distances

CP-conserving observables

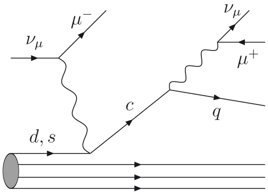
- Provide $|V_{cd}|$ and $|V_{cs}|$
- Accessible through leptonic and semileptonic D-decays
- Hadronic part controlled through lattice simulations
- Constraining for NP in tree decays

$\Longrightarrow$ Focus on latter observables both for SM and NP

Direct non-lattice constraints on $|V_{cd}|$ and $|V_{cs}|$

- $|V_{cd}|$: deep-inelastic scattering of ν, $\bar\nu$ on nucleons

$$\frac{d^3\sigma(\nu_\mu N \to \mu^+\mu^- X)}{d\xi dy dx} = \frac{d^2\sigma(\nu_\mu N \to cX)}{d\xi dy} D_{\mathrm{c}\to\mathrm{hadron}}(z) B_c(c \to \mu^+ X)$$



D hadronisation of c, B_c weighted average of cross-sections of charm mesons

$$\frac{d^2\sigma_{LO}(\nu_\mu N \to cX)}{d\xi dy} \propto [|V_{cd}|^2 d(\xi) + |V_{cs}|^2 s(\xi)]$$

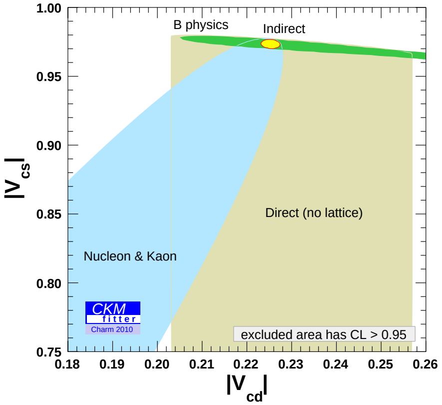
νN vs $\bar\nu N$: s cancel and $|V_{cd}|$ up to modelling of d parton distribution

- $|V_{cs}|$: charmed-tagged W decays $W \to cs$

$$|V_{cd}| = 0.230 \pm 0.011 \qquad \sigma(|V_{cd}|)/|V_{cd}| = 5\%$$

$$|V_{cs}| = 0.94^{+0.32}_{-0.26} \pm 0.13 \qquad \sigma(|V_{cs}|)/|V_{cs}| = 34\% \ (!)$$

Direct (non-lattice) vs indirect measurements



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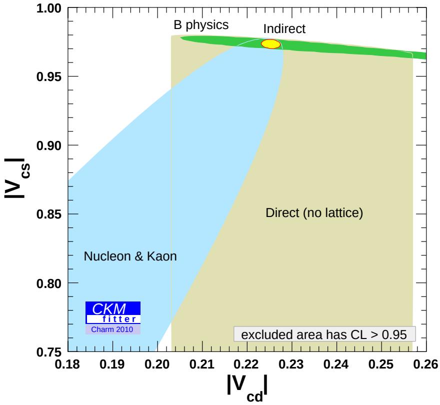

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$$|V_{cd}| = 0.230^{+0.009}_{-0.015}$$

$$|V_{cs}| = 0.972^{+0.004}_{-0.003}$$

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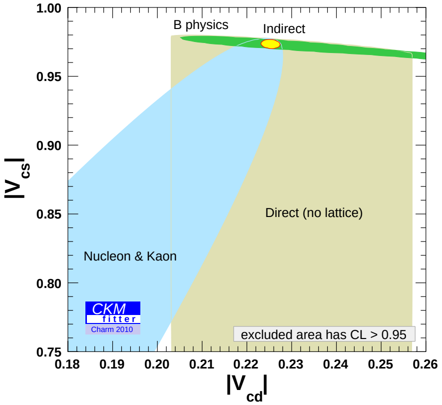

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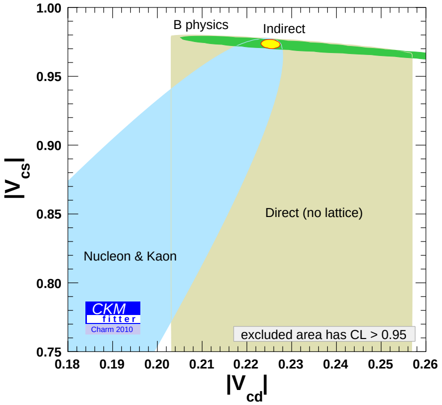

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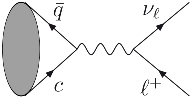
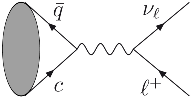
- Indirect (combination of the two above): already quite well determined: $|V_{cd}| = 0.2253 \pm 0.0001$ $|V_{cs}| = 0.9743^{+0.0002}_{-0.0002}$
- Direct (no lattice inputs): poorly known

(ellipse deformed by $|V_{cd}|^2 + |V_{cs}|^2 \leq 1$)

$|V_{cs}|$ from leptonic decays



$$\Gamma(D_s \to \ell\nu) = \frac{G_F^2}{8\pi}|V_{cs}|^2 f_{D_s}^2 m_\ell^2 m_{D_s}\left(1-\frac{m_\ell^2}{m_{D_s}^2}\right)^2 + O(\alpha)$$



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f_{D_s} (MeV)	Reference	Article	N_f	Mean	Stat	Syst
	CP-PACS00	0010009	2	267	13	$^{+27}_{-17}$
	MILC02	0206016	2	241	5	$^{+41}_{-30}$
	ETMC09	0904.0954	2	244	3	9
	HPQCD03	0311130	2+1	290	20	64
	FNAL-MILC09	0912.5221	2+1	260	6.8	14
	HPQCD10	1008.4018	2+1	248	1.4	4.5
	Our average			251.2	1.2	4.5

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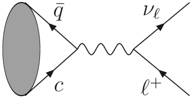

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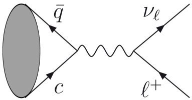
$\lvert V_{cs}\rvert f_{D_s}$ (MeV)		
	CLEO-c, Belle ($D_s \to \mu\nu$)	$254.3 \pm 9.6 \pm 1.8$
	Babar ($D_s \to \mu\nu$)	$231.1 \pm 16.3 \pm 1.7$
	CLEO-c, Babar ($D_s \to \tau\nu$)	$247.7 \pm 7.4 \pm 1.8$
	HFAG Average	248.0 ± 5.7

(last error correlated, from τ_{D_s})

$|V_{cd}|$ from leptonic decays



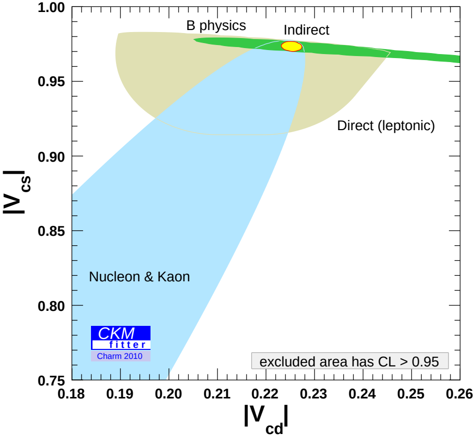
$$\Gamma(D \to \ell\nu) = \frac{G_F^2}{8\pi}|V_{cd}|^2 f_D^2 m_\ell^2 m_D \left(1 - \frac{m_\ell^2}{m_D^2}\right)^2 + O(\alpha)$$

f_{D_s}/f_D	Reference	Article	N_f	Mean	Stat	Syst
	CP-PACS00	0010009	2	1.182	0.039	$^{+0.087}_{-0.046}$
	MILC02	0206016	2	1.14	0.01	$^{+0.06}_{-0.07}$
	ETMC09	0904.0954	2	1.24	0.03	0.01
	HPQCD07	0706.1726	2+1	1.164	0.006	0.020
	FNAL-MILC09	0912.5221	2+1	1.200	0.016	0.025
	Our average			1.186	0.005	0.010

$|V_{cd}|f_D$ (MeV) CLEO-c ($D \to \mu\nu$) + PDG $46.4 \pm 1.9 \pm 0.6$ MeV

$\Longrightarrow$A lot to gain from more measurements. . .

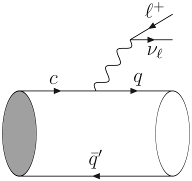
Leptonic decays



- Leptonic decays: $|V_{cd}| = 0.216^{+0.015}_{-0.014}$, $|V_{cs}| = 0.973^{+0.006}_{-0.026}$
- Indirect: $|V_{cd}| = 0.2253 \pm 0.0001$, $|V_{cs}| = 0.9743^{+0.0002}_{-0.0002}$

$|V_{cd}|$ from semileptonic decays

- Differential decay rate $\frac{d\Gamma(D\to\pi e\nu)}{dq^2} = \frac{G_F^2|V_{cd}|^2}{24\pi^3} p_\pi^3 |F_+^\pi(q^2)|^2$
- F_+^π vector from factor (neglecting scalar contribution $\propto m_e^2$)

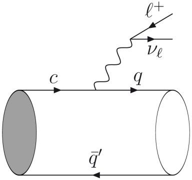


- Several parametrisations of q^2-dependence equivalent since smooth functions of q^2 (BK, modified pole, z-expansion ...)

$$\Gamma(D \to \pi e\nu) \propto |F_+^\pi(0)|^2 |V_{cd}|^2$$

$|V_{cd}|$ from semileptonic decays

- Differential decay rate $\frac{d\Gamma(D\to\pi e\nu)}{dq^2} = \frac{G_F^2|V_{cd}|^2}{24\pi^3} p_\pi^3 |F_+^\pi(q^2)|^2$
- F_+^π vector from factor (neglecting scalar contribution $\propto m_e^2$)



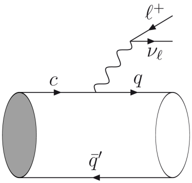
- Several parametrisations of q^2-dependence equivalent since smooth functions of q^2 (BK, modified pole, z-expansion . . .)

$$\Gamma(D \to \pi e\nu) \propto |F_+^\pi(0)|^2 |V_{cd}|^2$$

$F_+^\pi(0)$	Reference	Article	N_f	Mean	Stat	Syst
	MILC04	0408306	2+1	0.64	0.03	0.15
	Our average			0.64	0.03	0.15

$F_+^\pi(0)\|V_{cd}\|$	CLEO-c	0906.2983	$0.150 \pm 0.004 \pm 0.001$
	Belle	0604049	$0.139 \pm 0.004 \pm 0.007$
	Our average		0.148 ± 0.004

$|V_{cs}|$ from semileptonic decays



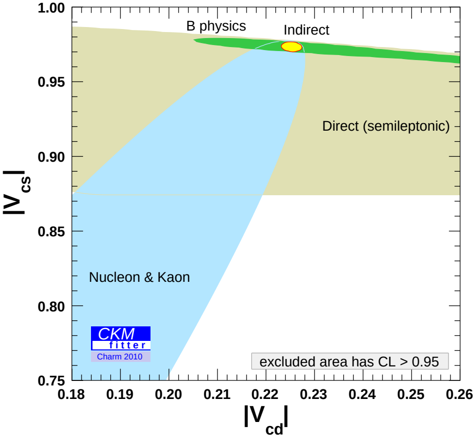
Similarly, up to parametrisation of q^2-dependence (part of exp. syst.)

$$\Gamma(D \to Ke\nu) \propto |F_+^K(0)|^2 |V_{cs}|^2$$

$F_+^K(0)$	Reference	Article	N_f	Mean	Stat	Syst
	MILC04	0408306	2+1	0.73	0.03	0.16
	HPQCD10	1008.4562	2+1	0.747	0.011	0.034
	Our average			0.747	0.011	0.034

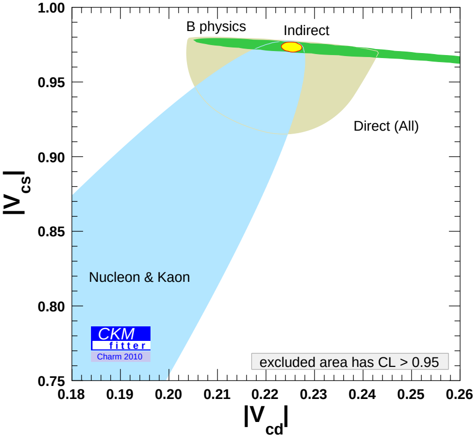
$F_+^K(0)\|V_{cs}\|$	CLEO-c	0906.2983	$0.719 \pm 0.006 \pm 0.005$
	Belle	0604049	$0.677 \pm 0.007 \pm 0.020$
	Babar	0704.0020	$0.707 \pm 0.010 \pm 0.005$
	Our average		0.712 ± 0.007

Semileptonic decays



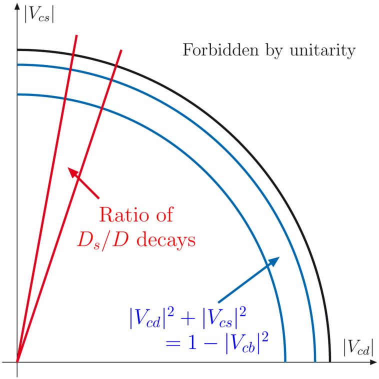
- Semileptonic decays: $|V_{cd}| = 0.245^{+0.078}_{-0.066}$, $|V_{cs}| = 0.975^{+0.037}_{-0.051}$
- Indirect: $|V_{cd}| = 0.2253 \pm 0.0001$, $|V_{cs}| = 0.9743^{+0.0002}_{-0.0002}$

Altogether



- Altogether: $|V_{cd}| = 0.225^{+0.008}_{-0.008}$, $|V_{cs}| = 0.955^{+0.002}_{-0.025}$
- Indirect: $|V_{cd}| = 0.2253 \pm 0.0001$, $|V_{cs}| = 0.9743^{+0.0002}_{-0.0002}$

The importance of being a ratio



- Unitarity powerful 1D constraint $|V_{cd}|^2 + |V_{cs}|^2 = 1 - |V_{cb}|^2$ [even if discrepancy between incl. and excl. determination of $|V_{cb}|$]
- orthogonal constraint from $\frac{|V_{cd}|}{|V_{cs}|}$

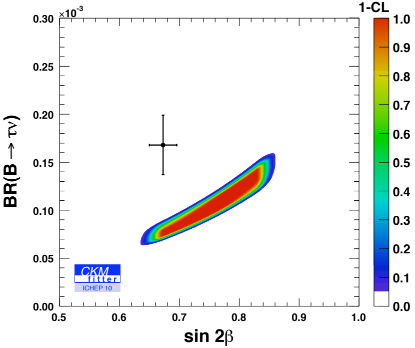
$$\frac{\Gamma(D \to \ell\nu)}{\Gamma(D_s \to \ell\nu)}, \frac{\Gamma(D \to \pi e\nu)}{\Gamma(D \to K e\nu)}$$

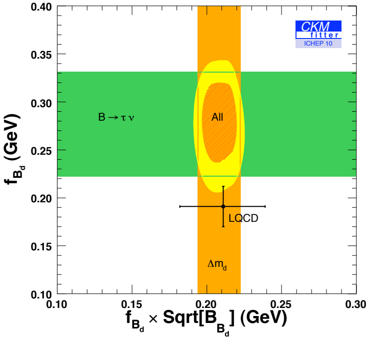
- reduced systematics reduced both exp and theo
  f_{D_s}/f_D U-spin breaking, $F_+^\pi(0)/F_+^K(0)\ldots$
- vector modes ? for instance, take ratio of $D \to \pi\ell\nu$ with $D_s \to \phi\ell\nu$, very narrow $s\bar{s}$ state, good control on lattice

$\Longrightarrow$ Think in terms of D_s/D ratios for V_{cd} and V_{cs} !

New Physics searches

Global fit χ^2_{min} drops by $\sim 2.6[2.8]\sigma$ if $\sin 2\beta_{c\bar{c}}$ $[B \to \tau\nu]$ removed



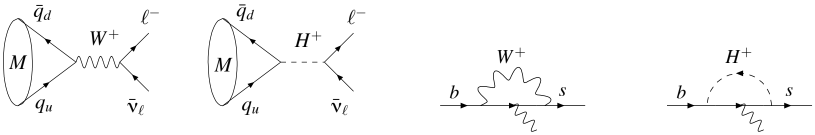


- Change in measured $Br(B \to \tau\nu)$ (2.8 σ)
- Correlated change in lattice values for f_{B_d} and B_{B_d} (2.8 σ)
- New Physics in mixing ($\Delta F = 2$) or in tree ($\Delta F = 1$)

Two-Higgs doublet model of type II vs SM

Simple and predictive extension of SM (embedded in susy models)

- One doublet coupling to down quarks, one to up's (and leptons)
- SM-like Yukawa terms for the quark sector
- No flavour-changing neutral currents at tree level
- CKM matrix only source of flavour-changing interactions, but new interactions : H^+ rather than W ($S-P$ vs $V-A$)



Additional d.o.f. and parameters:

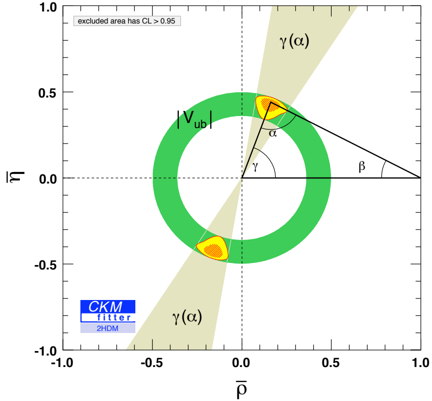
- 5 scalars : $H^\pm$ (charged), A (pseudoscalar), h^0 and H^0 (scalar)
- masses of $H^\pm$, H and A,
- ratio of Higgs vacuum expectation values $\tan\beta = v_2/v_1$
- angle describing the mixing between h^0 and H^0

$\Delta F = 1$ for 2HDM(II)

Analysis for $\Delta F = 1$ or electroweak processes with H^+ contributions

- Potential problems with leptonic decays ($B \to \tau\nu$, $D_s \to \ell\nu\ldots$)
- Parameters : CKM matrix, M_{H^+}, $\tan\beta$ (none from neutral Higgses)

O. Deschamps et al., 0907.5135



CKM matrix

- inputs where H^+ contribution suppressed, prop to $\frac{m_{\text{light}} m_{\text{heavy}}}{M^2_{H^+}}$ or $\frac{m^2_{\text{light}}}{M^2_{H^+}}$
- selects $|V_{ud}|$, $|V_{ub}|$, $|V_{cb}|$, γ (as a combination of α and β, not from $B \to DK$)

Leptonic decays

For any meson M, SM leptonic decay rate

$$\mathcal{B}[M \to \ell\nu_\ell]_{\rm SM} = \frac{G_F^2 m_M m_\ell^2}{8\pi}\left(1-\frac{m_\ell^2}{m_M^2}\right)^2 |V_{q_u q_d}|^2 f_M^2 \tau_M (1+\delta_{em}^{M\ell 2})$$

Charged Higgs contributions (helicity suppressed, vanish as $m_M \to 0$)

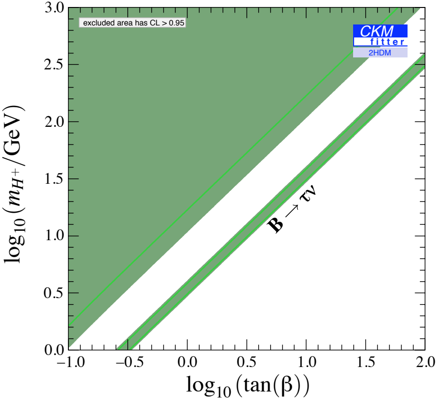
$$\mathcal{B}[M \to l\nu] = \mathcal{B}[M \to l\nu]_{\rm SM}(1+r_H)^2$$

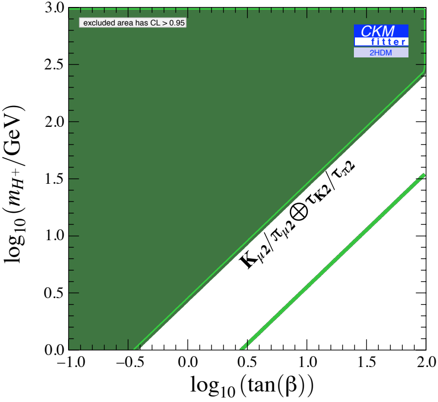
$$r_H = \left(\frac{m_{q_u} - m_{q_d}\tan^2\beta}{m_{q_u}+m_{q_d}}\right)\left(\frac{m_M}{m_{H^+}}\right)^2$$

If perfect agreement SM-data, two distinct solutions in 2HDM(II)

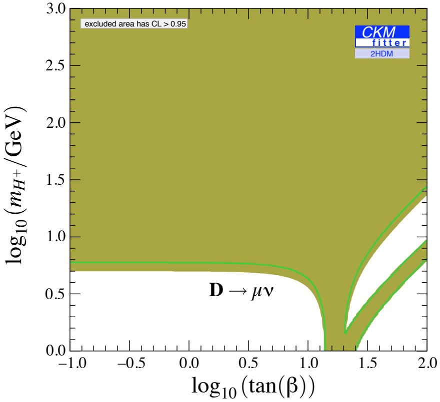
- decoupling : $r_H = 0$ ($m_{H^+} \to \infty$, $\tan\beta$ small)
- fine-tuned : $r_H = -2$ (linear correlation between m_H^+ and large $\tan\beta$, depends on meson mass

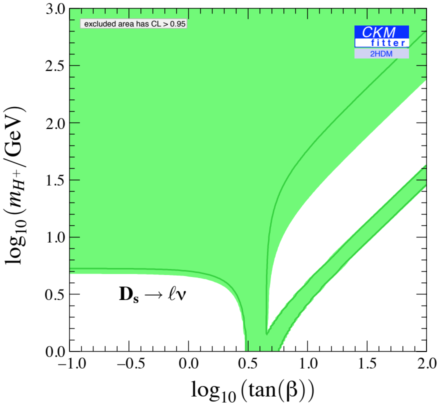
Leptonic decays : $B \to \tau\nu$ and $K \to \ell\nu/\pi \to \ell\nu$



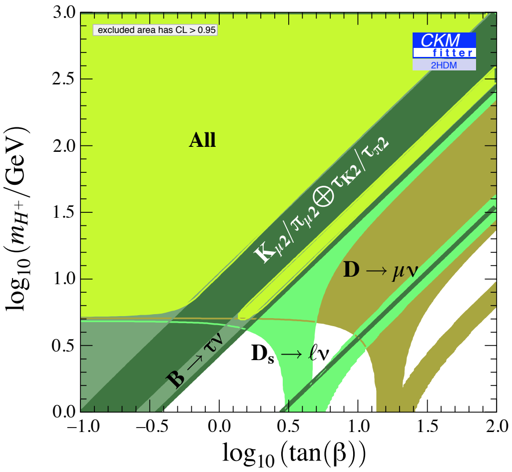


The 4 leptonic decays : $D \to \mu\nu$ and $D_s \to \ell\nu$



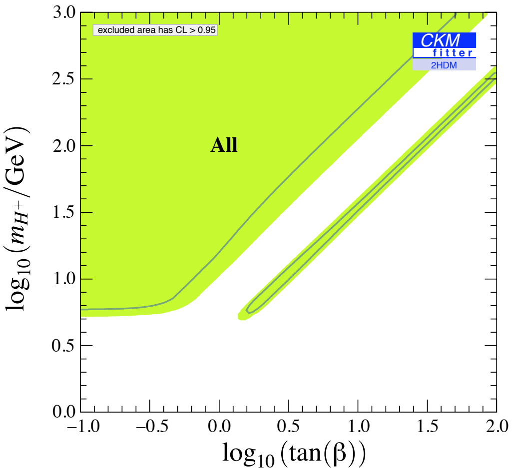


Leptonic decays combined



- Overlap of non-decoupling regions
- (an overlap of fine-tuned solutions would be much more exciting !)
- Leptonic D and D_s decays useful to discard some of the fine-tuned solutions...
- ...and to enhance the one from $B \to \tau\nu$

Leptonic decays combined



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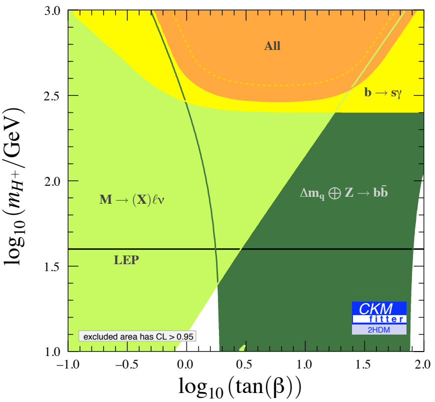
Further observables and combined fit



- semileptonic decays, with helicity-suppr scalar terms $\mathcal{B}[B \to D\tau\nu]/\mathcal{B}[B \to D\ell\nu]$ $\mathcal{B}[K^0 \to \pi\mu\nu]/\mathcal{B}[K^0 \to \pi e\nu]$
- $b \to s\gamma$ (very powerful drive towards SM)
- $Z \to b\bar{b}$ and $B\bar{B}$ mixing (similar shapes)
- all agree with SM and select large m_{H^+}, apart from large $\mathcal{B}[B \to \tau\nu]$ favouring fine-tuned sol at low m_{H^+}

- Limit on $m_{H^+} > 316$ GeV at 95% CL (LEP searches > 78.6 GeV)
- . . . but no constraint on tan β at 95%CL

Outlook

Outlook

CKM mechanism unifying scheme for flavour physics

- *D*-decays should have an impact in reducing uncertainty on γ
- Weak part of charm decays constrained by B and $K\dots$
- As long as one knows strong interaction part (lattice)

Two different ways of seeing the charm contribution

- CP-violation : *D*-unitarity triangle
- Semileptonic and leptonic decays : $[V_{cd}, V_{cs}]$ plot
- Progress in lattice and exp start making this CKM row relevant

NP searches

- Only loose constraints on loop processes due to hadronic uncert
- Strong constraints on tree decays, in competition with B, K
- Useful if NP connects the different corners (e.g., 2HDM)

More

CKMfitter global fit results as of FPCP 10:

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

Wolfenstein parameters and Jarlskog invariant:

Observable	Central ± 1 σ	± 2 σ	± 3 σ
A	0.8184 [+0.0094 -0.0311]	0.818 [+0.019 -0.040]	0.818 [+0.028 -0.048]
λ	0.22512 [+0.00075 -0.00075]	0.2251 [+0.0015 -0.0015]	0.2251 [+0.0022 -0.0022]
ρbar	0.139 [+0.027 -0.023]	0.139 [+0.051 -0.033]	0.139 [+0.063 -0.042]
ηbar	0.342 [+0.016 -0.015]	0.342 [+0.031 -0.027]	0.342 [+0.046 -0.037]
J [10^{-5}]	2.98 [+0.15 -0.19]	2.98 [+0.30 -0.23]	2.98 [+0.45 -0.28]

UT angles and sides:

Observable	Central ± 1 σ	± 2 σ	± 3 σ
sin 2α	-0.02 [+0.12 -0.14]	-0.02 [+0.18 -0.27]	-0.02 [+0.24 -0.34]
sin 2α (meas. not in the fit)	-0.254 [+0.328 -0.050]	-0.254 [+0.419 -0.097]	-0.25 [+0.48 -0.14]
sin 2β	0.686 [+0.023 -0.019]	0.686 [+0.046 -0.033]	0.686 [+0.069 -0.046]
sin 2β (meas. not in the fit)	0.831 [+0.013 -0.037]	0.831 [+0.026 -0.110]	0.831 [+0.038 -0.177]
ǀsin (2β+γ)ǀ	0.933 [+0.025 -0.027]	0.933 [+0.042 -0.045]	0.933 [+0.051 -0.063]
α [deg]	90.5 [+4.1 -3.6]	90.5 [+7.8 -5.2]	90.5 [+9.9 -6.8]
α [deg] (meas. not in the fit)	97.4 [+1.5 -9.5]	97.4 [+2.9 -12.1]	97.4 [+4.3 -13.9]
α [deg] (dir. meas.)	89.0 [+4.4 -4.2]	89.0 [+9.1 -8.3] ‖ 178.3 [+1.7 -5.6] ‖ 0 [+5 -0]	89 [+21 -13] ‖ 178.3 [+1.7 -13.8] ‖ 0 [+12 -0]
β [deg]	21.65 [+0.92 -0.75]	21.7 [+1.9 -1.3]	21.7 [+2.8 -1.8]
β [deg] (meas. not in the fit)	28.11 [+0.69 -1.84]	28.1 [+1.4 -5.0]	28.1 [+2.1 -7.7]
β [deg] (dir. meas.)	21.15 [+0.90 -0.88]	21.1 [+1.8 -1.7]	21.1 [+2.8 -2.6]

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

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

Back-up

Statistics : Framework

$q = (A, \lambda, \bar{\rho}, \bar{\eta} \ldots)$ to be determined

- $\mathcal{O}_{\rm exp}$ experimental values of the observables
- $\mathcal{O}_{\rm th}(q)$ theoretical description in a model

In case of experimental (Gaussian) uncertainties, likelihoods and χ^2

$$\mathcal{L}(q) = \prod_{\mathcal{O}} \mathcal{L}_{\mathcal{O}}(q) \qquad \chi^2(q) = -2 \ln \mathcal{L}(q) = \sum_{\mathcal{O}} \left(\frac{\mathcal{O}_{\rm th}(q) - \mathcal{O}_{\rm exp}}{\sigma_{\mathcal{O}}} \right)^2$$

Statistics : Framework

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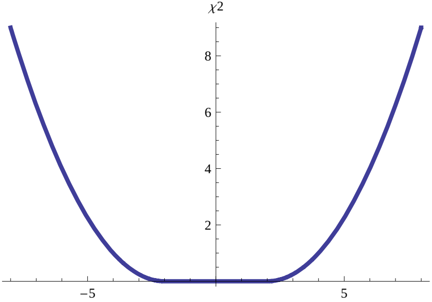
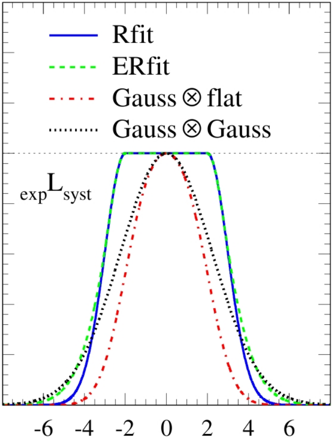
- Estimator $\hat{q}$ maximum likelood: $\chi^2(\hat{q}) = \min_q \chi^2(q)$
- Confidence level for a given q_0 (p-value for $q = q_0$) obtained from $\Delta\chi^2(q_0) = \chi^2(q_0) - \min_q \chi^2(q)$ (distributed like χ^2 law of $dim(q)$)

What to do in the case of systematic uncertainties,
which stand out of this picture ?

CKMfitter : Treatment of systematics within the Rfit scheme

- χ^2 with flat bottom (syst) and parabolic walls (stat), and
- corresponding likelihood $\mathcal{L} = \exp(-\chi^2/2)$
- all values within range of syst treated on the same footing





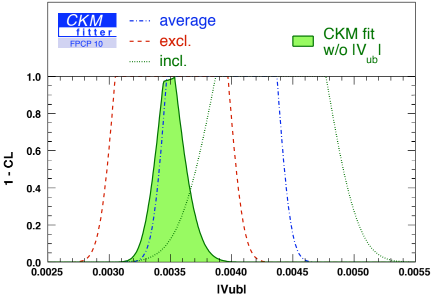
$|V_{ub}|$ inclusive and exclusive

Not all tensions are New Physics ! 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 $\times 10^{-3}$



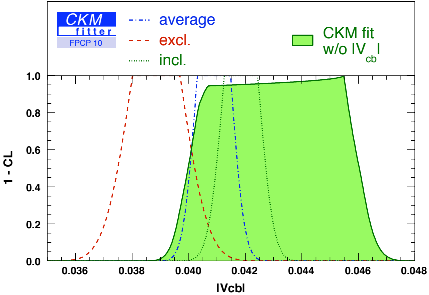
Tension depends on statistical treatment:

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

$|V_{cb}|$ inclusive and exclusive

$$|V_{cb}|_{inc} = 41.85 \pm 0.43 \pm 0.59$$
$$|V_{cb}|_{exc} = 38.85 \pm 0.77 \pm 0.84$$

$$|V_{cb}|_{ave} = 40.89 \pm 0.38 \pm 0.59$$



with all values to be multiplied by 10^{-3}

Tension depends on statistical treatment:

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

Selected inputs: ϵ_K

ϵ_K defined in $K \to \pi\pi$ [dominated by $I = 0$ from $\Delta I = 1/2$ rule]

$$\eta_{ab} = \frac{A(K_L \to \pi^a \pi^b)}{A(K_S \to \pi^a \pi^b)} \qquad \epsilon_K = \frac{\eta_{00} + 2\eta_{+-}}{3} \qquad \epsilon'_K = \frac{-\eta_{00} + \eta_{+-}}{3}$$

related to $K\bar{K}$ mixing: $|K_{S(L)}\rangle = [(1+\bar{\epsilon})|K^0\rangle \mp (1-\bar{\epsilon})|\bar{K}^0\rangle]/\sqrt{1+\bar{\epsilon}^2}$

$$\epsilon_K = \bar{\epsilon} + \xi = \sin\phi_\epsilon e^{i\phi_\epsilon}\left[\frac{\mathrm{Im} M_{12}}{\Delta M} + \xi\right] \qquad \xi = \frac{\mathrm{Im} A_0}{\mathrm{Re} A_0}$$

with strong-phase separation $A(K_0 \to (\pi\pi)_I) = A_I e^{i\delta_I^{strong}}$

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with strong-phase separation $A(K_0 \to (\pi\pi)_I) = A_I e^{i\delta_I^{strong}}$

- $\epsilon_K, \Delta M_K$ from experiment, $\phi_\epsilon = \arctan(-2\Delta M/\Delta\Gamma) \simeq \pi/4$
- $\mathrm{Im} M_{12}$ from effective Hamiltonian
  - keep only lowest-dimension contribution $\mathrm{Im} M_{12}^{(6)}$
  - top boxes $\otimes$ $\hat{B}_K \propto \langle \bar{K}^0|(\bar{s}d)_{V-A}(\bar{s}d)_{V-A}|K^0\rangle$

$$\epsilon_K \simeq C_\epsilon \hat{B}_K \lambda^2 \bar\eta^2 |V_{cb}|^2 [|V_{cb}|^2 (1-\bar\rho)\eta_{tt} S_0(x_t) + \eta_{ct} S_0(x_t, x_c) - \eta_{cc} S_0(x_c)]$$

Inami-Lim functions $S_0(x_q = m_q^2/m_W^2)$ and C_ϵ normalisation

Selected inputs: κ_ϵ (1)

$$\epsilon_K = \sin\phi_\epsilon e^{i\phi_\epsilon}\left[\frac{\mathrm{Im}M_{12}}{\Delta M}+\xi\right] = \kappa_\epsilon \frac{e^{i\phi_\epsilon}}{\sqrt{2}}\frac{\mathrm{Im}M_{12}^{(6)}}{\Delta M_K} \quad \text{with } \kappa_\epsilon \neq 1$$

1) $\phi_\epsilon = 43.5 \pm 0.7^\circ \neq 45^\circ$ $\qquad (\kappa_\epsilon)_\phi = 0.97 \pm 0.01$

2) $\xi = \mathrm{Im}A_0/\mathrm{Re}A_0$ $\qquad$ [Buras Guadagnoli 2008,2009]

- $\mathrm{Re}A_I$ from experiment (no theory for $\Delta I = 1/2$ rule)
- $\mathrm{Im}A_I$ from $\mathcal{H}_{\mathrm{eff}}^{\Delta S=1}$: $\mathrm{Im}A_I \propto \sum y_i \langle(\pi\pi)_I|Q_i|K\rangle$
  with y_i Wilson coefficients and Q_i $\Delta S = 1$ operators
- $\mathrm{Im}A_0$ (ξ) dominated by QCD penguin $\langle Q_6\rangle_0$ (not known)
- $\mathrm{Im}A_2$ dominated by electroweak penguin $\langle Q_8\rangle_2$ (lattice, sum rules)
- ϵ'/ϵ involves both $\mathrm{Im}A_0$ and $\mathrm{Im}A_2$

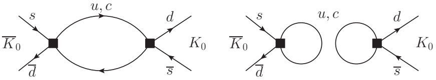
$$\langle Q_6\rangle_0 = f[(\epsilon'/\epsilon)_{\mathrm{exp}}, \langle Q_8\rangle_2] \qquad \xi = g[\langle Q_6\rangle_0] = g'[(\epsilon'/\epsilon)_{\mathrm{exp}}, \langle Q_8\rangle_2]$$

$$(\kappa_\epsilon)_{\phi+\xi} = 0.918 \pm 0.013|_{\epsilon'/\epsilon,\phi_\epsilon} \pm 0.007|_{Q_6,Q_8}$$

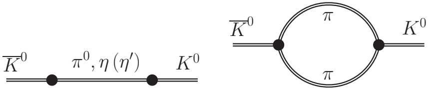
3) Higher-dim corr to $\mathrm{Im}M_{12}$ [Buras Guadagnoli Isidori 2010]

$$M_{12} = \langle K_0 | H_{\rm eff}^{|\Delta S|=2} | \bar{K}_0 \rangle - \langle K_0 | \int d^4x \mathrm{Re}[iT[H_{\rm eff}^{|\Delta S|=1}(x) H_{\rm eff}^{|\Delta S|=1}(0)]] | \bar{K}_0 \rangle$$

- Leading from $d = 6$ operator $(\bar{s}d)_{V-A}(\bar{s}d)_{V-A}$ in $H_{\rm eff}^{|\Delta S|=2}$
- $d = 8$ corr from $H_{\rm eff}^{|\Delta S|=2}$ m_K^2/m_c^2-suppressed wrt $d = 6$ charm [2%]
- $d = 8$ corrections from two insertions of $H_{\rm eff}^{|\Delta S|=1}$



computed using χPT for
$\Delta S = 1$ transitions:
$\xi \to \rho\xi$ with $\rho = 0.6 \pm 0.3$

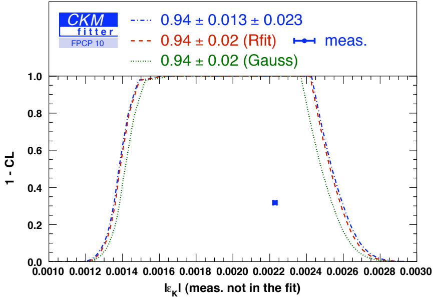


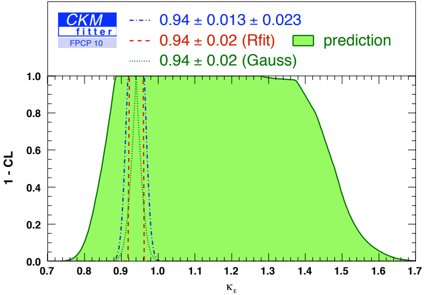
$(\kappa_\epsilon)_{\rm tot} = 0.940 \pm 0.013 \pm 0.023$

slightly more conservative than BGI (0.94 ± 0.2)

Selected inputs: $|\epsilon_K|$ in global fit (1)

- Assume something on κ_ϵ, compute ϵ_K and compare with expt
- Use measurement of ϵ_K and the global fit to study κ_ϵ





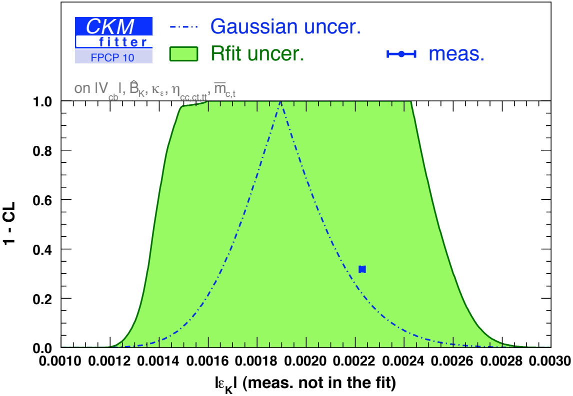
$\Longrightarrow$The correction κ_ϵ does not spoil the quality of the global fit

- $\kappa_\epsilon = 0.94 \pm 0.02$ (Gaussian)
- $\kappa_\epsilon = 0.94 \pm 0.02$ (Rfit)
- $\kappa_\epsilon = 0.940 \pm 0.013 \pm 0.023$

Selected inputs: $|\epsilon_K|$ in global fit (2)

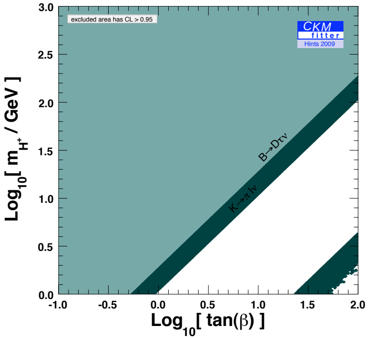
Impact of the statistical treatment of theoretical inputs on ϵ_K

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



- Gaussian error : 1.3 σ tension
- Rfit error : no tension

2HDM(II): Semileptonic decays



Semileptonic decays help to remove fined-tuned solutions at 95% CL

$$\mathcal{B}[B \to D\tau\nu]/\mathcal{B}[B \to D\ell\nu]$$
and
$$\mathcal{B}[K^0 \to \pi\mu\nu]/\mathcal{B}[K^0 \to \pi e\nu]$$

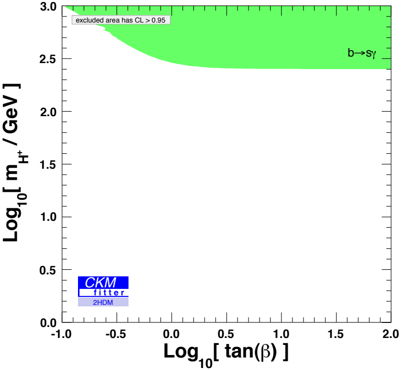
- Easier to study experimentally than purely leptonic decays
- Sensitive to scalar contributions through helicity-suppressed terms, enhanced by mass of the charged lepton

$\Longrightarrow$hence comparison between τ, μ, e

2HDM(II): $b \to s\gamma$

- NNLO BR from public package SusyBSG

$$\frac{\mathcal{B}[\bar{B}\to X_s\gamma]}{\mathcal{B}[\bar{B}\to X_c\ell\bar{\nu}]} = \left|\frac{V_{ts}^\star V_{tb}}{V_{cb}}\right|^2 \frac{6\alpha_{\rm EM}}{\pi C}(P+N),$$ [Misiak, Gambino, Haisch. . .]



- P leading term in $1/m_b$ expansion, perturbative
- N non-perturbative, higher orders (starting at $1/m_b^2$)

$$P+N = (C_{7,SM}^{\rm eff,(0)} + B\Delta C_{7,H^+}^{\rm eff,(0)})^2 + A$$

- $\Delta C_{7,H^+}^{\rm eff,(0)}$ models H^+ impact, dependence on $(m_{H^+}, \tan\beta)$, fitted from SusyBSG

NNLO SM estimate: $Br(B \to X_s\gamma) = (3.15 \pm 0.23)\cdot 10^{-4}$ [Misiak et al.]

Measurement: $B(B \to X_s\gamma) = (3.57 \pm 0.24)\cdot 10^{-4}$ [2009 WA]

- Further observables added : $R_b = \Gamma[Z \to b\bar{b}]/\Gamma[Z \to \mathrm{hadrons}]$ and $B\bar{B}$ mixing
- Charged Higgs contrib = shift in (perturbative) coeff describing decays