CKMfitter - The winter 2008 collection

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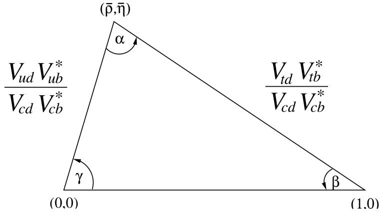
Rencontres de Moriond - 1-8 March 2008

CP-violation : the four parameters

In SM weak charged $W^{\pm}$ 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 big picture

The inputs

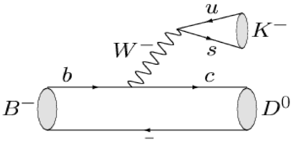
CKM fitter — CKM matrix within a frequentist framework ($\simeq \chi^2$ minimum) + specific scheme for theory errors (Rfit)

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

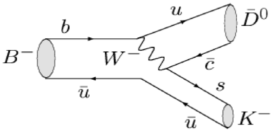
$\|V_{ud}\|$	superallowed β decays	arXiv 0710.3181
$\|V_{us}\|$	$K_{\ell 3}$ (Flavianet)	$f_+(0) = 0.964(5)$
ϵ_K	KTeV/KLOE	$B_K = 0.78 \pm 0.02 \pm 0.09$
$\|V_{ub}\|$	inclusive and exclusive	$\|V_{ub}\| \cdot 10^3 = 3.76 \pm 0.10 \pm 0.47$
$\|V_{cb}\|$	inclusive and exclusive	$\|V_{cb}\| \cdot 10^3 = 40.60 \pm 0.35 \pm 0.58$
Δm_d	last WA B_d-$\bar{B}_d$ mixing	$B_{B_s}/B_{B_d} = 1.00 \pm 0.02$
Δm_s	last WA B_s-$\bar{B}_s$ mixing	$B_{B_s} = 1.29 \pm 0.05 \pm 0.08$
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
$B \to \tau\nu$	last WA	$f_{B_s}/f_{B_d} = 1.2 \pm 0.02 \pm 0.05$
		$f_{B_s} = 268 \pm 17 \pm 20$ MeV

Selected inputs : γ

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



colour allowed
$A\lambda^3$



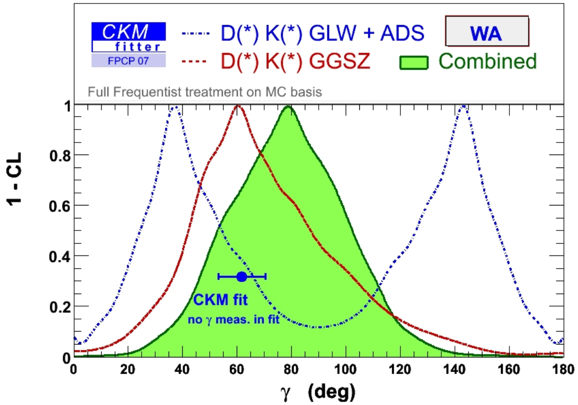
colour suppressed
$A\lambda^3(\rho + i\eta)$

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

- 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

Selected inputs : combined results on γ

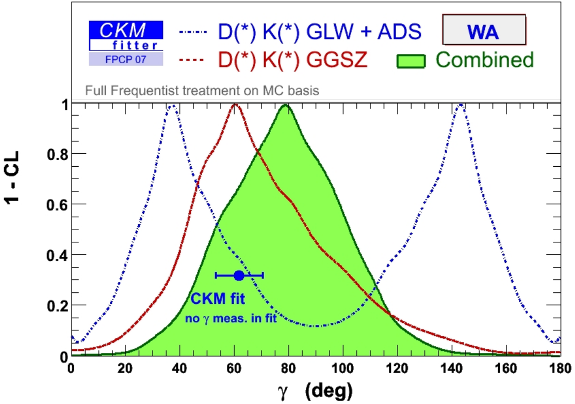
Several updates since Spring 2007



Selected inputs : combined results on γ

Several updates since Spring 2007

- GGSZ ($DK^{\pm}$, $D^*K^{\pm}$, $DK^{*\pm}$ with $D^* \to D\pi^0$ and $D \to K_S^- \pi^+\pi^-$) : increased statistics from Babar and Belle, Babar takes also neutral D into $K_S^0 K^+ K^-$
- GLW method : DK update from Babar
- ADS method : DK update from Belle



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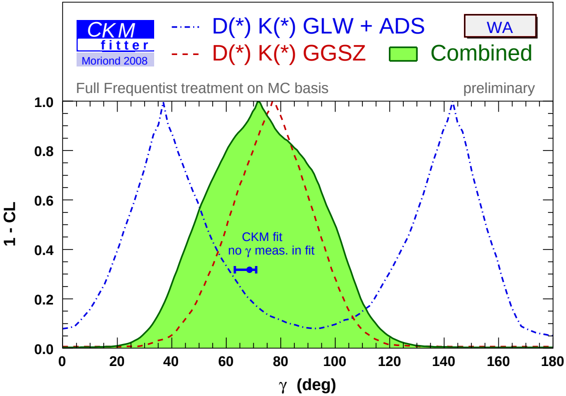


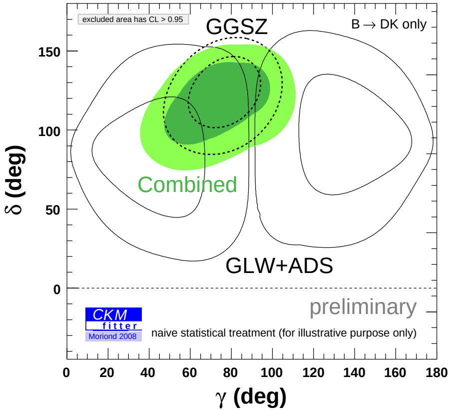
All methods combined : $\gamma = (72^{+34}_{-30})^\circ$ (68% CL)

From the global fit : $\gamma = (68.6^{+2.4}_{-5.3})^\circ$ (68% CL)

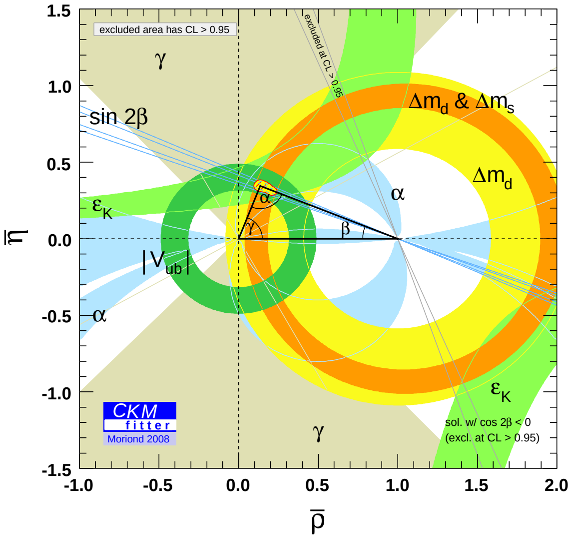
Selected inputs : combining methods for γ

Not only γ in 3 methods, also hadronic quantities (strong phases...)

- GLW (DK, D^*K, DK^*)
  $R_{CP\pm} = 1 \pm 2r_B \cos\delta_B \cos\gamma + r_B^2 \quad A_{CP\pm} = \pm 2r_B \sin\delta_B \sin\gamma / R_{CP\pm}$
- ADS (DK, D^*K, DK^* for $K\pi, K\pi\pi^0 \ldots$)
  $R_{ADS} = r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D)\cos\gamma$
- GGSZ (DK, D^*K, DK^*)
  $x_\pm = r_B \cos(\delta_B \pm \gamma)$
  $y_\pm = r_B \sin(\delta_B \pm \gamma)$
- Combining results may not yield the naive average and may not improve the accuracy
  ...at least sometimes (DK^*)



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

$$A = 0.795^{+0.025}_{-0.015}$$
$$\lambda = 0.2252^{+0.0008}_{-0.0008}$$
$$\bar\rho = 0.135^{+0.033}_{-0.016}$$
$$\bar\eta = 0.345^{+0.015}_{-0.018}$$
(68% CL)

$$B \to V\gamma$$

$B \to \rho\gamma$ and $B \to K^*\gamma$

$b \to d, s\gamma$: loop processes, give access to $|V_{t(d,s)}|$, complement $\Delta m_{d,s}$

Early days : focus on magnetic op. $Q_7 = (e/8\pi^2) m_b \bar{D} \sigma^{\mu\nu}(1+\gamma_5) F_{\mu\nu}\, b$
and assume short-distance dominance

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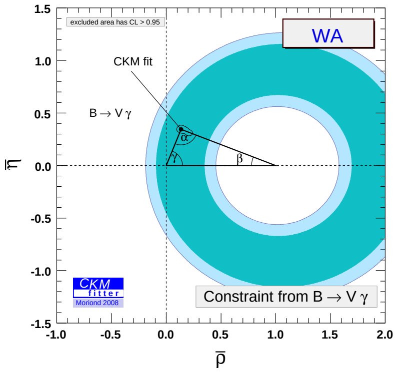


$$R_{\rho/\omega} = \frac{\bar{\mathcal{B}}(\rho^\pm\gamma) + \frac{\tau_{B^\pm}}{\tau_{B^0}}\left[\bar{\mathcal{B}}(\rho^0\gamma) + \bar{\mathcal{B}}(\omega\gamma)\right]}{\bar{\mathcal{B}}(K^{*\pm}\gamma) + \frac{\tau_{B^\pm}}{\tau_{B^0}}\left[\bar{\mathcal{B}}(K^{*0}\gamma)\right]}$$

$$= \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1 - m_\rho^2/m_B^2}{1 - m_{K^*}^2/m_B^2}\right)^3 \frac{1}{\xi^2}\left[1 + \Delta R\right]$$

- ξ ratio of form factors
- ΔR estimated as $\Delta R = 0.1 \pm 0.1$

Ali,Lunghi,Parkhomenko 02,04,06

Many open questions : dependence of ΔR on CKM matrix ? isopin breaking ? weak annihilation (tree for $(\rho, \omega)\gamma$) ?

A more sophisticated analysis

For each final state, estimate all contributions, expressed as factor to the leading amplitude (magnetic operator Q_7)

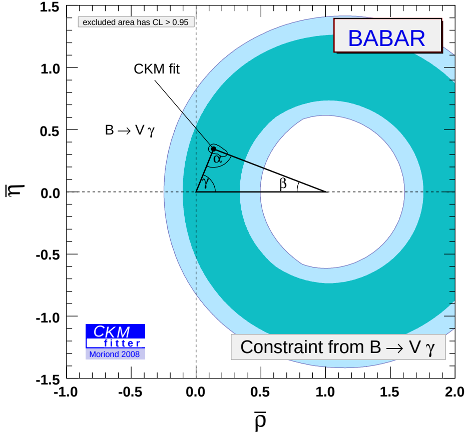
$$\bar{\mathcal{A}} \equiv \frac{G_F}{\sqrt{2}} \left(\lambda_u^D a_7^u(V) + \lambda_c^D a_7^c(V)\right) \langle V\gamma|Q_7|\bar{B}\rangle \qquad \lambda_U^D = V_{UD}^* V_{Ub}$$

$$a_7^U(V) = a_7^{U,\mathrm{QCDF}}(V) + a_7^{U,\mathrm{ann}}(V) + a_7^{U,\mathrm{soft}}(V) + \ldots$$

- QCDF : QCD factorisation for LO in $1/m_b$ up to $O(\alpha_s)$
  Bosch and Buchalla 02
- ann,soft : $1/m_b$-suppressed terms from light-cone sum rules
  Ball,Jones,Zwicky 06

- each decay described individually
- u and c internal loops (short and long dist), not “buried” into ΔR
- other operators than Q_7 taken into account

Impact on $(\bar{\rho}, \bar{\eta})$



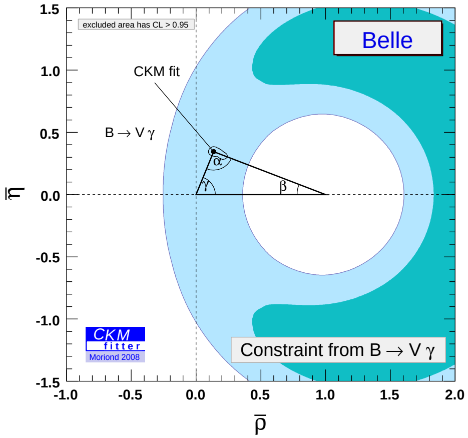
- HFAG (10^{-6})

$$K^{*-}\gamma \qquad 40.3 \pm 2.6$$
$$K^{*0}\gamma \qquad 40.1 \pm 2.0$$

- Babar (10^{-6})

$$\rho^{+}\gamma \qquad 1.10^{+0.37}_{-0.33} \pm 0.09$$
$$\rho^{0}\gamma \qquad 0.79^{+0.22}_{-0.20} \pm 0.06$$
$$\omega\gamma \qquad 0.40^{+0.24}_{-0.20} \pm 0.05$$

Impact on $(\bar{\rho}, \bar{\eta})$



- HFAG (10^{-6})

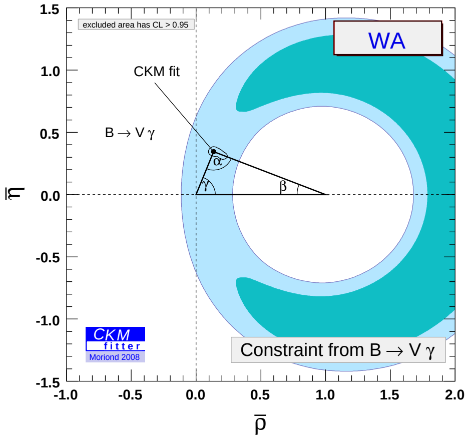
$K^{*-}\gamma$	40.3 ± 2.6
$K^{*0}\gamma$	40.1 ± 2.0

- Belle (10^{-6})

$\rho^+\gamma$	$0.55^{+0.42+0.09}_{-0.36-0.08}$
$\rho^0\gamma$	$1.25^{+0.37+0.07}_{-0.33-0.06}$
$\omega\gamma$	$0.56^{+0.34+0.05}_{-0.27-0.10}$

- Belle : $B(B_s \to \phi\gamma) = 57^{+18+12}_{-15-11} \cdot 10^{-6}$

Impact on $(\bar{\rho}, \bar{\eta})$



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- WA (10^{-6})

$$\rho^{+}\gamma \quad 0.88^{+0.28}_{-0.26}$$
$$\rho^{0}\gamma \quad 0.93^{+0.19}_{-0.18}$$
$$\omega\gamma \quad 0.46^{+0.20}_{-0.17}$$

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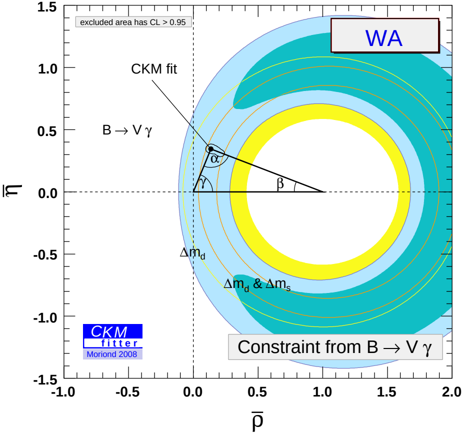

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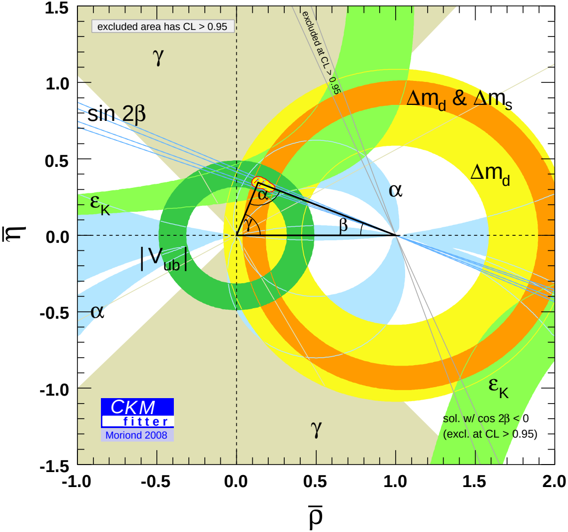
Constraint competitive with $B\bar{B}$ mixing
(box versus penguin, different theory inputs)

The B_s sector

Current constraints on UTs

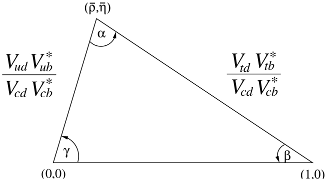


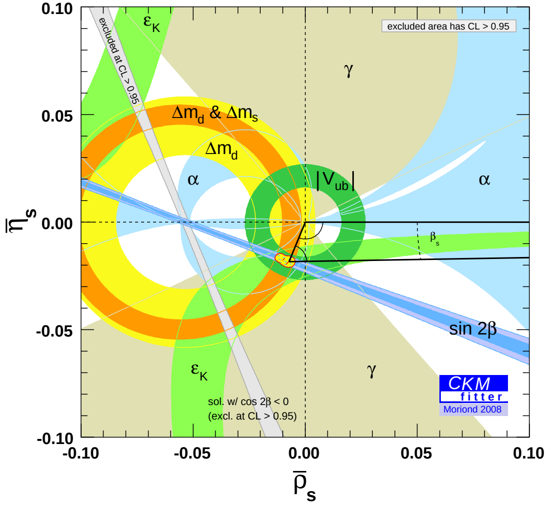
The unitarity triangle ?

The one associated with B_d meson

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

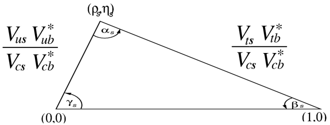
$$O(1) + O(1) + O(1)$$





(Squashed)
B_s unitarity triangle

$$\frac{V_{us}V_{ub}^*}{V_{cs}V_{cb}^*} + 1 + \frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*} = 0$$
$$O(\lambda^2) + O(1) + O(1)$$



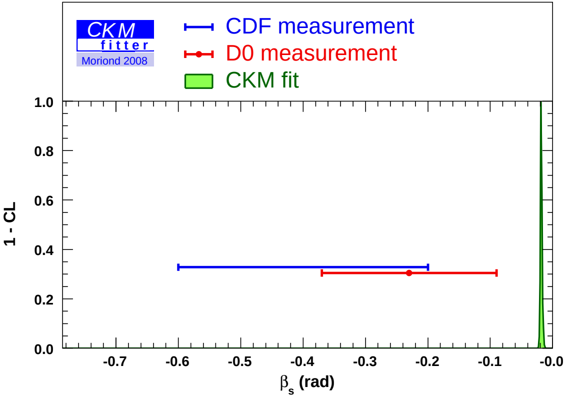
CP-violation for B_s meson

$$\bar\rho_s + i\bar\eta_s = -\frac{V_{us}V_{ub}^*}{V_{cs}V_{cb}^*}$$

Recent β_s measurements

$\beta_s = \arg\left(-\frac{V_{cs}V_{cb}^*}{V_{ts}V_{tb}^*}\right)$ angle opposite to the small size of B_s triangle

- In SM $\beta_s = -0.0183^{+0.0009}_{-0.0008}$ rad
- Recent flavour-tagged $B_s^0 \to J/\psi\phi$ analysis
  D0 : $\beta_s = -0.23 \pm 0.14$
  CDF : β_s in [-0.6,-0.2]
- Non trivial likelihoods and assumptions on nuisance parameters (strong phases, $\Gamma_s \ldots$) still to be understood



- A year at LHCb [2 fb^{-1}]: $\sigma(\beta_s) = 0.023$ $[B_s \to J/\psi(\mu\mu)\phi]$

O. Schneider EuroFlavour07

Lighter quarks and the lattice

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

Recently, big steps in lattice simulations : 3 dynamical quarks (unquenched) with light masses and (very) small errors

$\Longrightarrow$Essential role in reducing the theoretical QCD uncertainties

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- $|V_{ud}|$: improved analysis of nuclear β decays [in fit]
- $|V_{us}|$: $K \to \pi\ell\nu$ + (dom wall) $f_+(0) = 0.964(5)$ [in fit] (UKQCD+RBC)

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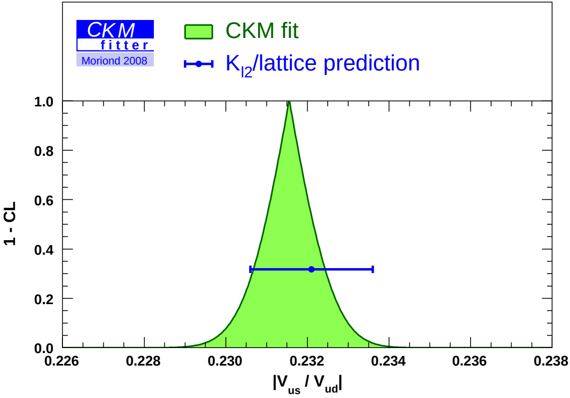
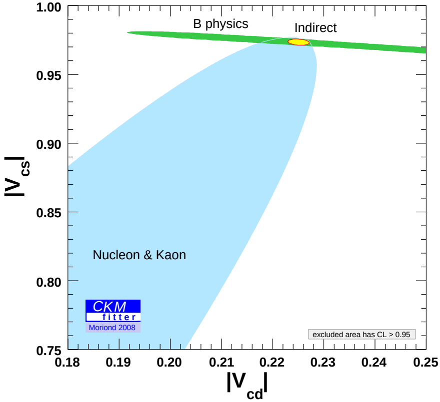
- $|V_{us}|$: $K \to \pi \ell \nu$ + (dom wall) $f_+(0) = 0.964(5)$ [in fit] (UKQCD+RBC)
- $|V_{us}/V_{ud}|$: $K \to \ell\nu / \pi \to \ell\nu$ + (staggered) $f_K/f_\pi = 1.189(7)$ [not in fit] (HPQCD+UKQCD)



Remarkable : f_K/f_π very difficult to control on the lattice [light quarks]

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

Charm sector favourite place to test lattice QCD [$m_c \sim \Lambda_{QCD}$]
$\Longrightarrow$form factors and decay constants [access to $|V_{cd}|$ and $|V_{cs}|$]



- K and nucleon: $V_{ud} \simeq V_{cs}$ and $V_{cd} \simeq V_{us}$ only at first non trivial order in λ (need b-input to fix higher orders)
- B alone: rather constraining
- Indirect (combination of the two above): already quite well determined
- Unitarity constraint: $|V_{cd}|^2 + |V_{cs}|^2 \leq 1$

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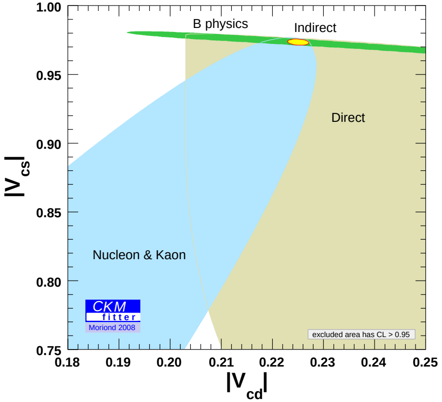

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- Direct (old) : $|V_{cd}|$ from νN scattering and $|V_{cs}|$ from charmed-tagged W decays

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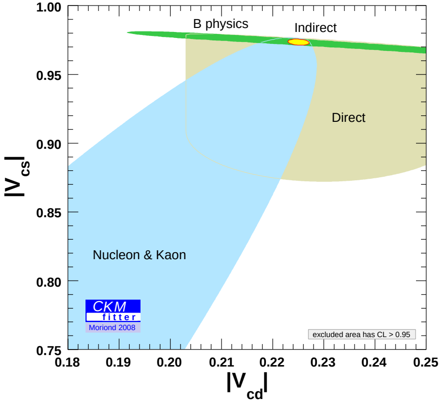

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- Direct (new) : $|V_{cd}|$ from νN scattering and $|V_{cs}|$ from CLEO-c $D \to K\ell\nu$ + lattice

I. Shipsey CLEO-c Aspen workshop

The trouble with $|V_{cs}|$

- $D_s \to \ell\nu$
  (CLEO-c,Belle. . .)
- Unquenched
  (staggered) lattice
  $f_{D_s} = 241 \pm 3$ MeV
  (HPQCD+UKQCD)
- Combined :
  $|V_{cs}| = 1.076 \pm 0.041$

The trouble with $|V_{cs}|$

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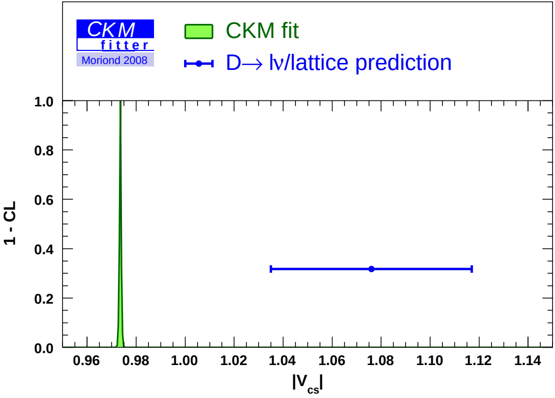
- Unquenched (staggered) lattice $f_{D_s} = 241 \pm 3$ MeV (HPQCD+UKQCD)
- Combined : $|V_{cs}| = 1.076 \pm 0.041$
- compared to fit value (68% CL) $|V_{cs}| = 0.97351^{+0.00020}_{-0.00022}$



f_{D_s} supposedly ideal for lattice (charm strange) and far worse than f_K/f_π (light quarks) !?

Uncontrolled systematics in full (unquenched) QCD simulations ??

Conclusion (?)

Conclusion

Impressive consistency of the CKM picture of CP violation

- More information on γ (the lesser known angle)
  $\Longrightarrow$not necessarily correlated improvement in accuracy
- First steps towards a check of the B_s triangle (Tevatron $\rightarrow$ LHCb)
- $B \rightarrow V\gamma$ competing and comparing with $\Delta m_{d,s}$
- Contrasted news from lighter quarks and the lattice (very good agreement for u, d, s, worries from charm)
  $\Longrightarrow$Unquenching very new : are all systematics under control ?

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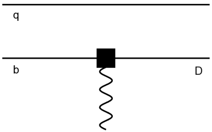
Still a lot of work ahead for flavour facilities . . . and for theorists !

Thank you !

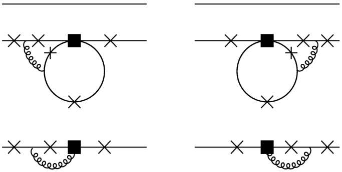
Backup

$B \to V\gamma$: QCD factorisation part

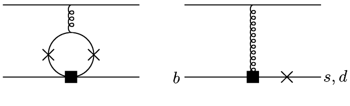
Bosch and Buchalla : explicit formulae for $a_{7L}^{U,\mathrm{QCDF}}$, complete to $O(\alpha_s)$



- LO contribution to T_1 from Q_7
- NLO from 4-quark $Q_{1\ldots6}$ and chromomagnetic Q_8

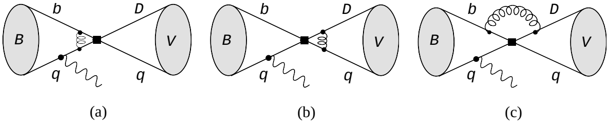


T_1 (vertex)



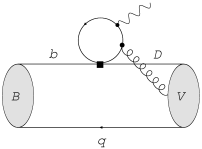
T_2 (hard-scattering)

$B \to V\gamma$: weak annihilation and soft gluons



Weak annihilation

- Short-distance part estimated within QCDF
- Long-distance contribution : photon emission from B meson estimated through LCSR

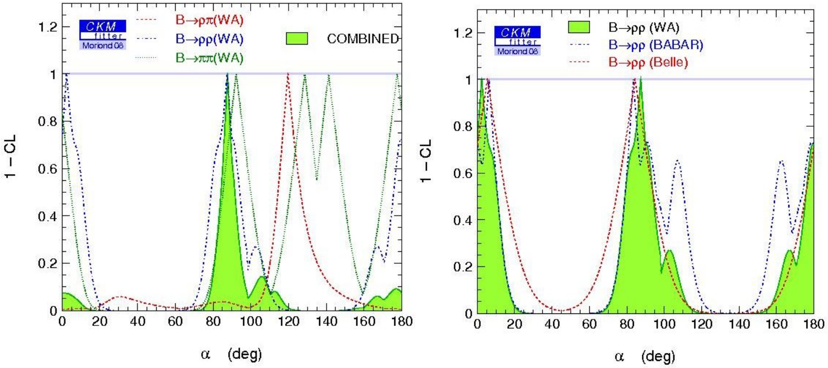


Soft-gluon emission from a quark loop

- for light-quark loop : fairly complicated LCSR
- for heavy-quark loop : $1/m_Q$ expansion, then LCSR

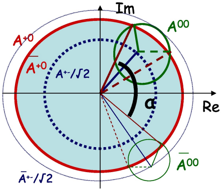
Selected inputs : α

Only one update : Belle value for $\mathrm{Br}(\rho^0\rho^0)$
$\Longrightarrow$leading to a slight decrease in the accuracy on α

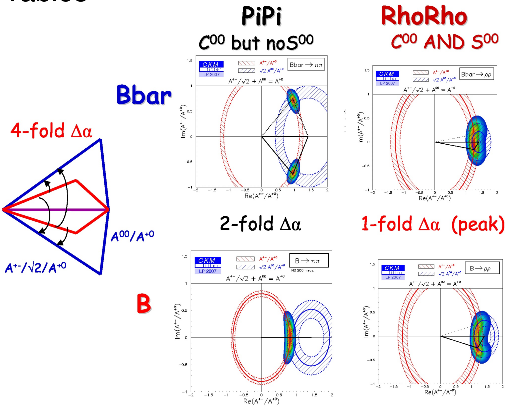


All methods combined : $\alpha = (87.8^{+5.8}_{-5.4})^\circ$
From the global fit : $\alpha = (89.7^{+5.3}_{-2.4})^\circ$

α and the closure of the triangles



- Isospin relation between amplitudes $A(\pi^+\pi^0) = A(\pi^+\pi^-)/\sqrt{2} + A(\pi^0\pi^0)$ (and CP conjugates)
- Reconstruction of the two triangles from observables



- 1 or 2 solution for each of the 2 triangles
- 2 solutions for α_{eff}

$\Longrightarrow$ 2,4 or 8 solutions for α

The observables depend on γ and $\mu = (r_B, \delta)$

- Minimise $\chi^2(\gamma, \mu)$ w.r.t μ and subtract the minimum to get $\Delta\chi^2(\gamma)$
- Assume that the true value of μ is μ_t and compute PDF$[\Delta\chi^2(\gamma)|\gamma, \mu_t]$
- compute (1-CL)$_{\mu_t}(\gamma)$ through Toy Monte Carlo
- Maximise w.r.t μ_t to get (1-CL)(γ)

$\Longrightarrow$Quite general, but computing demanding procedure

[previous alternative : assume that μ_t is the value of μ minimising $\chi^2(\gamma, \mu)$ on real data]