CKM fits and kaon decays

Sébastien Descotes-Genon

Laboratoire de Physique Théorique
CNRS & Université Paris-Sud, 91405 Orsay, France

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LPT Orsay

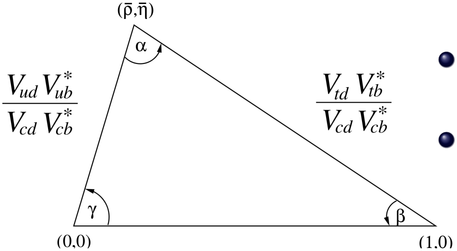
CKM fitter

CKMfitter

The CKM matrix

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

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



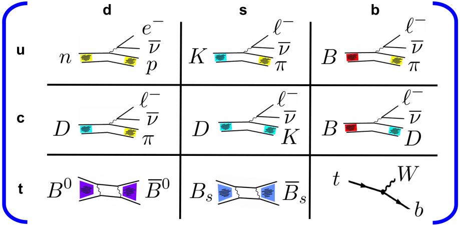
- 3 generations $\Longrightarrow$ 1 phase, only source of *CP*-violation in SM
- Wolfenstein parametrisation, defined to hold to all orders in λ and rephasing invariant

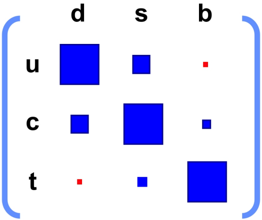
$$\lambda^2 = \frac{|V_{us}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad A^2\lambda^4 = \frac{|V_{cb}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad \bar\rho + i\bar\eta = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$$

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

The inputs

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

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

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

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

$\Longrightarrow$Specific scheme to treat theoretical uncertains (currently Rfit)

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

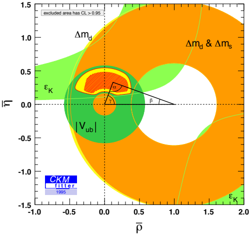
Illustration for f_K/f_π

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

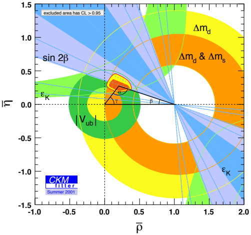
- Other values proposed: 1.194 ± 0.005 ($N_f = 2$ FLAG), 1.192 ± 0.005 ($N_f = 3$ FLAG)...
- Results for QCD decay constants (further etm corrections in BRs)
- Strange for absolute reference + ratio of non-strange and strange
- Used for decay constants, bag parameters, form factors...

Two decades of CKM

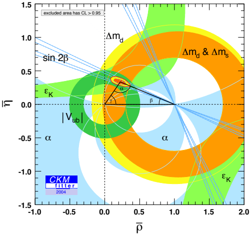
[LEP, KTeV, NA48, Babar, Belle, CDF, DØ, LHCb, CMS. . .]



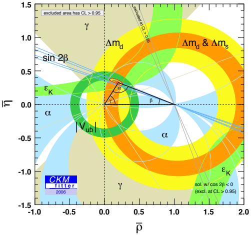
1995



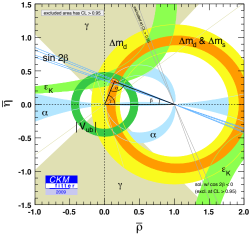
2001



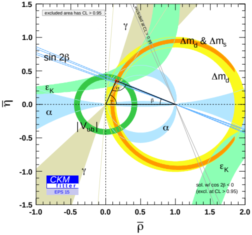
2004



2006

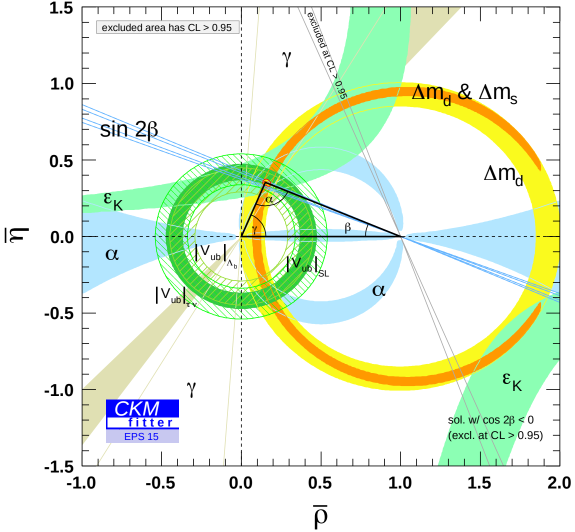


2009



2015

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

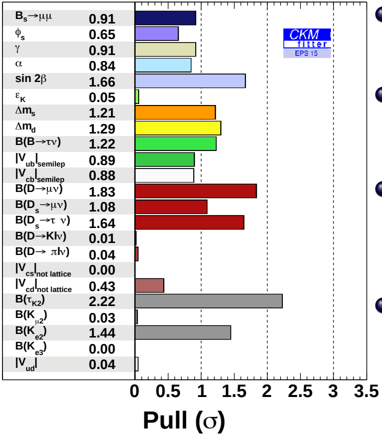
$\sin 2\beta$

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)

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

Leptonic and semileptonic decays

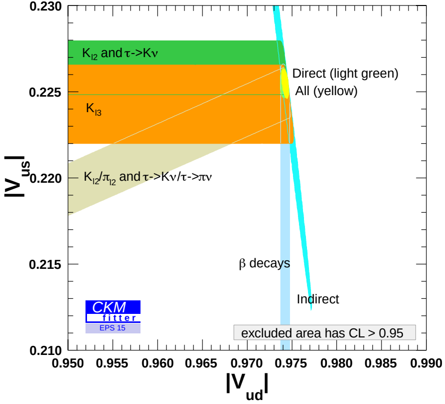
Leptonic and semileptonic kaon decays

Two type of constraints in the global fit from kaons

- tree-level decays: leptonic and semileptonic decays
- kaon mixing

$\lvert V_{us}\rvert f_+^{K\to\pi}(0)$	0.21664 ± 0.00048	[PDG]
$Br(K^- \to e^-\bar\nu_e)$	$(1.581 \pm 0.008) \times 10^{-5}$	[PDG]
$Br(K^- \to \mu^-\bar\nu_\mu)$	0.6355 ± 0.0011	[PDG]
$Br(\tau^- \to K^-\bar\nu_\tau)$	$(0.6955 \pm 0.0096) \times 10^{-2}$	[HFAG]
$Br(K^- \to \mu^-\bar\nu_\mu)/Br(\pi^- \to \mu^-\bar\nu_\mu)$	1.3365 ± 0.0032	[PDG]
$Br(\tau^- \to K^-\bar\nu_\tau)/Br(\tau^- \to \pi^-\bar\nu_\tau)$	$(6.43 \pm 0.09) \times 10^{-2}$	[HFAG]
$f_+^{K\to\pi}(0)$	$0.9645 \pm 0.0015 \pm 0.0045$	[our average]
f_K	$(155.2 \pm 0.2 \pm 0.6)$ MeV	[our average]
f_K/f_π	$1.1952 \pm 0.0007 \pm 0.0029$	[our average]

$|V_{ud}|$ 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		Semilep
	$\lvert V_{us}\rvert$	$\lvert V_{us}/V_{ud}\rvert$	$\lvert V_{us}\rvert$
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. . .

Radiative corrections for $K \to e\nu$, $K \to \mu\nu$, $\tau \to K\nu$

[Marciano-Sirlin, Decker-Finkemeier, Cirigliano-Rosell]

$$B = B_0 \times \text{short} - \text{dist. ew corr} \times \text{long} - \text{dist. ew corr} \times \text{struct} - \text{dep.corr}$$

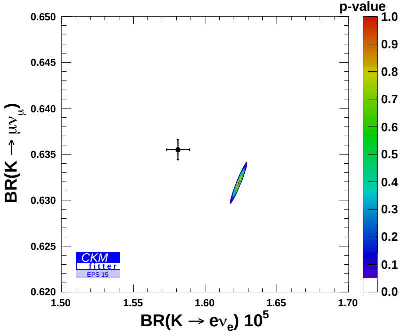
- Short. dist. expressing W exchanges in terms of G_F [universal]
- Long. dist. using a point-like meson [universal]
- Struct. dep. probing the structure of the meson [process-dep.]

$$B(K \to \ell\nu) = \frac{G_F^2 |V_{us}|^2}{8\pi} f_K^2 m_K m_\ell^2 \left(1 - \frac{m_\ell^2}{M_K^2}\right)^2 \left(1 + 2\frac{\alpha}{\pi} \log \frac{M_Z}{M_\rho}\right) \left(1 + \frac{\alpha}{\pi} F(m_\ell/m_K)\right)(1 + O(\alpha))$$

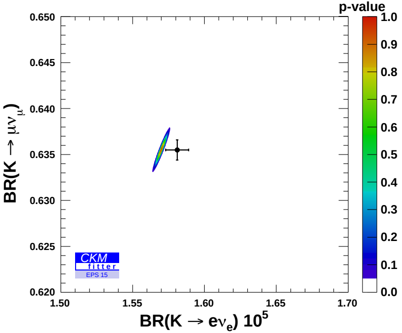
$$B(\tau \to K\nu_\tau) = \frac{G_F^2 |V_{us}|^2}{16\pi} f_K^2 m_K m_\ell^2 \left(1 - \frac{m_K^2}{M_\tau^2}\right)^2 \left(1 + 2\frac{\alpha}{\pi} \log \frac{M_Z}{M_\tau}\right) \left(1 + \frac{\alpha}{\pi} G(m_K/m_\tau)\right)(1 + O(\alpha))$$

The importance of radiative corrections

Comparing the indirect fit results with the measurement for $Br(K \to \ell\nu)$
$\Longrightarrow$Good test of radiative corrections and lattice QCD !



No radiative corrections

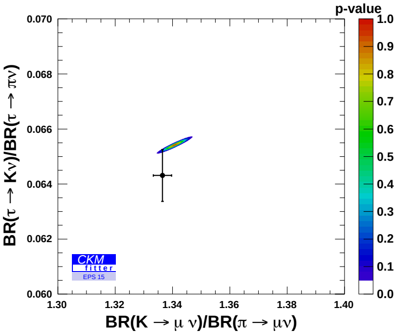


Radiative corrections

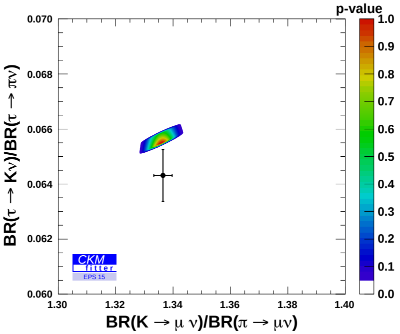
NB: Struct-dep corr not incuded but much smaller than the two others

. . . but not in all cases

Ratios of K and π leptonic decays into μ or τ less sensitivity to the issue (part of radiative corrections cancel + heavy leptons)



No radiative corrections



Radiative corrections

Radiative corrections needed in the global fit to get a decent fit
$\chi^2_{\min} = 58$ (naive p-value 0.002%) $\rightarrow \chi^2_{\min} = 20$ (naive p-value 49.3%)

Kaon mixing

Two type of constraints in the global fit from kaons

- tree-level decays
- kaon mixing: ϵ_K

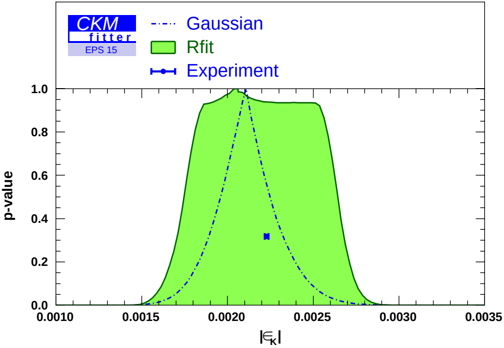
$$|\epsilon_K| = \kappa_\epsilon C_\epsilon \hat{B}_K [\mathrm{Im}[(V_{ts} V_{td}^*)^2] \eta_{tt} S(x_t) + 2\mathrm{Im}[(V_{cs} V_{cd}^* V_{ts} V_{td}^*)] \eta_{ct} S(x_c, x_t) + \mathrm{Im}[(V_{cs} V_{cd}^*)^2] \eta_{cc} S(x_c)]$$

- Inami-Lim $S_0(x_q = m_x^2/m_W^2)$
- C_ϵ normalisation
- κ_ϵ correcting factor (determination of Q_6, higher order OPE)

$\lvert\epsilon_K\rvert$	$(2.228 \pm 0.011) \times 10^{-3}$	PDG
B_K	$0.7615 \pm 0.0027 \pm 0.0137$	[our average]
η_{cc}	$1.87 \pm 0 \pm 0.76$	[Brod-Gorbahn]
η_{ct}	$0.497 \pm 0 \pm 0.047$	[Brod-Gorbahn]
η_{tt}	$0.5765 \pm 0 \pm 0.0065$	[Nierste]
κ_ϵ	$0.940 \pm 0.013 \pm 0.023$	[Buras, Guadagnoli, Isidori]

From time to time, issues with the compatibility of ϵ_K with the rest of the fit, related to the fact that ϵ_K has a strong dependence on

- B_K : role of theoretical uncertainties
- $|V_{cb}|$: inclusive, exclusive or average



- Rfit versus Gaussian treatment of theoretical uncertainties
- agreement of prediction with experiment in both cases

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

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

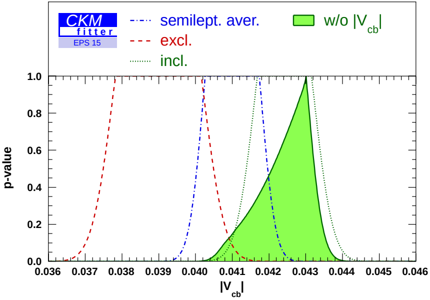
- Inclusive : $b \to c\ell\nu$ + OPE for moments [HFAG, Gambino and Schwanda]
- Exclusive : $B \to D(^*)\ell\nu$ + Form factors [J. A. Bailey et al., Fermilab-MILC]

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

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

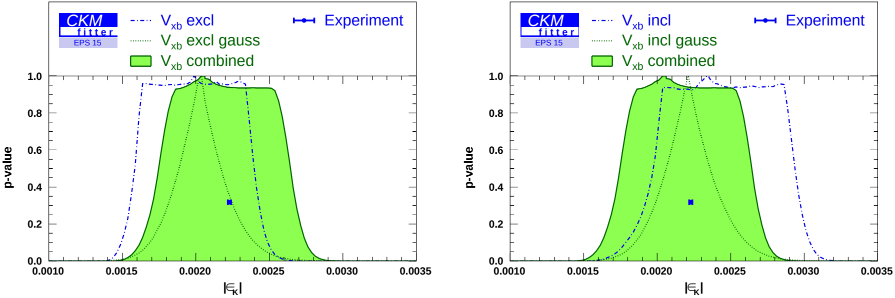
with all values $\times 10^{-3}$

- 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%)

Exclusive versus inclusive for ϵ_K



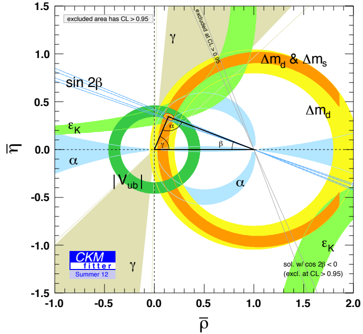
$|V_{xb}|$ exclusive only $\qquad$ $|V_{xb}|$ inclusive only

- Exclusive slightly off compared to inclusive
- But good agreement in all cases

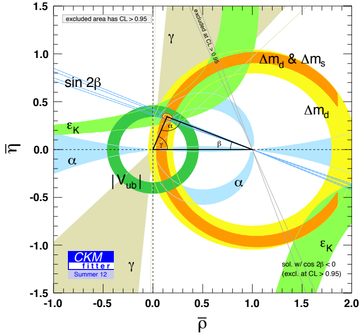
ϵ_K at NNLO

QCD short-distance corrections computed up to NNLO

- η_{tt}: $0.5765 \pm 0.0065 \to 0.5765 \pm 0.0065$ [Buras, Jamin, Weisz]
- η_{ct}: $0.47 \pm 0.04 \to 0.496 \pm 0.047$ [Brod, Gorbahn]
- η_{cc}: $(1.46 \pm \delta_{cc}) \left[1 - 1.2\left(\frac{\bar{m}_c}{1.25\ \mathrm{GeV}}\right)\right] \left[1 + 52(\alpha_s(M_Z) - 0.118)\right],\ \delta_{cc} \simeq 0.22$
  $\to 1.87 \pm 0.76$ [Brod, Gorbahn]



η at NLO (Rfit)



η at NNLO (Rfit)

The role of lattice inputs

- Compare input and fit result (without including the inputs)
- Fit results consistent, but not always competitive in 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%)
$f_+^{K\to\pi}(0)$	$0.9645 \pm 0.0015 \pm 0.0045$	(0.5%)	$0.9594^{+0.0024}_{-0.0029}$	(0.3%)
$\hat{B}_K$	$0.762 \pm 0.003 \pm 0.014$	(1.9%)	$0.70^{+0.28}_{-0.05}$	(24%)

Similarly for κ_ϵ, we have

	Input		Fit [input not included]	
κ_ϵ	$0.940 \pm 0.013 \pm 0.023$	(2.8%)	$0.875^{+0.317}_{-0.069}$	(22%)

$K \to \pi\nu\bar{\nu}$

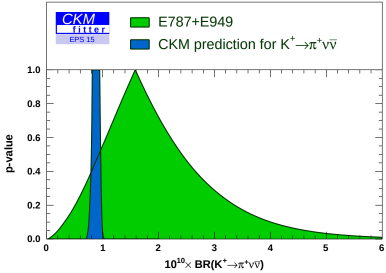
$K \to \pi\nu\bar{\nu}$

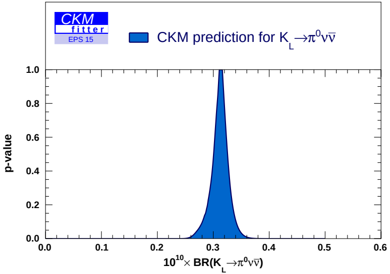
$$\mathcal{B}[K^+ \to \pi^+\nu\bar{\nu}]_{\rm SM} = \kappa_+ (1+\Delta_{em}) \left[\left(\frac{Im\lambda_t}{\lambda^5} X_t\right)^2 + \left(\frac{Re\lambda_c}{\lambda}(P_c + \delta P_{c,u}) + \frac{Re\lambda_t}{\lambda^5} X_t\right)^2 \right]$$

$$\mathcal{B}[K_L \to \pi^0\nu\bar{\nu}]_{\rm SM} = \kappa_L \left(\frac{Im\lambda_t}{\lambda^5} X_t\right)^2 ,$$

[Buras et al.; Brod, Gorbahn; Mescia, Smith]

- isospin-breaking parameter $\kappa_{+,L}$ from semileptonic K decays
- Δ_{em} electromagnetic correction,
- X_t top-quark contributions, P_c and $\delta P_{c,u}$ light-quark contributions

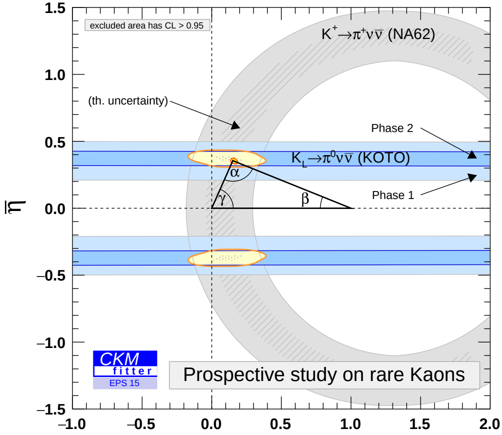




$Br(K^+ \to \pi^+\nu\bar{\nu}) = (0.89^{+0.09}_{-0.10}) \times 10^{-10}$ $\quad$ $Br(K_L \to \pi^0\nu\bar{\nu}) = (0.31^{+0.02}_{-0.02}) \times 10^{-10}$

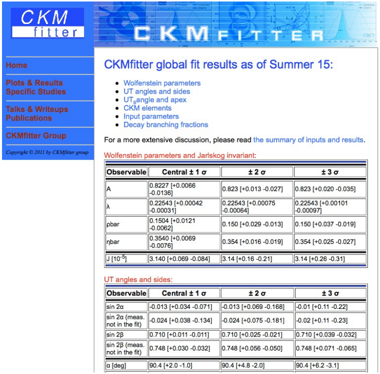
Prospective

- NA62 : $Br(K^+ \to \pi^+ \nu\bar{\nu})$ at 10% accuracy
- KOTO : Phase 1 $\sim 3\sigma$ constraint on the branching ratio (SM), Phase 2 stage with $Br(K_L \to \pi^0 \nu\bar{\nu})$ at 10% accuracy



- NA62: in grey the role played by theoretical uncertainties
- KOTO : phases 1 and 2 indicated

More information



CKM fitter

CKMFITTER

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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

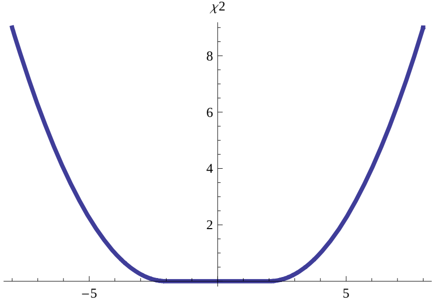
J. Charles, Theory
O. Deschamps, LHCb
SDG, Theory
H. Lacker, ATLAS/BaBar
A. Menzel, ATLAS
S. Monteil, LHCb
V. Niess, LHCb
J. Ocariz, ATLAS/BaBar
J. Orloff, Theory
A. Perez, Babar
W. Qian, LHCb
V. Tisserand, BaBar/LHCb
K. Trabelsi, Belle/LHCb
P. Urquijo, Belle/Belle II
L. Vale Silva, Theory

Spares

Rfit scheme

CKMfitter : 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



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

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

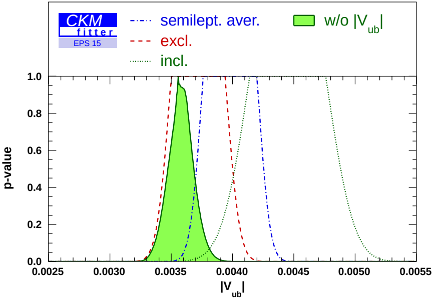
- Inclusive : $b \to u\ell\nu$ + Operator Product Expansion [HFAG BLNP]
- Exclusive : $B \to \pi\ell\nu$ + Form factors [J. A. Bailey et al., Fermilab-MILC]

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

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

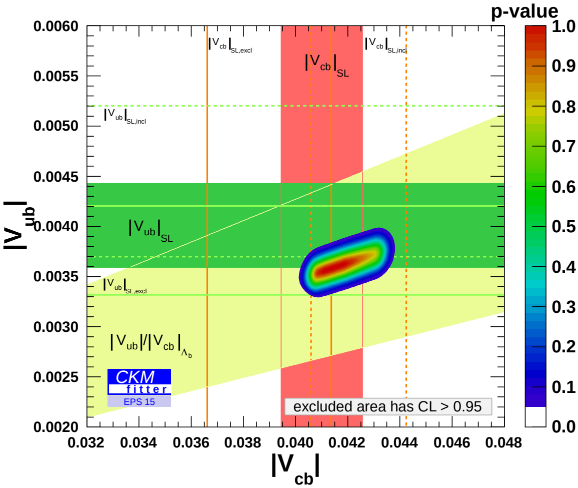
with all values $\times 10^{-3}$

- 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%)

$|V_{ub}|, |V_{cb}|$

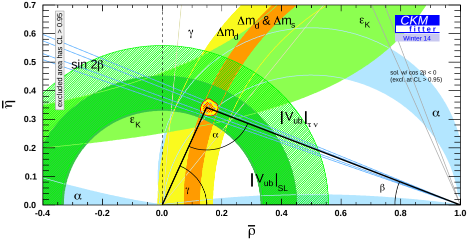


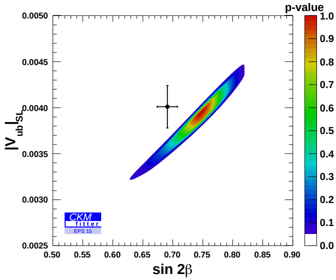
- Information on $|V_{ub}|$ from $Br(B \to \tau\nu)$
- New LHCb result on $|V_{ub}/V_{cb}|$ from $\Gamma(\Lambda_b \to p\mu\nu)/\Gamma(\Lambda_b \to \Lambda_c\mu\nu)$ at high q^2

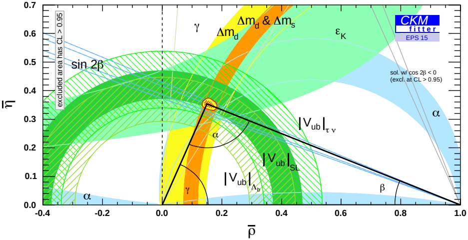
  [Detmold, Lehner and Meinel]

- Global fit favours exclusive $|V_{ub}|_{SL}$ but inclusive $|V_{cb}|_{SL}$

From 2014 to 2015

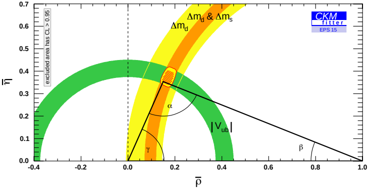




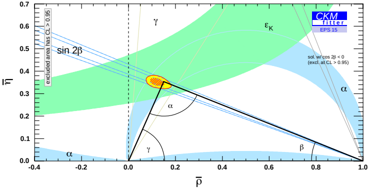


- Increase in the average used as input for $|V_{ub}|_{SL}$
- slight tension between $|V_{ub}|_{SL}$ and $\sin(2\beta)$ (1.5 σ for 2D hyp)
- reducing uncertainty on CKM params (mostly $\bar\eta$)

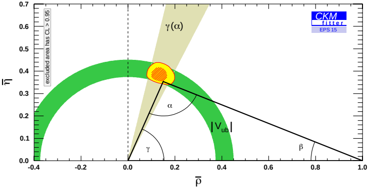
Consistency of the KM mechanism



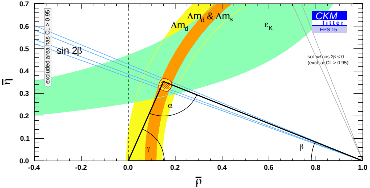
CP-allowed only



CP-violating only



Tree only



Loop only

Validity of Kobayashi-Maskawa picture of *CP* violation