CKMfitter keynote (well, beamer. . .) talk

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Fundamental parameters from Lattice QCD
31 August 2015

LPT Orsay

CKM fitter

The name of the game

Why flavour ?

$$\mathcal{L}_{SM} = \mathcal{L}_{gauge}(A_a, \Psi_j) + \mathcal{L}_{Higgs}(\phi, A_a, \Psi_j)$$

Gauge part $\mathcal{L}_{gauge}(A_a, \Psi_j)$

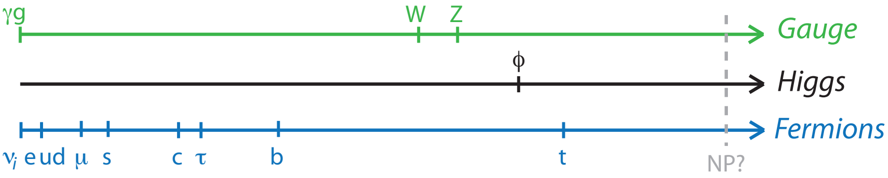
- Highly symmetric (gauge symmetry, flavour symmetry)
- Well-tested experimentally (electroweak precision tests)
- Stable with respect to quantum corrections

Higgs part $\mathcal{L}_{Higgs}(\phi, A_a, \Psi_j)$

- Ad hoc potential
- Dynamics not fully tested (more room for NP)
- Not stable w.r.t quantum corrections
- Origin of flavour structure of the Standard Model

Flavour structure: Quark masses and CKM matrix from diagonalisation of Yukawa couplings after EWSB

Quark flavours, SM and NP



Important, unexplained hierarchy among 10 of 19 params of $SM_{m_\nu=0}$

- Mass (6 params, a lot of small ratios of scales)
- CP violation (4 params, strong hierarchy between generations)

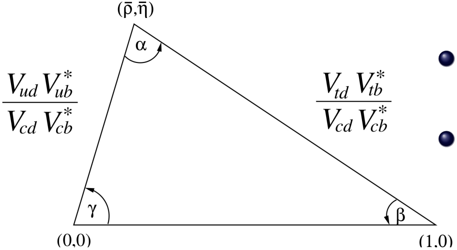
With interesting phenomenological consequences

- Hierarchy of CP asymmetries according to generations
- Quantum sensitivity (via loops) to large range of scales
- GIM suppression of Flavour-Changing Neutral Currents
- Potential to unravel patterns of deviations from NP
  (in a time where direct searches have not succeeded)

The CKM matrix

In SM, flavour dynamics related to weak charged transitions which mix quarks of different generations

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

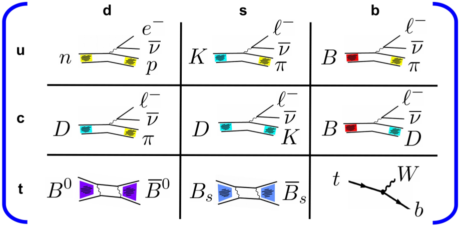


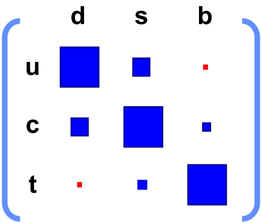
- 3 generations $\Longrightarrow$ 1 phase, only source of *CP*-violation in SM
- Wolfenstein parametrisation, defined to hold to all orders in λ and rephasing invariant

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

$\Longrightarrow$ 4 parameters describing the CKM matrix

Extracting the CKM parameters

V = 



- *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	$B \to DK$	γ	$B(b) \to D(c)\ell\nu$	$\lvert V_{cb}\rvert$ vs form factor (OPE)
			$B(b) \to \pi(u)\ell\nu$	$\lvert V_{ub}\rvert$ vs form factor (OPE)
			$M \to \ell\nu$	$\lvert V_{UD}\rvert$ vs f_M (decay cst)
Loop	$B \to J/\Psi K_s$	β	ϵ_K (K mixing)	$(\bar\rho, \bar\eta)$ vs B_K (bag parameter)
	$B \to \pi\pi, \rho\rho$	α	$\Delta m_d, \Delta m_s$ (B_d, B_s mixings)	$\lvert V_{tb} V_{tq}\rvert$ vs $f_B^2 B_B$ (bag param)

The inputs

frequentist ($\simeq \chi^2$ minim.) + Rfit scheme for theory uncert.

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

$\vert V_{ud}\vert$	superallowed β decays	PRC79, 055502 (2009)
$\vert V_{us}\vert$	$K_{\ell 3}$ (Flavianet)	$f_+(0) = 0.9645 \pm 0.0015 \pm 0.0045$
	$K \to \ell\nu, \tau \to K\nu_\tau$	$f_K = 155.2 \pm 0.2 \pm 0.6$ MeV
$\vert V_{us}/V_{ud}\vert$	$K \to \ell\nu/\pi \to \ell\nu, \tau \to K\nu_\tau/\tau \to \pi\nu_\tau$	$f_K/f_\pi = 1.1952 \pm 0.0007 \pm 0.0029$
ϵ_K	PDG	$\hat{B}_K = 0.7615 \pm 0.0027 \pm 0.0137$
$\vert V_{cd}\vert$	$D \to \mu\nu$, $D \to \pi\ell\nu$	$f_{D_s}/f_D = 1.175 \pm 0.001 \pm 0.004$, $f_+^{D\to\pi}(0)$
$\vert V_{cs}\vert$	$D_s \to \mu\nu$, $D_s \to \tau\nu$, $D \to \pi\ell\nu$	$f_{D_s} = 248.2 \pm 0.3 \pm 1.9$ MeV, $f_+^{D\to K}(0)$
$\vert V_{ub}\vert$	inclusive and exclusive B semileptonic	$\vert V_{ub}\vert \cdot 10^3 = 4.01 \pm 0.08 \pm 0.22$
$\vert V_{cb}\vert$	inclusive and exclusive B semileptonic	$\vert V_{cb}\vert \cdot 10^3 = 41.00 \pm 0.33 \pm 0.74$
$B \to \tau\nu$	$(1.24 \pm 0.22) \cdot 10^{-4}$	$f_{B_s}/f_{B_d} = 1.205 \pm 0.003 \pm 0.006$
		$f_{B_s} = 224.0 \pm 1.0 \pm 2.0$ MeV
$\vert V_{ub}/V_{cb}\vert$	Λ_b semileptonic decays	integrals of Λ_b form factors
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	$B_{B_s} = 1.320 \pm 0.016 \pm 0.030$
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

as well as $m_t, m_c, \alpha_s(M_Z)$!

Statistical framework

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

- $\mathcal{O}_{\rm meas} \pm \sigma_{\mathcal{O}}$ experimental values of observables
- $\mathcal{O}_{\rm th}(q)$ theoretical description in a given model

In case of statistical uncertainties $\sigma_{\mathcal{O}}$, likelihoods and χ^2

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

- Central value: estimator $\hat{q}$ max likelihood: $\chi^2(\hat{q}) = \min_q \chi^2(q)$
- Range: confidence level for each q_0 (p-value for $q = q_0$) by:

$$\Delta\chi^2(q_0) = \chi^2(q_0) - \min_q \chi^2(q)$$

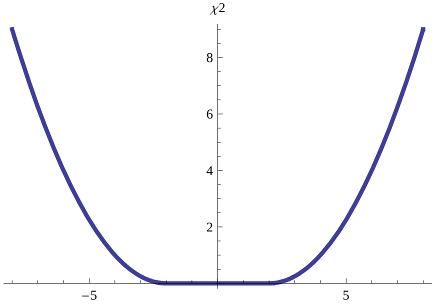
  assumed to obey χ^2 law with $N = dim(q)$ to yield CIs
- Pull: comparison of $\chi^2_{\rm min}$ with and without one measurement

$$p_{\mathcal{O}} = \sqrt{\min_q \chi^2_{\rm with\ meas}(q) - \min_q \chi^2_{\rm without\ meas}(q)}$$

Rfit scheme

CKM fitter : Treatment of systematics within the Rfit scheme

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



[More in Jérôme Charles' talk on Wednesday]

Averaging lattice results

Collecting lattice results

- follow FLAG to exclude limited results
- supplement with more recent published results with error budget

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 using error budget

"Educated Rfit" used to combine the results

- no correlations assumed
- product of (Gaussian + Rfit) likelihoods for central value
- product of Gaussian (stat) likelihoods for stat uncertainty
- syst uncertainty of the combination = most precise method
  - the present state of art cannot allow us to reach a better theoretical accuracy than the best of all estimates
  - best estimate should not be penalized by less precise methods

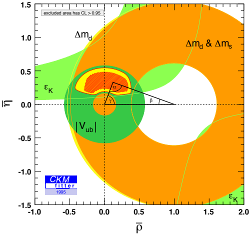
Illustration for f_K/f_π

Reference	N_f	Mean	Stat	Syst
ETMC09	2	1.210	0.006	0.024
HPQCD/UKQCD07	2+1	1.189	0.002	0.014
MILC10	2+1	1.197	0.002	$^{+0.003}_{-0.007}$
BMW10	2+1	1.192	0.007	0.013
LVdW11	2+1	1.202	0.011	0.024
RBC-UKQCD12	2+1	1.1991	0.0116	0.0185
HPQCD13	2+1+1	1.1938	0.0015	0.0032
FNAL-MILC14	2+1+1	1.1956	0.0010	$^{+0.0033}_{-0.0024}$
ETMC14	2+1+1	1.188	0.011	0.020
Our average		1.1952	0.0007	0.0029

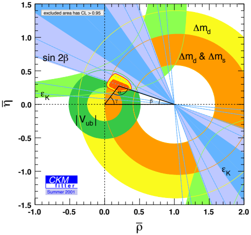
- Other values proposed: 1.194 ± 0.005 ($N_f = 2$ FLAG), 1.192 ± 0.005 ($N_f = 3$ FLAG)...
- Results for QCD decay constants (further corrections in BRs)
- Used for decay constants, bag parameters, form factors...
- Some assumptions on correlations for B_{B_s} and B_{B_d}/B_{B_s} since some collaborations quote only $f_B\sqrt{B}$

Two decades of CKM

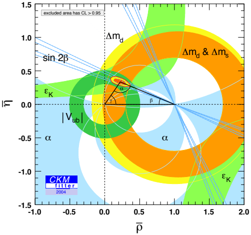
[LEP, KTeV, NA48, Babar, Belle, CDF, DØ, LHCb, CMS. . .]



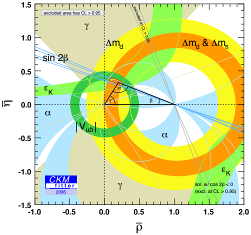
1995



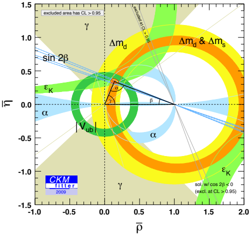
2001



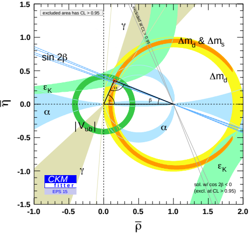
2004



2006



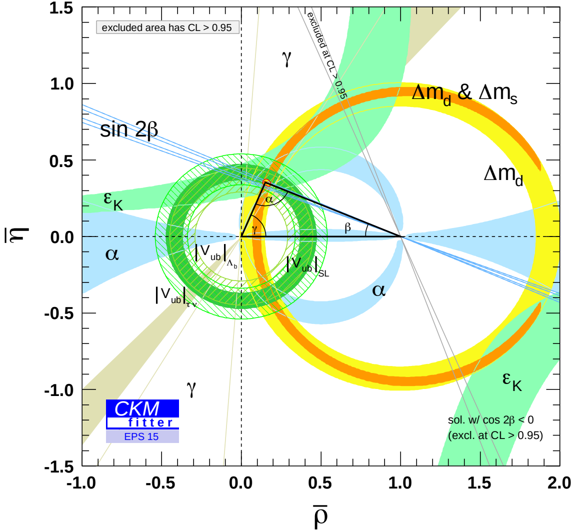
2009



2015

Where we are now

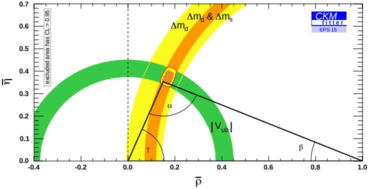
EPS-HEP 2015



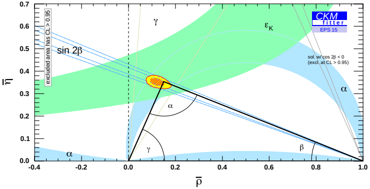
$|V_{ud}|, |V_{us}|$
$|V_{cb}|, |V_{ub}|_{SL}$
$B \to \tau\nu$
$|V_{ub}/V_{cb}|_{\Lambda_b}$
$\Delta m_d, \Delta m_s$
ϵ_K
$\sin 2\beta$
α
γ

$$A = 0.823^{+0.007}_{-0.014}$$
$$\lambda = 0.2254^{+0.0004}_{-0.0003}$$
$$\bar\rho = 0.150^{+0.012}_{-0.006}$$
$$\bar\eta = 0.354^{+0.007}_{-0.008}$$
(68% CL)

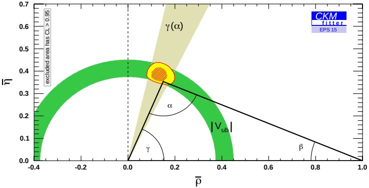
Consistency of the KM mechanism



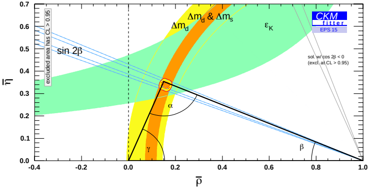
CP-allowed only



CP-violating only



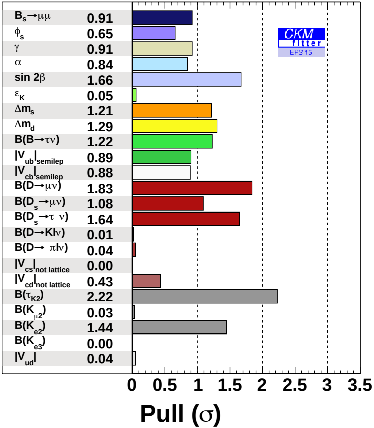
Tree only



Loop only

Validity of Kobayashi-Maskawa picture of *CP* violation

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

No indication of significant deviations from CKM picture

$|V_{ub}|$ from semileptonic B decays

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

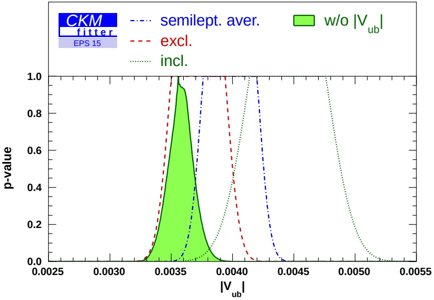
- Inclusive : $b \to u\ell\nu$ + Operator Product Expansion [HFAG BLNP]
- Exclusive : $B \to \pi\ell\nu$ + Form factors [J. A. Bailey et al., Fermilab-MILC]

$$|V_{ub}|_{inc} = 4.45 \pm 0.18 \pm 0.31$$
$$|V_{ub}|_{exc} = 3.72 \pm 0.09 \pm 0.22$$

$$|V_{ub}|_{ave} = 4.01 \pm 0.08 \pm 0.22$$

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

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



Indirect det. from global fit: $|V_{ub}|_{fit} = 3.57^{+0.15}_{-0.14}$ (4%)

$|V_{cb}|$ from semileptonic B decays

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

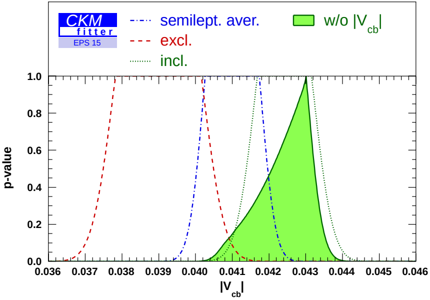
- Inclusive : $b \to c\ell\nu$ + OPE for moments [HFAG, Gambino and Schwanda]
- Exclusive : $B \to D(^*)\ell\nu$ + Form factors [J. A. Bailey et al., Fermilab-MILC]

$$|V_{cb}|_{inc} = 42.42 \pm 0.44 \pm 0.74$$
$$|V_{cb}|_{exc} = 38.99 \pm 0.49 \pm 1.17$$

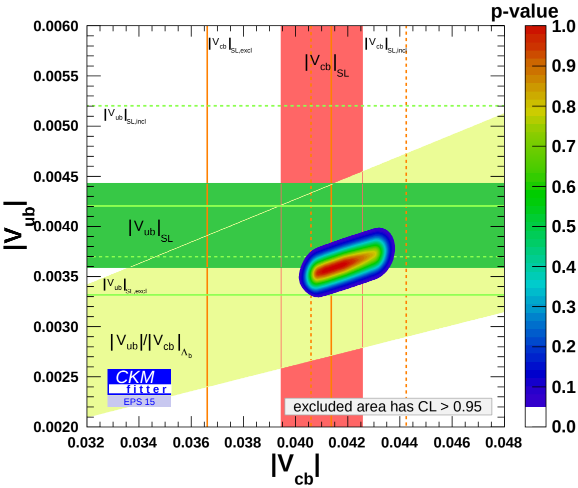
$$|V_{cb}|_{ave} = 41.00 \pm 0.33 \pm 0.74$$

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

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



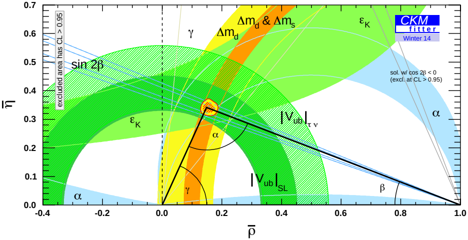
Indirect det. from global fit: $|V_{cb}|_{fit} = 43.0^{+0.4}_{-1.4}$ (4%)

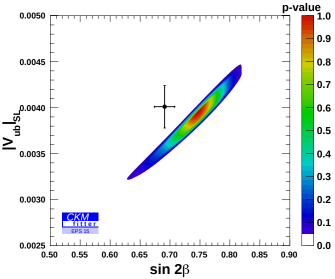


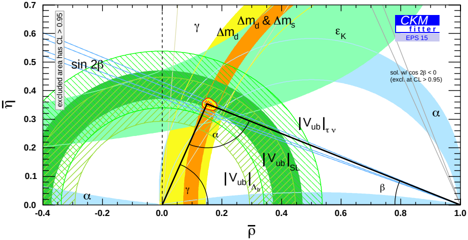
- Information on $|V_{ub}|$ from $Br(B \to \tau\nu)$
- New LHCb result on $|V_{ub}/V_{cb}|$ from $\Gamma(\Lambda_b \to p\mu\nu)/\Gamma(\Lambda_b \to \Lambda_c\mu\nu)$ at high q^2

  [Detmold, Lehner and Meinel]
- Global fit favours exclusive $|V_{ub}|_{SL}$ but inclusive $|V_{cb}|_{SL}$

From 2014 to 2015

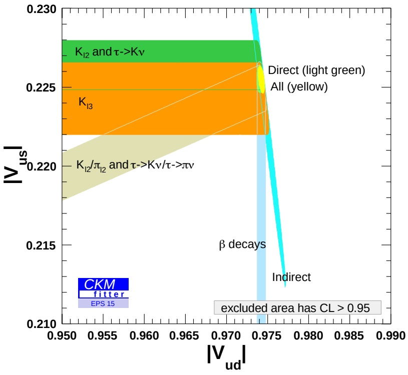






- Increase in the average used as input for $|V_{ub}|_{SL}$
- slight tension between $|V_{ub}|_{SL}$ and $\sin(2\beta)$ (1.5 σ for 2D hyp)
- reducing uncertainty on CKM params (mostly $\bar{\eta}$)

$|V_{ud}|$ and $|V_{us}|$

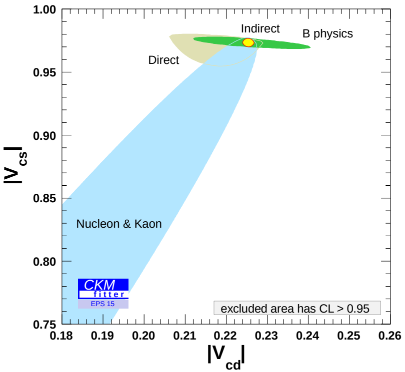


- "Direct" (semi- and leptonic) vs "indirect" (other sectors)
- $(|V_{ud}|, |V_{us}|)$: nuclear β + leptonic K, π and τ decays
- Same level of accuracy for exp and lattice inputs

	Leptonic $|V_{us}|$	Leptonic $|V_{us}/V_{ud}|$	Semilep $|V_{us}|$
Exp	0.1%	0.1%	0.2%
Lattice	0.4%	0.3%	0.5%

- $|V_{ud}|$ from superallowed β decays is 10 times more accurate...

$|V_{cd}|$ and $|V_{cs}|$



- "Direct" (semi- and leptonic) vs "indirect" (other sectors)
- $(|V_{cd}|, |V_{cs}|)$: $D \to \pi\ell\nu$, $D \to K\ell\nu$, leptonic decays
- Direct constraint mostly from leptonic decays

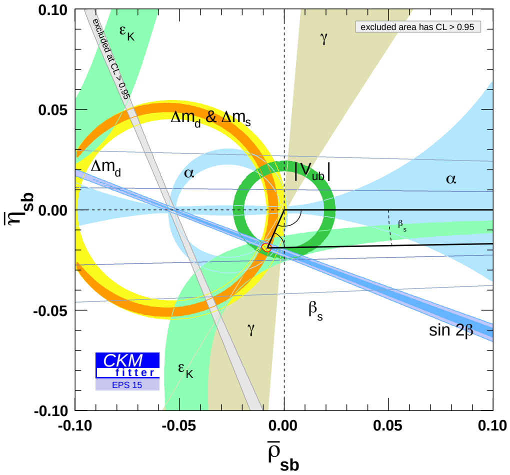
	Leptonic		Semileptonic	
	$\lvert V_{cd}\rvert$	$\lvert V_{cs}\rvert$	$\lvert V_{cd}\rvert$	$\lvert V_{cs}\rvert$
Exp	2.2%	2.1%	2.7%	1.0%
Lattice	0.8%	0.8%	7.8%	4.8%

Hadronic inputs from lattice

- Possibility to compare input and fit result (without including the inputs)
- Fit results consistent, but mostly not competitive om accuracy, with lattice results

	Input		Fit [input not included]	
f_K	$155.2 \pm 0.2 \pm 0.6$	(0.4%)	$156.5^{+0.1}_{-0.8}$	(0.3%)
f_K/f_π	$1.194 \pm 0.001 \pm 0.003$	(0.3%)	$1.191^{+0.006}_{-0.003}$	(0.4%)
$\hat{B}_K$	$0.762 \pm 0.003 \pm 0.014$	(1.9%)	$0.70^{+0.28}_{-0.05}$	(24%)
f_{B_s}	$225.6 \pm 1.1 \pm 5.4$	(2.4%)	$225.9^{+6.4}_{-6.7}$	(2.9%)
f_{B_s}/f_{B_d}	$1.205 \pm 0.003 \pm 0.006$	(0.6%)	$1.242^{+0.043}_{-0.031}$	(2.3%)
B_{B_s}	$1.320 \pm 0.016 \pm 0.030$	(2.6%)	$1.313^{+0.094}_{-0.071}$	(6.3%)
B_{B_s}/B_{B_d}	$1.023 \pm 0.013 \pm 0.014$	(1.9%)	$1.128^{+0.052}_{-0.071}$	(5.4%)

B_s triangle

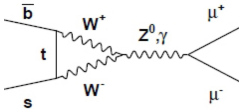


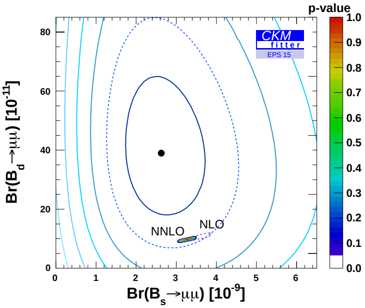
- $\bar{\rho}_{B_s} + i\bar{\eta}_{B_s} = -\frac{V_{us}V_{ub}^*}{V_{cs}V_{cb}^*}$ provides the B_s Unitarity Triangle $(\lambda^4, \lambda^2, \lambda^2)$
- Information on B_s mixing angle β_s from $B_s \to J/\psi\phi$
- Not relevant for SM determination of CKM parameters

$$\bar{\rho}_{Bs} = -0.00805^{+0.00034}_{-0.00065}$$
$$\bar{\eta}_{Bs} = -0.01897^{+0.00041}_{-0.00036}$$

FCNC now and in the future

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





- $\Delta F = 1$ FCNC sensitive to pseudo/scalar contributions, measured by LHCb and CMS
- Theoretical progress
  - Inclusion of B_s mixing in experimental time-integrated rate $\langle Br(B_s \to \mu\mu)\rangle \simeq 1.1 Br_{t=0}$
  - NLO QCD + LO EW $\to$ NNLO QCD + NLO EW

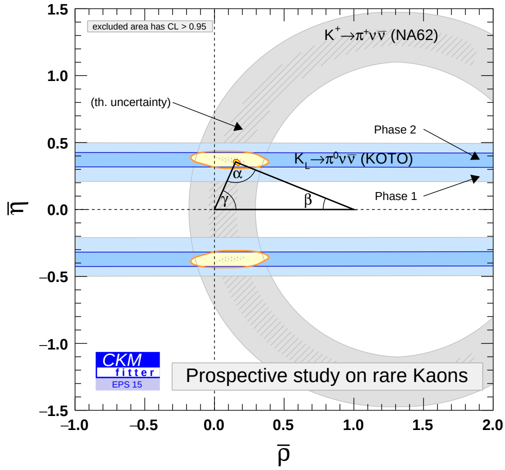
[Fleischer et al., Bobeth et al.]

- SM (and MFV) correlation between $Br(B_d \to \mu\mu)$ and $Br(B_s \to \mu\mu)$, driven by $\Delta m_d/\Delta m_s$:

$$Br(B_d \to \mu\mu)_{t=0}/Br(B_s \to \mu\mu)_{t=0} = 0.0298^{+0.0008}_{-0.0010}$$

- Further test of pseudo/scalar operators provided by

$$Br(B_d \to \tau\tau)_{t=0} \times 10^8 = 2.05^{+0.13}_{-0.15} \qquad Br(B_s \to \tau\tau)_{t=0} \times 10^7 = 6.98^{+0.38}_{-0.43}$$



- $K \to \pi\nu\bar{\nu}$ rare decays very clean probes of Z penguins and boxes
- $Br(K^+ \to \pi^+\nu\bar{\nu}) = (0.88^{+0.09}_{-0.10}) \times 10^{-10}$ and $Br(K_L \to \pi^0\nu\bar{\nu}) = (0.31^{+0.02}_{-0.02}) \times 10^{-10}$
- NA62 and KOTO expected to provide measurements at 10% accuracy for charged and neutral modes respectively

$\Delta F = 2$: observables

Neutral-meson mixing described by

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

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

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

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

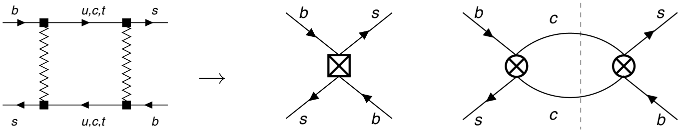
In terms of M_{12}^q and Γ_{12}^q

- Mass difference $\Delta m_q = M_H^q - M_L^q$
- Width difference $\Delta\Gamma_q = \Gamma_L^q - \Gamma_H^q$
- Semileptonic asymmetry $a_{SL}^q = \frac{\Gamma(\bar{B}_q(t)\to\ell^+\nu X)-\Gamma(B_q(t)\to\ell^-\nu X)}{\Gamma(\bar{B}_q(t)\to\ell^+\nu X)+\Gamma(B_q(t)\to\ell^-\nu X)}$
- Mixing phase in time-dep analysis

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

$\Delta F = 2$: New Physics potential

Eff. Hamiltonian integrating out heavy W, Z, t



- M_{12} dominated by (virtual) top boxes

  (involves $Q = \bar{q}_L \gamma_\mu b_L \bar{q}_L \gamma^\mu b_L$)

  [affected by NP, e.g., if heavy new particles in the box]

- Γ_{12} dominated by tree decays into (real) charm states

  (involves Q and $\tilde{Q}_S = \bar{q}_L^\alpha b_R^\beta \bar{q}_L^\beta b_R^\alpha$)

  [affected by NP if changes in (constrained) tree-level decays]

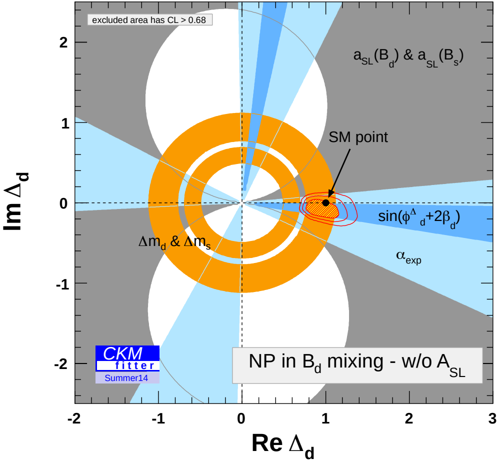
Model-independent parametrisation assuming NP affects M_{12} only

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

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

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

$\Delta F = 2$: B_d mixing

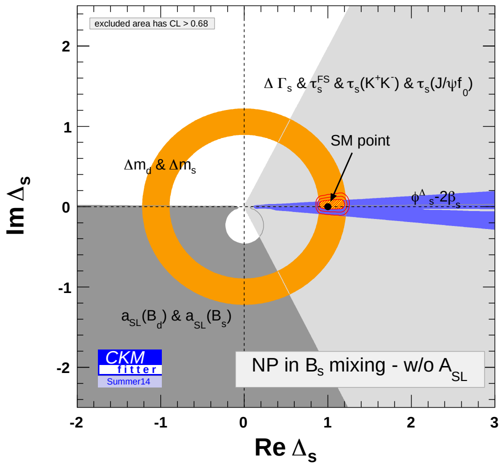


[Constraints @ 68% CL]

- Dominant constraint from β and Δm_d
- Good agreement with other constraints (α, $a_{SL}^{d,s}$)
- Compatible with SM
- Still room for NP in Δ_d

$\Delta_d = 0.94^{+0.18}_{-0.15} + i \cdot (-0.11^{+0.11}_{-0.05})$ 2D SM hyp. ($\Delta_d = 1 + i \cdot 0$): 0.9 σ

$\Delta F = 2$: B_s mixing



[Constraints @ 68% CL]

- Dominant constraints from Δm_s and ϕ_s
- ϕ_s favours SM situation
- A_{SL}, combining a^d_{SL} and a^s_{SL}, measured by $D\emptyset$ not included
- still room for NP in Δ_s

$\Delta_s = 1.05^{+0.14}_{-0.13} + i \cdot (-0.03^{+0.04}_{-0.04})$

2D SM hyp ($\Delta_s = 1 + i \cdot 0$): 0.3 σ

Bounds/prospects for New Physics in future

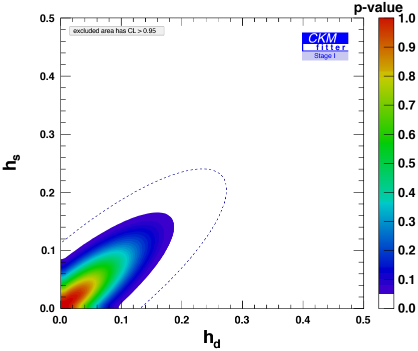
- Stage I: 7 fb^{-1} LHCb data + 5 ab^{-1} Belle II
- Stage II: 50 fb^{-1} LHCb data + 50 ab^{-1} Belle II

$\Delta F = 2$: Inputs for prospective

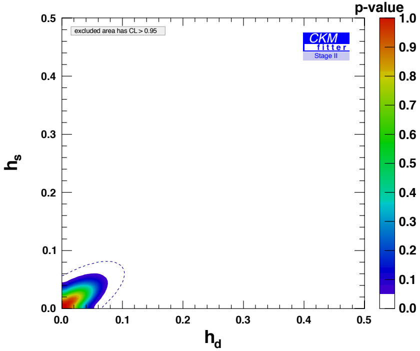
	2003	2013	Stage I	Stage II
$\|V_{ud}\|$	0.9738 ± 0.0004	$0.97425 \pm 0 \pm 0.00022$	id	id
$\|V_{us}\|$ $(K_{\ell 3})$	$0.2228 \pm 0.0039 \pm 0.0018$	$0.2258 \pm 0.0008 \pm 0.0010$	0.22494 ± 0.0006	id
$\|\epsilon_K\|$	$(2.282 \pm 0.017) \times 10^{-3}$	$(2.228 \pm 0.011) \times 10^{-3}$	id	id
Δm_d [ps^{-1}]	0.502 ± 0.006	0.507 ± 0.004	id	id
Δm_s [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
α (mod π)	—	$(85.4^{+4.0}_{-3.8})^\circ$	$(91.5 \pm 2)^\circ$	$(91.5 \pm 1)^\circ$
γ (mod π)	—	$(68.0^{+8.0}_{-8.5})^\circ$	$(67.1 \pm 4)^\circ$	$(67.1 \pm 1)^\circ$
β_s	—	-0.005 ± 0.035	0.0178 ± 0.012	0.0178 ± 0.004
$\mathcal{B}(B \to \tau\nu) \times 10^4$	—	1.15 ± 0.23	0.83 ± 0.10	0.83 ± 0.05
$\mathcal{B}(B \to \mu\nu) \times 10^7$	—	—	3.7 ± 0.9	3.7 ± 0.2
$A^d_{\rm SL} \times 10^4$	10 ± 140	23 ± 26	-7 ± 15	-7 ± 10
$A^s_{\rm SL} \times 10^4$	—	-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} [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

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

$\Delta F = 2$: 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	B_s mixing
$\lvert C_{ij}\rvert = \lvert V_{ti} V_{tj}^*\rvert$ (CKM-like)	tree level	17	19
	one loop	1.4	1.5
$\lvert C_{ij}\rvert = 1$ (no hierarchy)	tree level	2×10^3	5×10^2
	one loop	2×10^2	40

Outlook

Flavour physics

- Connection between Higgs and fermion sectors
- Potential to unravel NP patterns in absence of direct production
- Analysis of flavour processes crucial

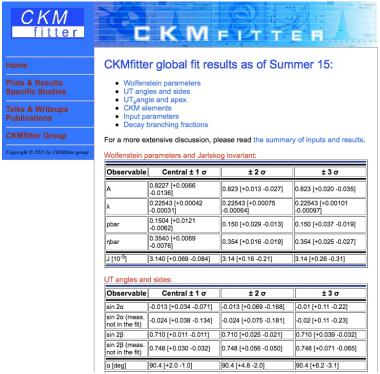
Determination of CKM matrix

- Mature field, with lattice accuracy often compteing with exp
- No significant deviations in the global fit
- Other processes to include ?
- $|V_{ub}|$ and $|V_{cb}|$?

Study of FCNC and NP

- $\Delta F = 1$: $B_s \to \mu\mu$, $K \to \pi\nu\bar{\nu}$
- $\Delta F = 2$: bounds for NP in mixing
- Prospectives for new processes studied/better inputs from lattice ?

More information


CKM fitter

CKMFITTER

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Plots & Results
Specific Studies

Talks & Writeups
Publications

CKMfitter Group

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CKMfitter global fit results as of Summer 15:

- Wolfenstein parameters
- UT angles and sides
- UT_s angle and apex
- CKM elements
- Input parameters
- Decay branching fractions

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	0.8227 [+0.0066 -0.0136]	0.823 [+0.013 -0.027]	0.823 [+0.020 -0.035]
λ	0.22543 [+0.00042 -0.00031]	0.22543 [+0.00075 -0.00064]	0.22543 [+0.00101 -0.00097]
ρbar	0.1504 [+0.0121 -0.0062]	0.150 [+0.029 -0.013]	0.150 [+0.037 -0.019]
ηbar	0.3540 [+0.0069 -0.0076]	0.354 [+0.016 -0.019]	0.354 [+0.025 -0.027]
J [10^{-5}]	3.140 [+0.069 -0.084]	3.14 [+0.16 -0.21]	3.14 [+0.26 -0.31]

UT angles and sides:

Observable	Central ± 1 σ	± 2 σ	± 3 σ
sin 2α	-0.013 [+0.034 -0.071]	-0.013 [+0.069 -0.168]	-0.01 [+0.11 -0.22]
sin 2α (meas. not in the fit)	-0.024 [+0.038 -0.134]	-0.024 [+0.075 -0.181]	-0.02 [+0.11 -0.23]
sin 2β	0.710 [+0.011 -0.011]	0.710 [+0.025 -0.021]	0.710 [+0.039 -0.032]
sin 2β (meas. not in the fit)	0.748 [+0.030 -0.032]	0.748 [+0.056 -0.050]	0.748 [+0.071 -0.065]
α [deg]	90.4 [+2.0 -1.0]	90.4 [+4.8 -2.0]	90.4 [+6.2 -3.1]

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