

CKM fits: from SM parameters to NP searches

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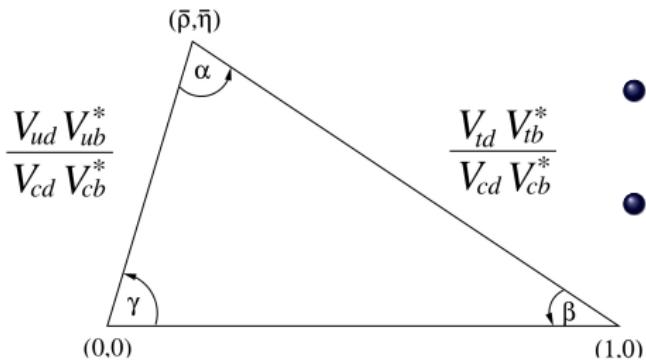


Assessing the CKM paradigm in the SM

CP -violation : the four parameters

In SM weak charged transitions mix quarks of different generations

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

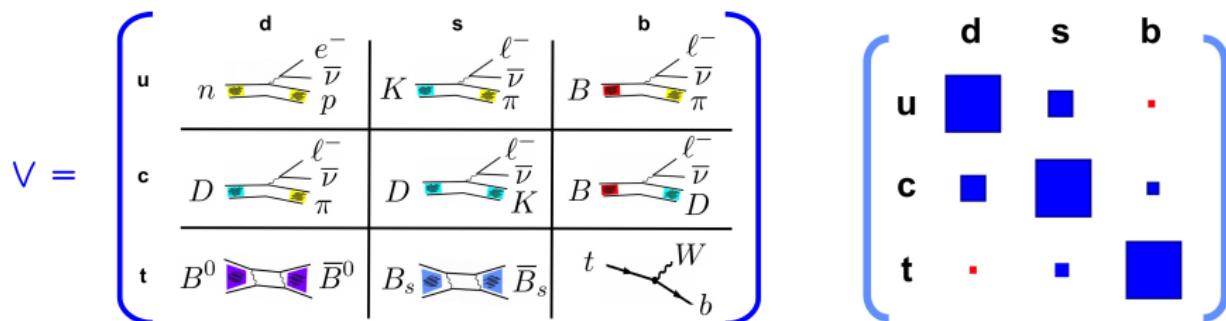


- 3 generations \Rightarrow 1 phase, only source of CP -violation in SM
- Wolfenstein parametrisation, defined to hold to all orders in λ and rephasing invariant

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

\Rightarrow 4 parameters describing the CKM matrix,
to determine from data under the SM hypothesis

Extracting the CKM parameters



- CP -invariance of QCD to build hadronic-indep. CP -violating asym. or to determine hadronic inputs from data
- Statistical framework to combine data and assess uncertainties

	Exp. uncert.		Theoretical uncertainties
Tree	$B \rightarrow DK$	γ	$B(b) \rightarrow D(c)\ell\nu$ $B(b) \rightarrow \pi(u)\ell\nu$ $M \rightarrow \ell\nu$
Loop	$B \rightarrow J/\Psi K_s$	β	ϵ_K (K mixing)
	$B \rightarrow \pi\pi, \rho\rho$	α	$\Delta m_d, \Delta m_s$ (B_d, B_s mixings)
			$ \bar{\rho}, \bar{\eta} $ vs B_K (bag parameter)
			$ V_{tb} V_{tq} $ vs $f_B^2 B_B$ (bag param)

The inputs

CKM
fitter

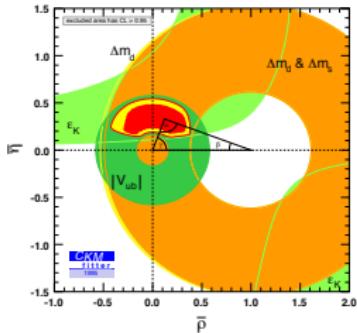
CKM matrix within a frequentist framework ($\simeq \chi^2$ minim.)
+ specific scheme for theory uncertainties (Rfit)

data = weak \otimes QCD \implies Need for hadronic inputs (mostly lattice)

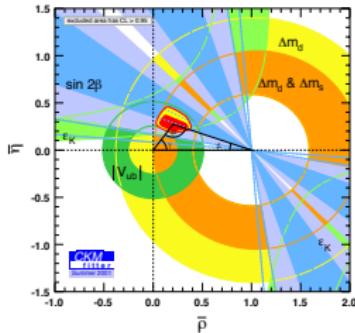
$ V_{ud} $	superallowed β decays	PRC79, 055502 (2009)
$ V_{us} $	$K_{\ell 3}$ (Flavianet)	$f_+(0) = 0.9641 \pm 0.0015 \pm 0.0045$
	$K \rightarrow \ell\nu, \tau \rightarrow K\nu_\tau$	$f_K = 155.2 \pm 0.2 \pm 0.6$ MeV
$ V_{us}/V_{ud} $	$K \rightarrow \ell\nu/\pi \rightarrow \ell\nu, \tau \rightarrow K\nu_\tau/\tau \rightarrow \pi\nu_\tau$	$f_K/f_\pi = 1.194 \pm 0.001 \pm 0.003$
ϵ_K	PDG	$\hat{B}_K = 0.7615 \pm 0.0027 \pm 0.0137$
$ V_{ub} $	inclusive and exclusive	$ V_{ub} \cdot 10^3 = 3.70 \pm 0.12 \pm 0.26$
$ V_{cb} $	inclusive and exclusive	$ V_{cb} \cdot 10^3 = 41.00 \pm 0.33 \pm 0.74$
Δm_d	last WA B_d - \bar{B}_d mixing	$B_{B_s}/B_{B_d} = 1.023 \pm 0.013 \pm 0.014$
Δm_s	last WA B_s - \bar{B}_s mixing	$B_{B_s} = 1.320 \pm 0.017 \pm 0.030$
β	last WA $J/\psi K^{(*)}$	
α	last WA $\pi\pi, \rho\pi, \rho\rho$	isospin
γ	last WA $B \rightarrow D^{(*)} K^{(*)}$	GLW/ADS/GGSZ
$B \rightarrow \tau\nu$	$(1.24 \pm 0.22) \cdot 10^{-4}$	$f_{B_s}/f_{B_d} = 1.205 \pm 0.004 \pm 0.007$
		$f_{B_s} = 225.6 \pm 1.1 \pm 5.4$ MeV

Two decades of CKM

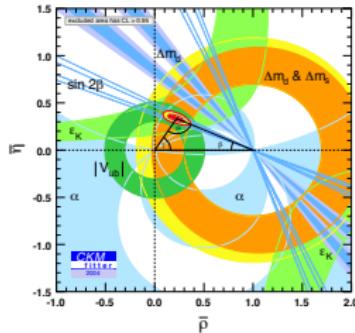
[LEP, KTeV, NA48, Babar, Belle, CDF, DØ, LHCb, CMS...]



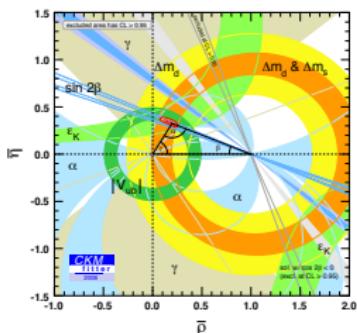
1995



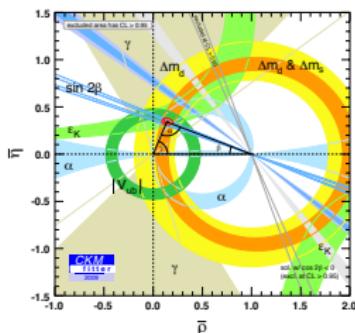
2001



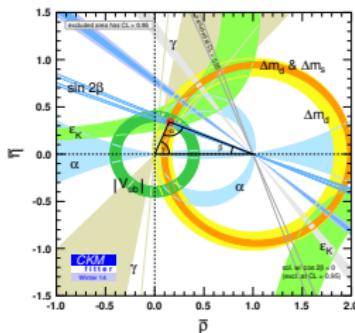
2004



2006

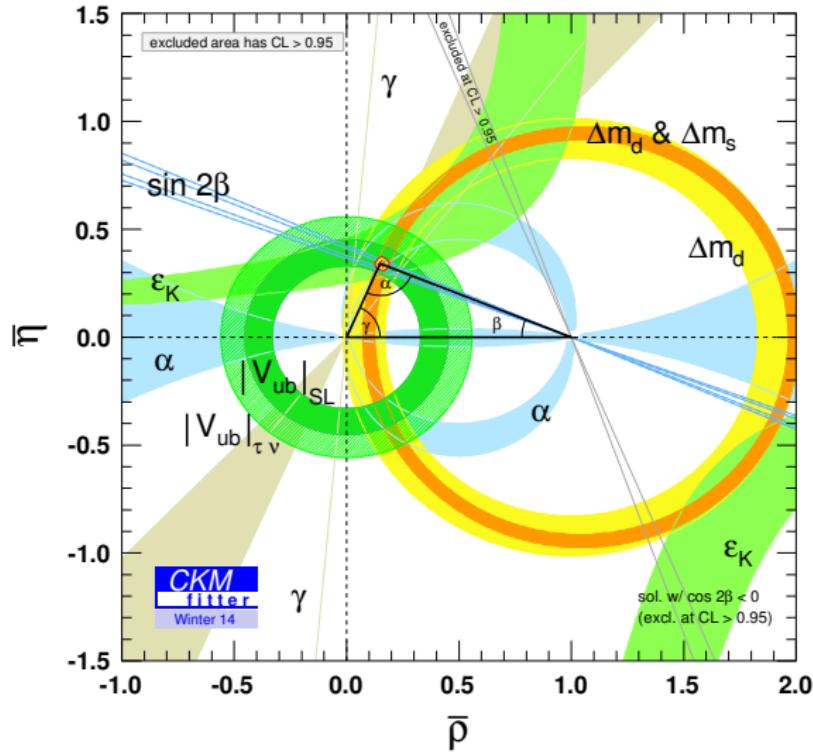


2009



2014

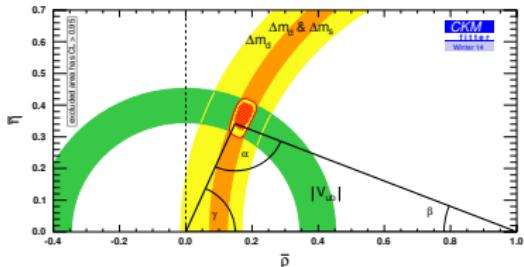
Moriond 2014



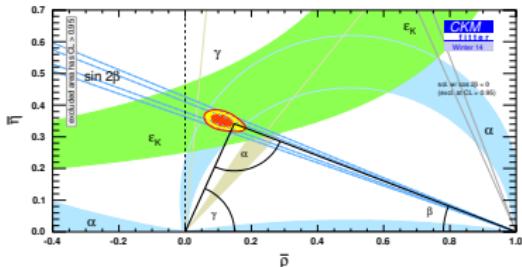
$|V_{ud}|, |V_{us}|$
 $|V_{cb}|, |V_{ub}|_{SL}$
 $B \rightarrow \tau\nu$
 $\Delta m_d, \Delta m_s$
 ϵ_K
 $\sin 2\beta$
 α
 γ

$$\begin{aligned}
A &= 0.813^{+0.015}_{-0.027} \\
\lambda &= 0.2255^{+0.0007}_{-0.0003} \\
\bar{\rho} &= 0.149^{+0.016}_{-0.008} \\
\bar{\eta} &= 0.342^{+0.013}_{-0.011} \\
&\quad (68\% \text{ CL})
\end{aligned}$$

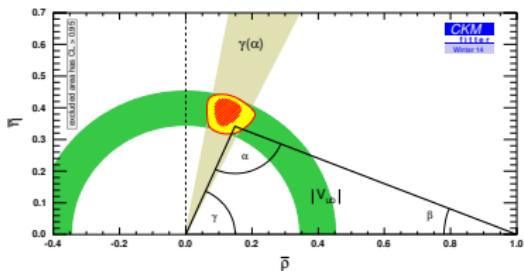
Consistency of the KM mechanism



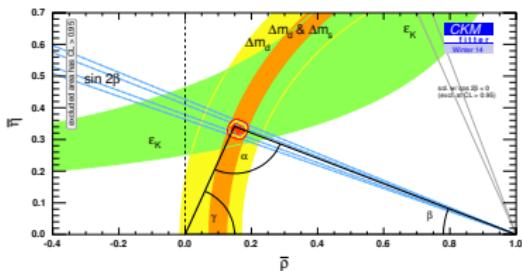
CP -allowed only



CP -violating only



Tree only



Loop only

Validity of Kobayashi-Maskawa picture of CP violation

$|V_{ub}|$ semileptonic

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

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

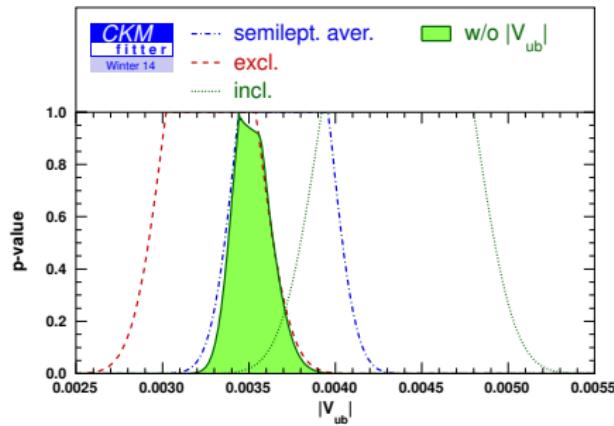
$$|V_{ub}|_{inc} = 4.36 \pm 0.18 \pm 0.44$$

$$|V_{ub}|_{exc} = 3.28 \pm 0.15 \pm 0.26$$

$$|V_{ub}|_{ave} = 3.70 \pm 0.12 \pm 0.25$$

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

- HFAG, with theory errors added linearly
- systematics combined using Educated Rfit



Indirect det. from global fit: $|V_{ub}|_{fit} = 3.43^{+0.25}_{-0.08}$ (4.8%)

$|V_{cb}|$ semileptonic

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

- Inclusive : $b \rightarrow c\ell\nu$ + Operator Product Expansion for moments
- Exclusive : $B \rightarrow D(*)\ell\nu$ + Form factors

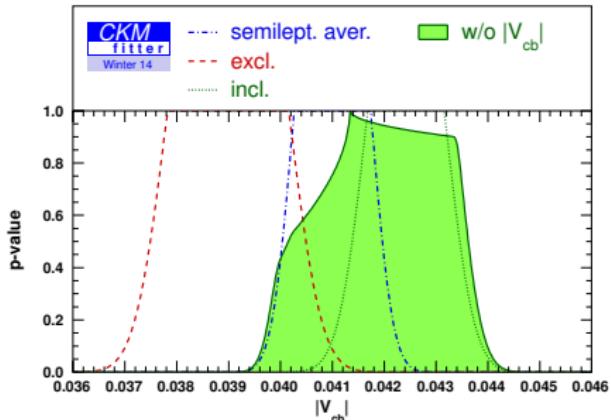
$$|V_{cb}|_{inc} = 42.42 \pm 0.44 \pm 0.74$$

$$|V_{cb}|_{exc} = 38.99 \pm 0.49 \pm 1.17$$

$$|V_{cb}|_{ave} = 41.00 \pm 0.33 \pm 0.74$$

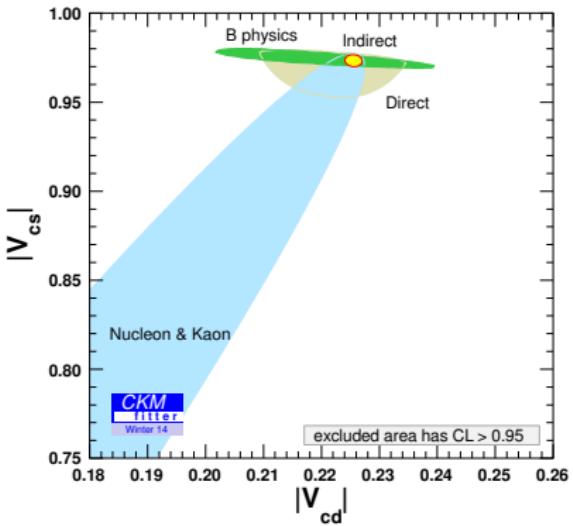
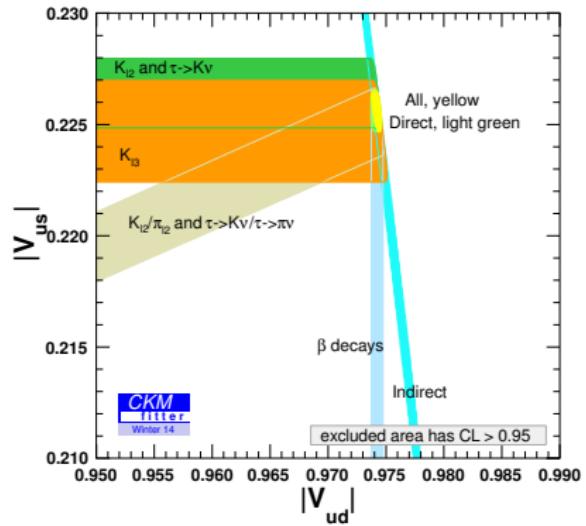
with all values $\times 10^{-3}$

- HFAG, with theory errors added linearly
- systematics combined using Educated Rfit



Indirect det. from global fit: $|V_{cb}|_{fit} = 41.4^{+2.4}_{-1.4}$ (4.6%)

The upper-left square: $|V_{ud}|, |V_{us}|$ and $|V_{cd}|, |V_{cs}|$

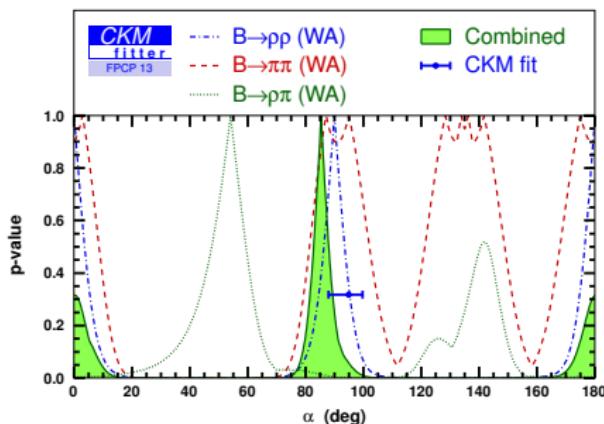


- “Direct” (semi- and leptonic) vs “indirect” (other sectors)
- ($|V_{ud}|, |V_{us}|$): nuclear β + leptonic K, π and τ decays
- ($|V_{cd}|, |V_{cs}|$): mostly leptonic

	Leptonic		Semileptonic	
	$ V_{cd} $	$ V_{cs} $	$ V_{cd} $	$ V_{cs} $
Exp input	3%	4-5%	2.7%	1.0%
Lattice	0.9%	1.9%	7.8%	4.8%

α and the legacy of the B -factories

- Combined analysis of $B \rightarrow \pi\pi$, $B \rightarrow \rho\pi$, $B \rightarrow \rho\rho$
- Using isospin to separate penguin and tree contributions
- Similar accuracy of direct and indirect determinations



Winter 09

$$\begin{aligned}\alpha[\text{comb}] &= (89.0^{+4.4}_{-4.2})^\circ \\ \alpha[\text{ind}] &= (95.6^{+3.3}_{-8.8})^\circ \\ \alpha[\text{fit}] &= (90.6^{+3.8}_{-4.2})^\circ\end{aligned}$$

Winter 12

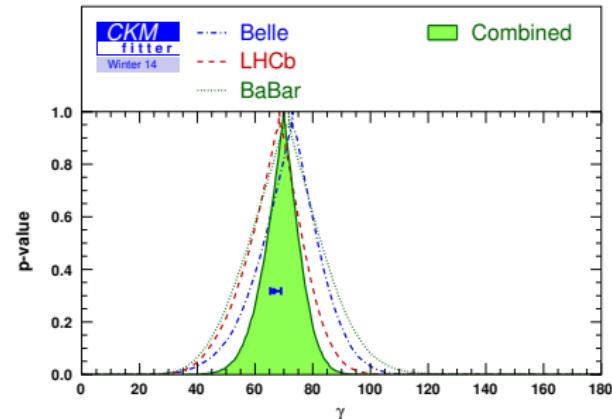
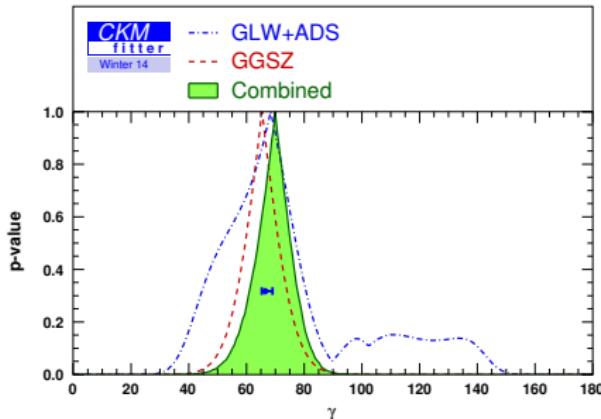
$$\begin{aligned}\alpha[\text{comb}] &= (88.7^{+4.6}_{-4.2})^\circ \\ \alpha[\text{ind}] &= (95.9^{+2.2}_{-5.6})^\circ \\ \alpha[\text{fit}] &= (91.1^{+4.3}_{-4.3})^\circ\end{aligned}$$

Spring 13

$$\begin{aligned}\alpha[\text{comb}] &= (85.4^{+4.0}_{-3.9})^\circ \\ \alpha[\text{ind}] &= (94.9^{+4.8}_{-6.8})^\circ \\ \alpha[\text{fit}] &= (88.5^{+2.8}_{-1.5})^\circ\end{aligned}$$

γ and a little help from LHCb

- $B^- \rightarrow D^{(*)0} K^{(*)-}$ vs $\bar{D}^{(*)0} K^{(*)-}$ with 3 different D^0 decay modes
- Similar accuracy from Babar, Belle, LHCb (starts dominating)
- Charm inputs from CLEO, BES, Babar, Belle, CDF, LHCb



Summer 10

$$\begin{aligned}\gamma[\text{comb}] &= (71_{-25}^{+21})^\circ \\ \gamma[\text{ind}] &= (67.2_{-3.9}^{+3.9})^\circ \\ \gamma[\text{fit}] &= (67.2_{-3.9}^{+3.9})^\circ\end{aligned}$$

Winter 12

$$\begin{aligned}\gamma[\text{comb}] &= (66_{-12}^{+12})^\circ \\ \gamma[\text{ind}] &= (67.2_{-4.6}^{+4.4})^\circ \\ \gamma[\text{fit}] &= (67.1_{-4.3}^{+4.3})^\circ\end{aligned}$$

Winter 14

$$\begin{aligned}\gamma[\text{comb}] &= (70_{-9}^{+8})^\circ \\ \gamma[\text{ind}] &= (66.4_{-3.3}^{+1.2})^\circ \\ \gamma[\text{fit}] &= (66.5_{-2.5}^{+1.3})^\circ\end{aligned}$$

For CKM14 update, see K. Trabelsi's talk

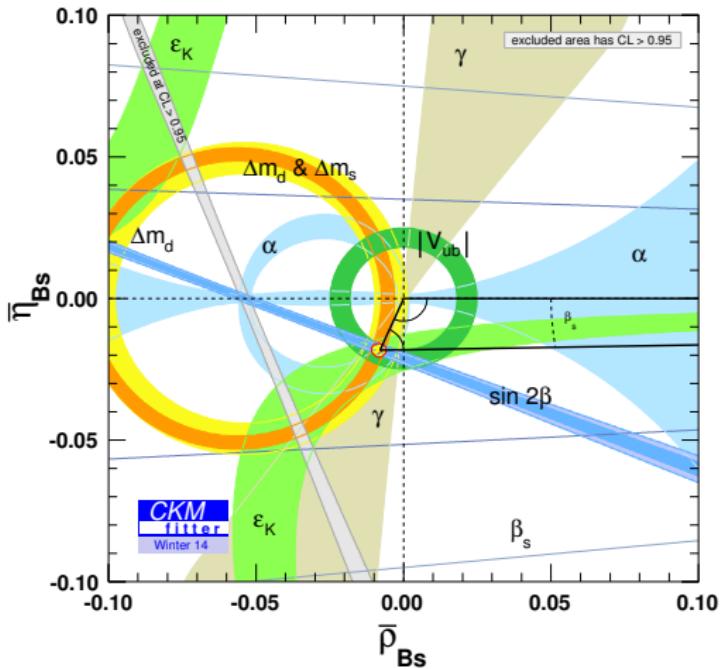
Hadronic inputs from lattice

- Lattice results usually dominated by systematic uncertainties
- Only published papers, with error budgets, using Flavour Lattice Averaging Group report as a guide to sort results
- Educated Rfit for averages : usual average for stat errors, smallest of systematics for syst (with linear addition of syst)

	Input	Fit [input not included]
f_K	$155.2 \pm 0.2 \pm 0.6$ (0.4%)	$156.5^{+0.1}_{-1.2}$ (0.4%)
f_K/f_π	$1.194 \pm 0.001 \pm 0.003$ (0.3%)	$1.190^{+0.007}_{-0.005}$ (0.5%)
\hat{B}_K	$0.762 \pm 0.003 \pm 0.014$ (1.9%)	$0.84^{+0.26}_{-0.19}$ (22%)
f_{B_s}	$225.6 \pm 1.1 \pm 5.4$ (2.4%)	$237.2^{+2.4}_{-16.9}$ (4.0%)
f_{B_s}/f_{B_d}	$1.205 \pm 0.004 \pm 0.007$ (0.7%)	$1.258^{+0.046}_{-0.036}$ (3.2%)
B_{B_s}	$1.320 \pm 0.017 \pm 0.030$ (2.6%)	$1.250^{+0.132}_{-0.035}$ (6.7%)
B_{B_s}/B_{B_d}	$1.023 \pm 0.013 \pm 0.014$ (1.9%)	$1.163^{+0.064}_{-0.078}$ (6.1%)

Fit results consistent, but mostly not competitive, with lattice results

Other triangles: B_s

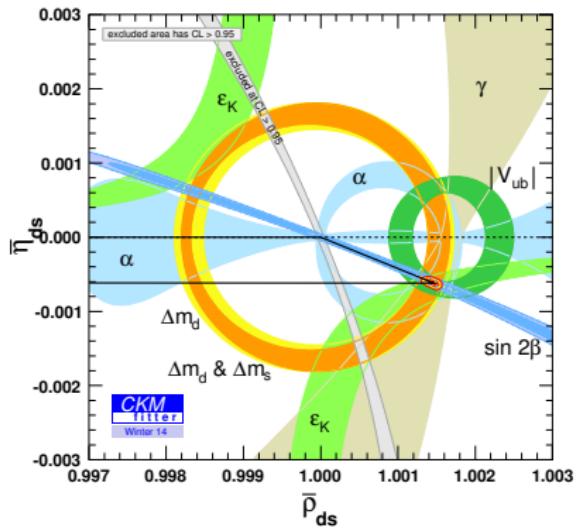


- $\bar{\rho}_{B_s} + i\bar{\eta}_{B_s} = -\frac{V_{us} V_{ub}^*}{V_{cs} V_{cb}^*}$ provides the B_s Unitarity Triangle ($\lambda^4, \lambda^2, \lambda^2$)
- Information on B_s mixing angle β_s from $B_s \rightarrow J/\psi \phi$
- Not relevant for SM determination of CKM parameters

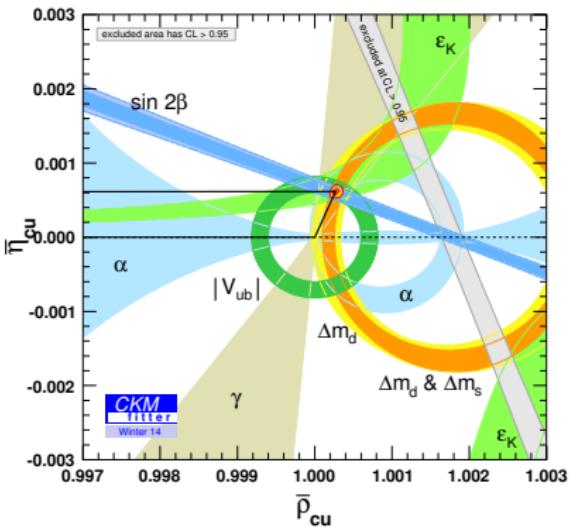
$$\bar{\rho}_{B_s} = -0.00797^{+0.00046}_{-0.00085}$$

$$\bar{\eta}_{B_s} = -0.01832^{+0.00060}_{-0.00068}$$

Other triangles: K, D

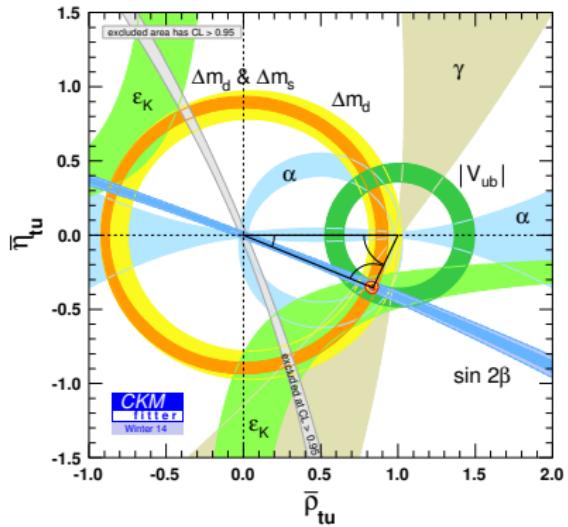


$$\bar{\rho}_{ds} + i\bar{\eta}_{ds} = -\frac{V_{ud} V_{us}^*}{V_{cd} V_{cs}^*} (\lambda, \lambda, \lambda^5)$$

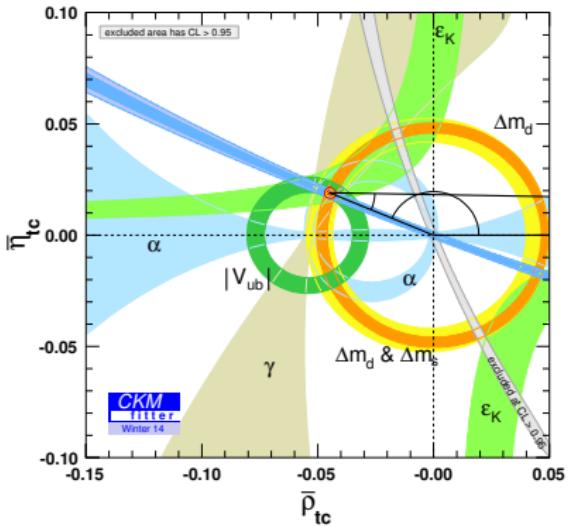


$$\bar{\rho}_{cu} + i\bar{\eta}_{cu} = -\frac{V_{cd} V_{ud}^*}{V_{cs} V_{us}^*} (\lambda, \lambda, \lambda^5)$$

Other triangles: (tu) , (tc)

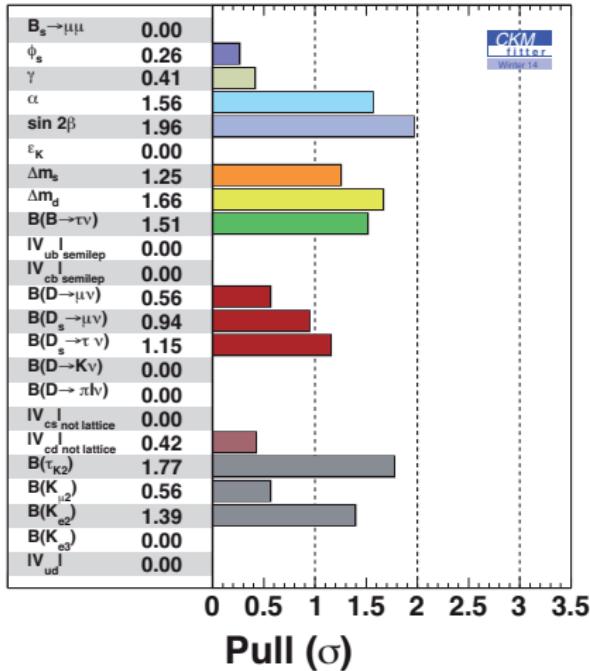


$$\bar{\rho}_{tu} + i\bar{\eta}_{tu} = -\frac{V_{td} V_{ud}^*}{V_{ts} V_{us}^*} (\lambda^3, \lambda^3, \lambda^3)$$



$$\bar{\rho}_{tc} + i\bar{\eta}_{tc} = -\frac{V_{td} V_{cd}^*}{V_{ts} V_{cs}^*} (\lambda^4, \lambda^2, \lambda^2)$$

Pulls

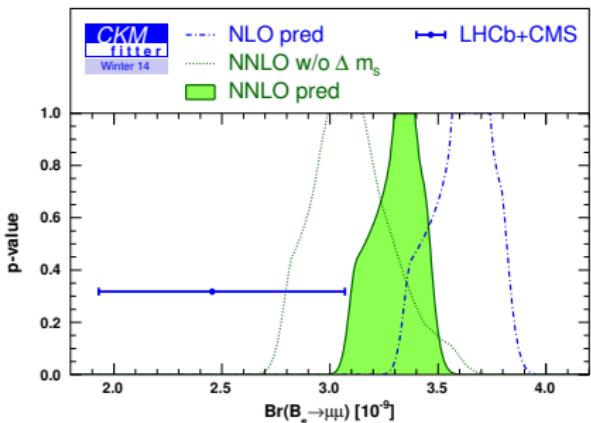
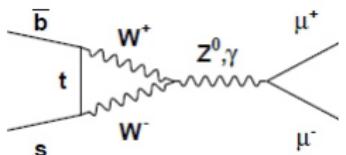


- Pulls for various observables (included in the fit or not)
- For 1D, pull obs = $\sqrt{\chi^2_{\text{min; with obs}} - \chi^2_{\text{min; w/o obs}}}$
- If Gaussian errors, uncorrelated, random vars of mean 0 and variance 1
- Here correlations, and some pulls = 0 due to the Rfit model for syst
- $\sin 2\beta, Br(B \rightarrow \tau\nu)$ discrepancy softened (recent Belle result)

No indication of significant deviations from CKM picture

Probing New Physics via FCNC

$\Delta F = 1: B_s \rightarrow \mu\mu$



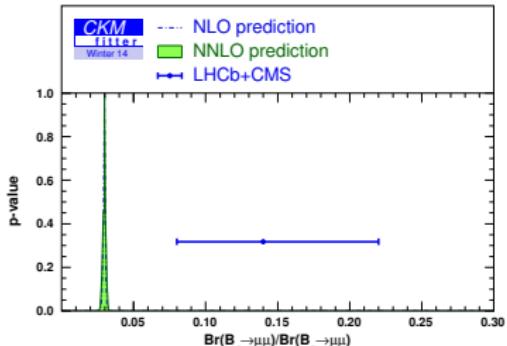
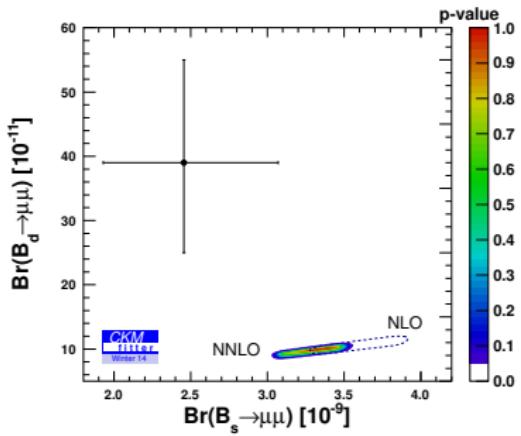
- $\Delta F = 1$ FCNC sensitive to pseudo/scalar contributions
- LHCb+CMS: $\langle \text{Br}(B_s \rightarrow \mu\mu) \rangle = (2.8^{+0.7}_{-0.6}) \times 10^{-9}$
- Theoretical progress
 - Inclusion of B_s mixing in time-integrated rate from LHCb and CMS: $\langle \text{Br}(B_s \rightarrow \mu\mu) \rangle \simeq 1.1 \text{Br}_{t=0}$
 - NLO QCD + LO EW \rightarrow NNLO QCD + NLO EW

Fleischer et al., Bobeth et al.

see E. Stamou's talk

- Correlation with Δm_s : $\text{Br}(B_s \rightarrow \mu\mu)/\Delta m_s$ is free from CKM factors ($|V_{tb} V_{ts}|^2$ cancels) and from input on f_{B_s} Buras et al.
- Fit: $\text{Br}_{NLO,t=0} \times 10^9 = 3.65^{+0.18}_{-0.30} \rightarrow \text{Br}_{NNLO,t=0} \times 10^9 = 3.34^{+0.14}_{-0.25}$

$\Delta F = 1: B_{d,s} \rightarrow \mu\mu$



- $Br(B_d \rightarrow \mu\mu)$ also within reach
see F. Archilli's talk
- Correlation in SM between $Br(B_d \rightarrow \mu\mu)$ and $Br(B_s \rightarrow \mu\mu)$, driven by $\Delta m_d/\Delta m_s$:

$$Br(B_d \rightarrow \mu\mu)_{t=0}/Br(B_s \rightarrow \mu\mu)_{t=0} = 0.0298^{+0.0008}_{-0.0010}$$
- Holds also in MFV (but not necessarily with same absolute values)
- Further test of pseudo/scalar operators provided by

$$Br(B_d \rightarrow \tau\tau)_{t=0} \times 10^8 = 2.05^{+0.13}_{-0.15}$$

$$Br(B_s \rightarrow \tau\tau)_{t=0} \times 10^7 = 6.98^{+0.38}_{-0.43}$$

$\Delta F = 2$: observables

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

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

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

of masses $M_{H,L}^q$, widths $\Gamma_{H,L}^q$

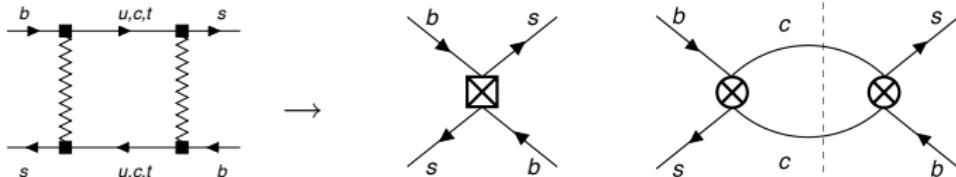
In terms of M_{12}^q , $|\Gamma_{12}^q|$ and $\phi_q = \arg \left(-\frac{M_{12}^q}{\Gamma_{12}^q} \right)$ [using $|\Gamma_{12}^q| \ll |M_{12}^q|$]

- Mass difference $\Delta m_q = M_H^q - M_L^q \simeq 2|M_{12}^q|$
- Width difference $\Delta\Gamma_q = \Gamma_L^q - \Gamma_H^q \simeq 2|\Gamma_{12}^q| \cos(\phi_q)$
- $a_{SL}^q = \frac{\Gamma(\bar{B}_q(t) \rightarrow \ell^+ \nu X) - \Gamma(B_q(t) \rightarrow \ell^- \nu X)}{\Gamma(\bar{B}_q(t) \rightarrow \ell^+ \nu X) + \Gamma(B_q(t) \rightarrow \ell^- \nu X)} \simeq \frac{|\Gamma_{12}^q|}{|M_{12}^q|} \sin \phi_q \simeq \frac{\Delta\Gamma_q}{\Delta m_q} \tan \phi_q$
- Mixing in time-dep analysis $q/p \simeq -M_{12}^{q*}/|M_{12}^q| = -e^{-i\phi_{B_q}}$

Accessible for B_d and B_s at Babar, Belle, CDF, DØ, LHCb...

$\Delta F = 2$: computation of the observables

Eff. Hamiltonian
integrating out
heavy W, Z, t



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

- M_{12}^q dominated by dispersive part of top boxes [Re[loops]]
 - related to heavy virtual states ($t\bar{t}\dots$)
 - 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]]
 - 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 $\tilde{Q}_S = \bar{q}_L^\alpha b_R^\beta \bar{q}_L^\beta b_R^\alpha$

M. Beneke et al., M. Ciuchini et al., U. Nierste, A. Lenz; see A. Lenz's talk

$\Delta F = 2$: New Physics

- 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

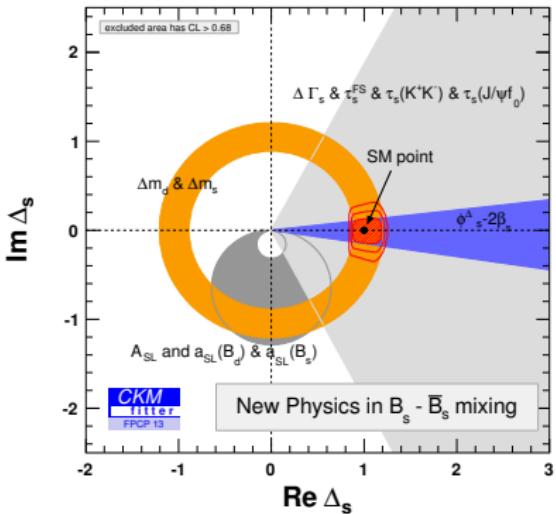
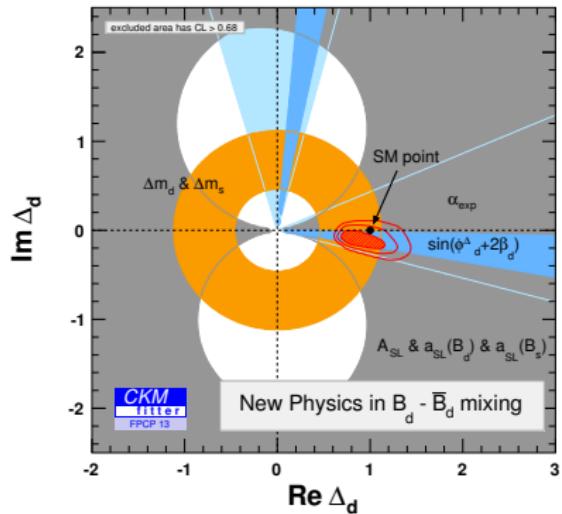
$$M_{12}^q = (M_{12}^q)_{SM} \times \Delta_q \quad \Delta_q = |\Delta_q| e^{i\phi_q^\Delta} = (1 + h_q e^{2i\sigma_q})$$

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

Use Δm_d , Δm_s , β , ϕ_s , a_{SL}^d , a_{SL}^s , $\Delta \Gamma_s$ to constrain Δ_d and Δ_s

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$\Delta F = 2$: Current constraints



$$\Delta_d = 0.80^{+0.27}_{-0.10} + i \cdot (-0.11^{+0.07}_{-0.06})$$

$$\Delta_s = 0.97^{+0.20}_{-0.08} + i \cdot (-0.01^{+0.09}_{-0.09})$$

Bounds/prospects for New Physics at

- **Stage I:** 7 fb^{-1} LHCb data + 5 ab^{-1} Belle II
- **Stage II:** 50 fb^{-1} LHCb data + 50 ab^{-1} Belle II

Lattice QCD at the Intensity Frontier, Implications of LHCb measurements and future prospects, Physics at Super B Factory

$\Delta F = 2$: Inputs

	2003	2013	Stage I	Stage II
$ V_{ud} $	0.9738 ± 0.0004	$0.97425 \pm 0 \pm 0.00022$	id	id
$ V_{us} (K_{\ell 3})$	$0.2228 \pm 0.0039 \pm 0.0018$	$0.2258 \pm 0.0008 \pm 0.0010$	0.22494 ± 0.0006	id
$ \epsilon_K $	$(2.282 \pm 0.017) \times 10^{-3}$	$(2.228 \pm 0.011) \times 10^{-3}$	id	id
$\Delta m_d [\text{ps}^{-1}]$	0.502 ± 0.006	0.507 ± 0.004	id	id
$\Delta m_s [\text{ps}^{-1}]$	> 14.5 [95% CL]	17.768 ± 0.024	id	id
$ V_{cb} \times 10^3$	$41.6 \pm 0.58 \pm 0.8$	$41.15 \pm 0.33 \pm 0.59$	42.3 ± 0.4	42.3 ± 0.3
$ V_{ub} \times 10^3$	$3.90 \pm 0.08 \pm 0.68$	$3.75 \pm 0.14 \pm 0.26$	3.56 ± 0.10	3.56 ± 0.08
$\sin 2\beta$	0.726 ± 0.037	0.679 ± 0.020	0.679 ± 0.016	0.679 ± 0.008
$\alpha (\text{mod } \pi)$	—	$(85.4^{+4.0}_{-3.8})^\circ$	$(91.5 \pm 2)^\circ$	$(91.5 \pm 1)^\circ$
$\gamma (\text{mod } \pi)$	—	$(68.0^{+8.0}_{-8.5})^\circ$	$(67.1 \pm 4)^\circ$	$(67.1 \pm 1)^\circ$
β_s	—	-0.005 ± 0.035	0.0178 ± 0.012	0.0178 ± 0.004
$\mathcal{B}(B \rightarrow \tau \nu) \times 10^4$	—	1.15 ± 0.23	0.83 ± 0.10	0.83 ± 0.05
$\mathcal{B}(B \rightarrow \mu \nu) \times 10^7$	—	—	3.7 ± 0.9	3.7 ± 0.2
$A_{SL}^d \times 10^4$	10 ± 140	23 ± 26	-7 ± 15	-7 ± 10
$A_{SL}^s \times 10^4$	—	-22 ± 52	0.3 ± 6.0	0.3 ± 2.0
\bar{m}_c	$1.2 \pm 0 \pm 0.2$	$1.286 \pm 0.013 \pm 0.040$	1.286 ± 0.020	1.286 ± 0.010
\bar{m}_t	167.0 ± 5.0	$165.8 \pm 0.54 \pm 0.72$	id	id
$\alpha_s(m_Z)$	$0.1172 \pm 0 \pm 0.0020$	$0.1184 \pm 0 \pm 0.0007$	id	id
B_K	$0.86 \pm 0.06 \pm 0.14$	$0.7615 \pm 0.0026 \pm 0.0137$	0.774 ± 0.007	0.774 ± 0.004
$f_{B_S} [\text{GeV}]$	$0.217 \pm 0.012 \pm 0.011$	$0.2256 \pm 0.0012 \pm 0.0054$	0.232 ± 0.002	0.232 ± 0.001
B_{B_S}	1.37 ± 0.14	$1.326 \pm 0.016 \pm 0.040$	1.214 ± 0.060	1.214 ± 0.010
f_{B_S}/f_{B_d}	$1.21 \pm 0.05 \pm 0.01$	$1.198 \pm 0.008 \pm 0.025$	1.205 ± 0.010	1.205 ± 0.005
B_{B_S}/B_{B_d}	1.00 ± 0.02	$1.036 \pm 0.013 \pm 0.023$	1.055 ± 0.010	1.055 ± 0.005
$\tilde{B}_{B_S}/\tilde{B}_{B_d}$	—	$1.01 \pm 0 \pm 0.03$	1.03 ± 0.02	id
\tilde{B}_{B_S}	—	$0.91 \pm 0.03 \pm 0.12$	0.87 ± 0.06	id

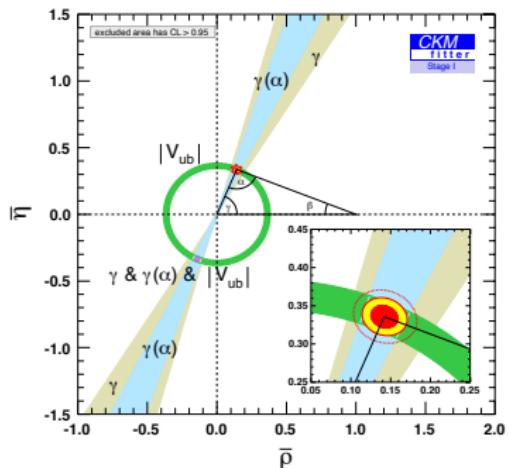
NB: No DØ A_{SL} input

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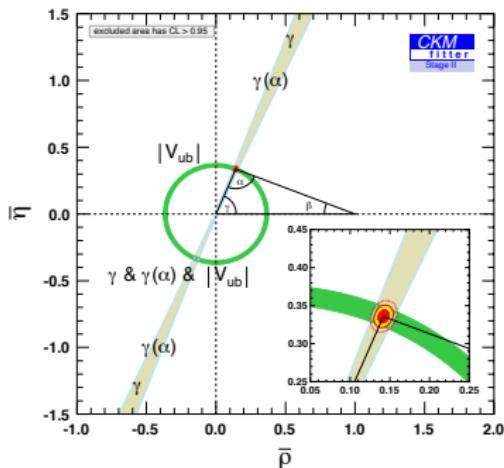
$\Delta F = 2$: CKM projections

Observables not affected by NP, used to fix CKM :

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



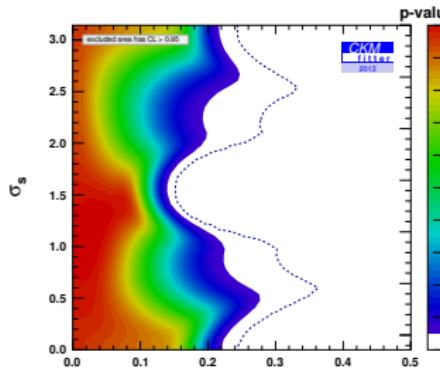
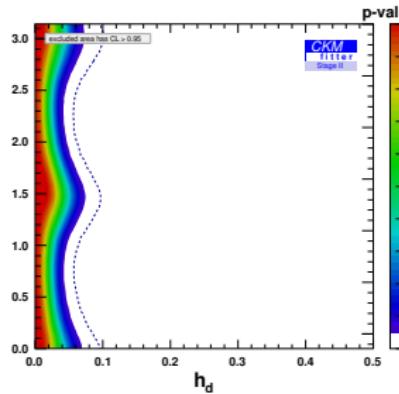
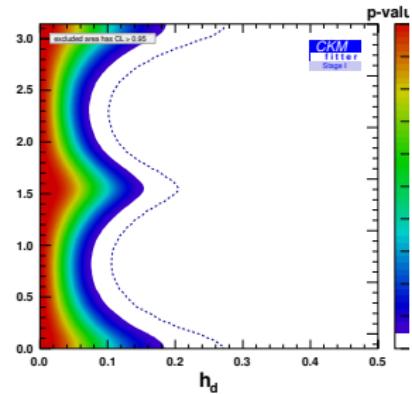
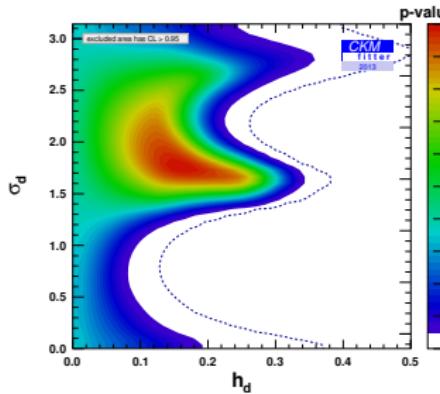
Stage I



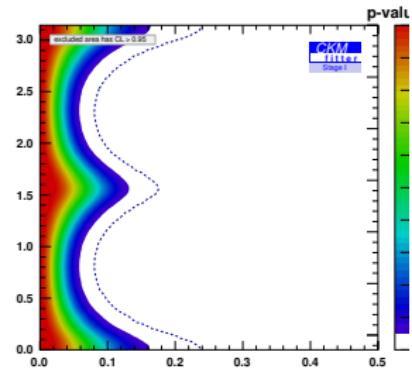
Stage II

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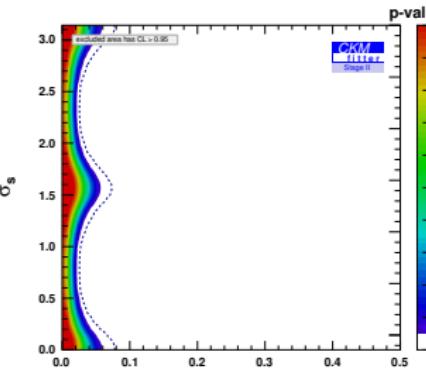
$\Delta F = 2$: bounds for $B_{d,s}$ mixings



2013

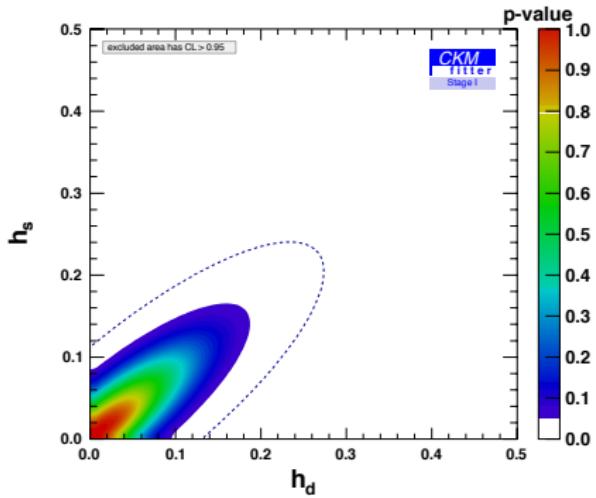


Stage I

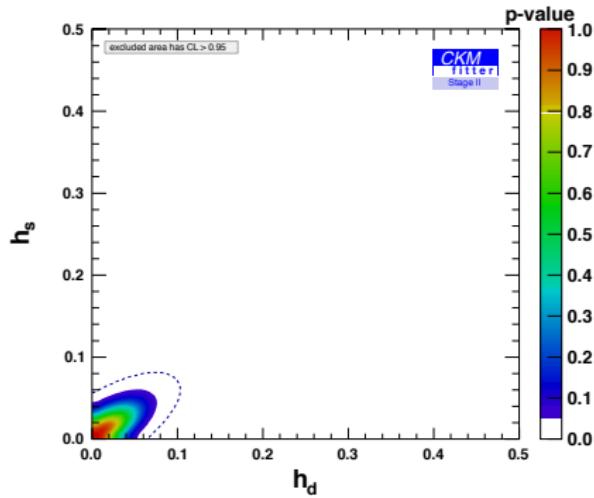


Stage II

$\Delta F = 2$: bounds on energy scale



Stage I



Stage II

From $C_{ij}^2/\Lambda^2 \times (\bar{b}_L \gamma^\mu q_{j,L})^2$

$$h \simeq 1.5 \frac{|C_{ij}|^2}{|V_{ti} V_{tj}|^2} \frac{(4\pi)^2}{G_F \Lambda^2}$$

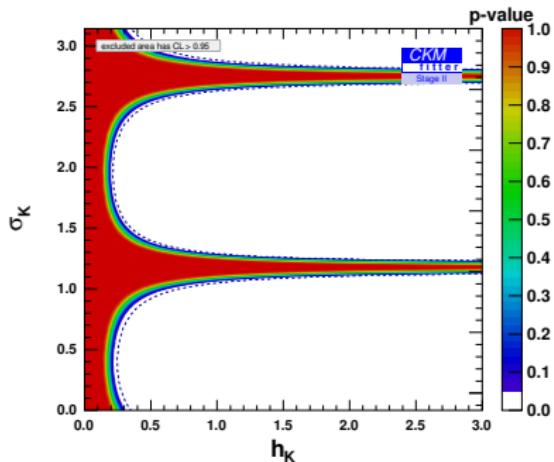
Couplings	NP loop order	Scales (in TeV) probed by B_d mixing	Scales (in TeV) probed by B_s mixing
$ C_{ij} = V_{ti} V_{tj}^* $ (CKM-like)	tree level	17	19
	one loop	1.4	1.5
$ C_{ij} = 1$ (no hierarchy)	tree level	2×10^3	5×10^2
	one loop	2×10^2	40

$\Delta F = 2$: ϵ_K

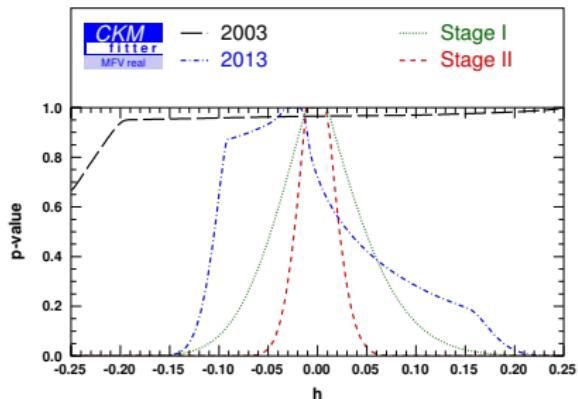
- K , B_d and B_s mixings in general not related
- ϵ_K not enough to bound NP in K mixing, even if NP only in $t\bar{t}$ box
- But in the case of MFV, possible to exploit all neutral mesons

$$h = h_d e^{2i\sigma_d} = h_s e^{2i\sigma_s} = h_K e^{2i\sigma_K} \text{ with } \sigma_i = 0 \pmod{\pi/2}$$

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Arbitrary NP in $t\bar{t}$ K boxes - Stage II



MFV case

More information



The CKMfitter interface screenshot shows the logo at the top, followed by a navigation menu with links to Home, Plots & Results, Specific Studies, Talks & Writeups Publications, and CKMfitter Group. Below the menu is a section titled "CKMfitter global fit results as of Moriond14:" which lists various parameters with their central values and 1, 2, and 3-sigma ranges. A note below states: "For a more extensive discussion, please read the summary of inputs and results." At the bottom, it says "Wolferstein parameters and Jarlskog invariant".

More on <http://ckmfitter.in2p3.fr>

J. Charles, Theory
O. Deschamps, LHCb
SDG, Theory
H. Lacker, ATLAS/BaBar

A. Menzel, ATLAS
S. Monteil, LHCb
V. Niess, LHCb
J. Ocariz, ATLAS/BaBar
J. Orloff, Theory
A. Perez, Babar
W. Qian, LHCb

V. Tisserand, BaBar/LHCb
K. Trabelsi, Belle/LHCb
P. Urquijo, Belle/Belle II
L. Vale Silva, Theory