Unitarity Triangle Analysis within and beyond the SM

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On behalf of UTfit group

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Use the Bayesian statistics to obtain the most probable values and credibility intervals from the current data.*

Bayes theorem says: if $P(A|B) = \frac{P(A \cap B)}{P(B)}$ and $P(B|A) = \frac{P(A \cap B)}{P(A)}$

than $P(A|B) = \frac{P(B|A)P(A)}{P(B)}$

Before the observation *B*, our degree of belief of *A* is *P(A)* (*prior* probability)

Having observed *B*, our degree of belief changes into *P(A|B)* (*posterior* probability)

Thus, having several observables with their probabilities, one is able to understand the value and uncertainty of the parameter needed. We use likelihoods of measurements where possible. Gaussian PDFs are used to represent statistical and systematic uncertainties otherwise.

Other UT analyses exist, by:
CKMfitter (http://ckmfitter.in2p3.fr/),
Laiho&Lunghi&Van de Water (http://krone.physik.unizh.ch/~lunghi/webpage/LatAves/page3/page3.htm),
Lunghi&Soni (1010.6069)

*The results included into this talk are based on studies that were public by August 2013 (Lattice and EPS conferences)

Technically, this means that we construct

$$\mathcal{F}(x_1, x_2, ..., x_N | c_1, ..., c_M) \propto \mathcal{F}(c_1, ..., c_M | x_1, ..., x_N) \mathcal{F}_0(x_1, ..., x_N)$$

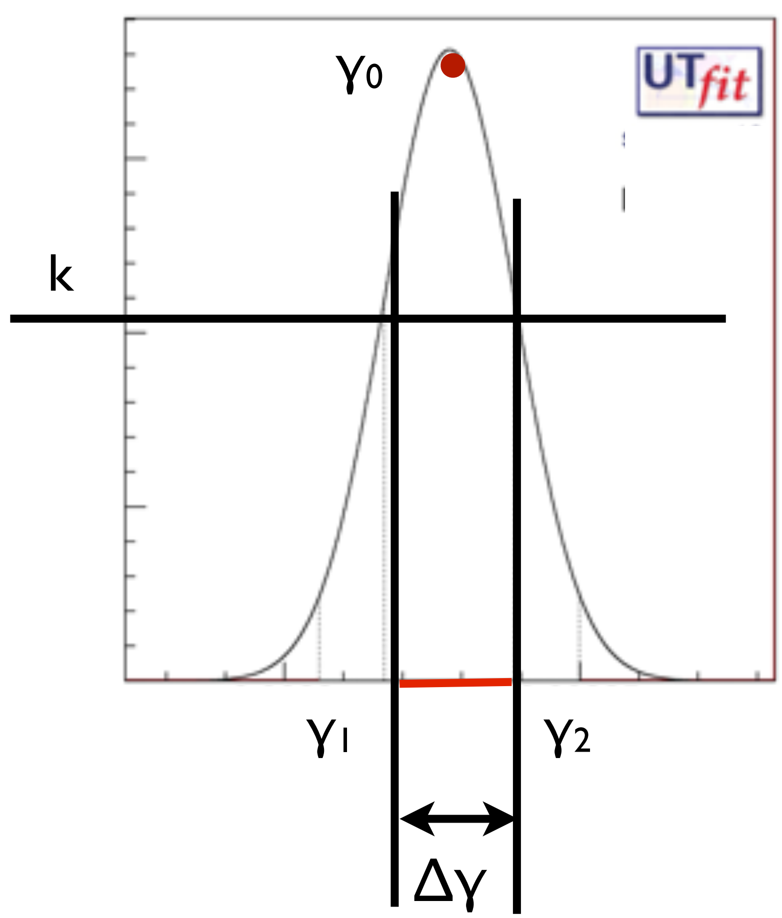
where F is the PDF for the constraints $\{c_i\}$ and F_0 is the prior probability for the parameters of interest $\{x_i\}$.
In order to obtain the posterior PDF, in case of absence of mutual correlations for parameter $\gamma = x_1$ we have

$$\mathcal{G}(\gamma) \propto \int \prod_{j=1}^{M} \mathcal{F}_j(c_j | \gamma, x_2, ..., x_N) \prod_{i=2}^{N} \mathcal{F}_0(x_i) \mathcal{F}_0(\gamma)$$

This means, that we have to "just" integrate the PDFs used.

We than obtain 68% and 95% credibility intervals looking at the integral of posterior PDF.
We look at minimum k fulfilling:

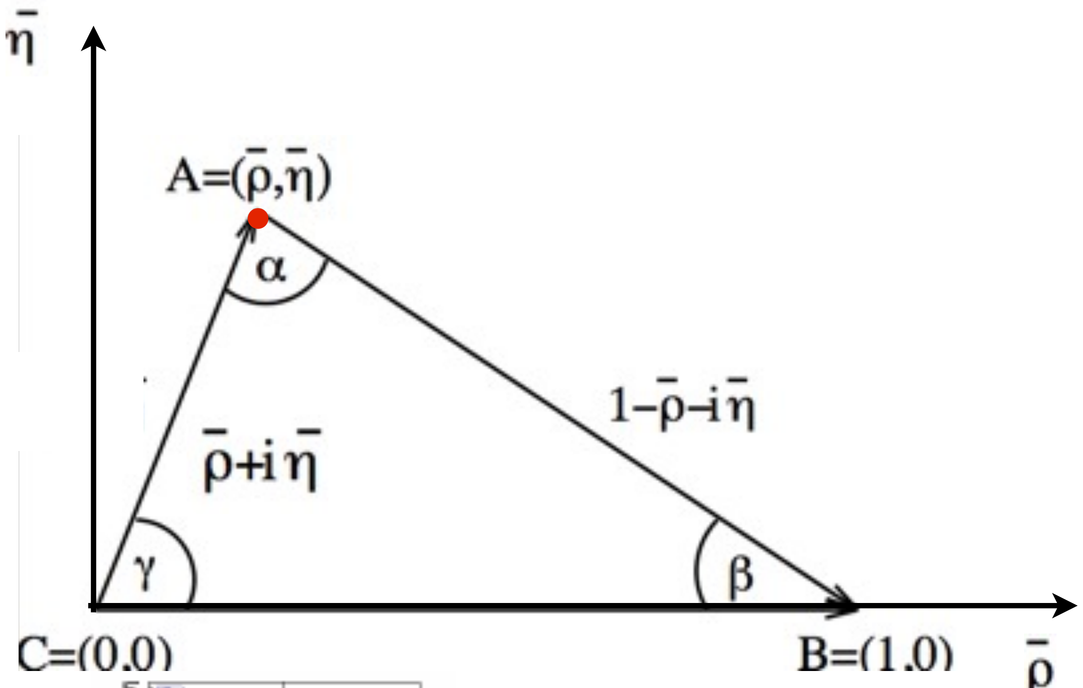
$$\frac{\int_{\mathcal{G}(\gamma)>k} d\gamma\, \mathcal{G}(\gamma)}{\int d\gamma\, \mathcal{G}(\gamma)} > 0.683$$



In the example, we take 68% credibility interval to be $[\gamma_1; \gamma_2]$.
We quote $\gamma_0 \pm \Delta\gamma/2$,
where $\Delta\gamma = \gamma_2 - \gamma_1$ (in case of symmetric distributions)

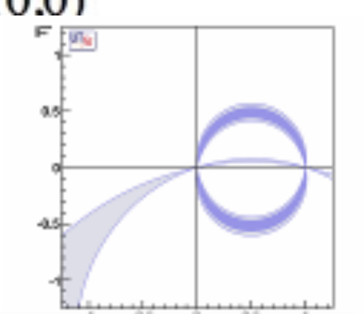
Constraints used (angles)

In the Wolfenstein parameterisation, one can represent the Unitarity Conditions in graphical way.



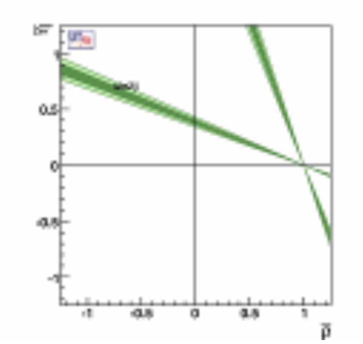
We now want to test this picture using different possible constraints.

α



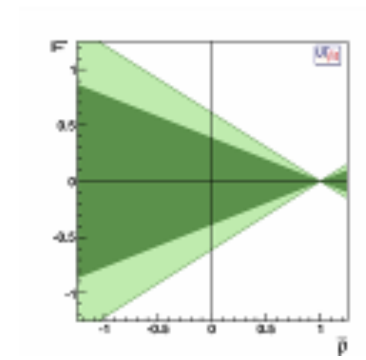
$B\to\pi\pi$, $B\to\rho\rho$, $B\to\rho\pi$

$\sin(2\beta)$



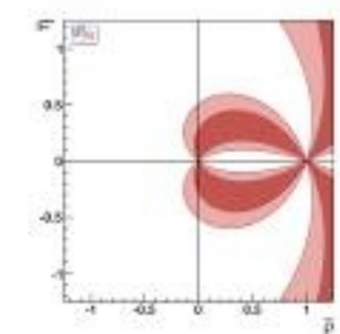
$B\to J/\Psi K$

$\cos(2\beta)$



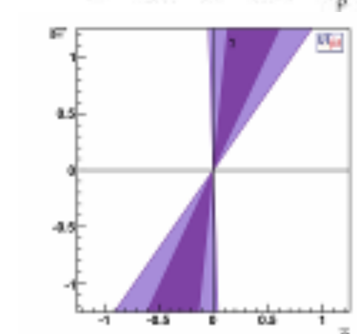
$B\to DK$, $B\to D\pi$

$2\beta+\gamma$

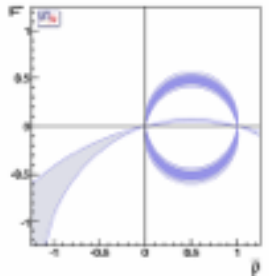


$B\to DK$, $B\to D\pi$

γ



$B\to DK$



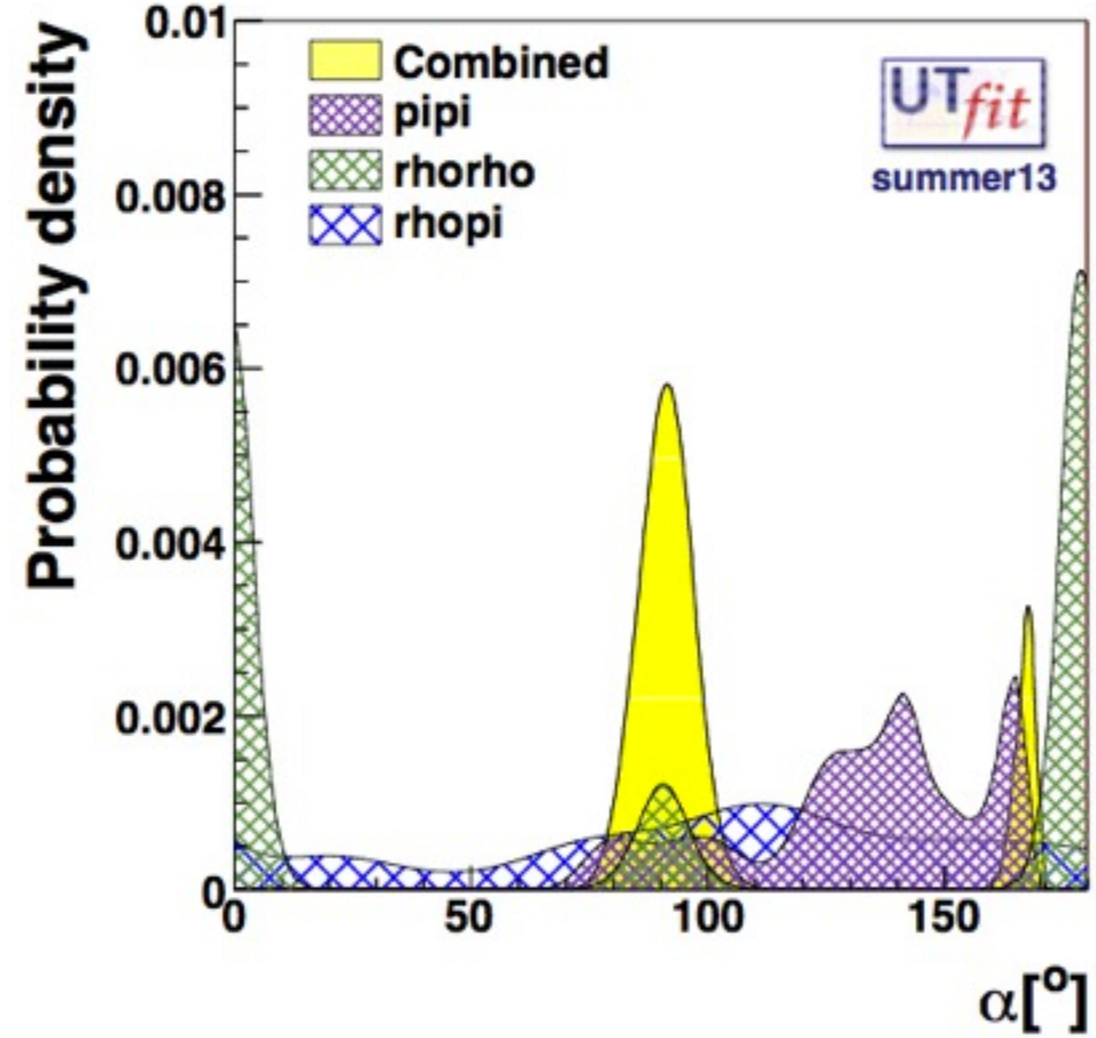
Alpha from B→ππ

B→π⁺π⁻, B→π⁰π⁰, B→π⁺π⁰ decays are connected from isospin relations. ππ states can have I = 2 or I = 0,
the gluonic penguins contribute only to the I = 0 state (ΔI=1/2) π⁺π⁰ is a pure I = 2 state (ΔI = 3/2) and it gets contribution only from the tree diagram
triangular relations allow for the determination of the phase difference induced on α.

$$
\begin{aligned}
A^{+-} &= -Te^{-i\alpha} + Pe^{i\delta_P} \\
A^{+0} &= -\frac{1}{\sqrt{2}}\left[e^{-i\alpha}(T + T_c\, e^{i\delta_{T_c}})\right] \\
A^{00} &= -\frac{1}{\sqrt{2}}\left[e^{-i\alpha}T_c\, e^{i\delta_{T_c}} + P\, e^{i\delta_P}\right] ,
\end{aligned}
$$

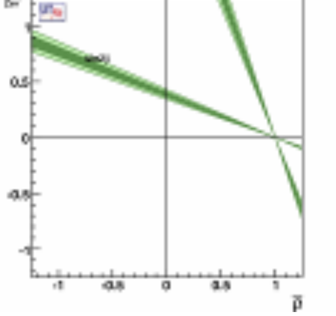
We can construct the observables, like *CP* asymmetries and branching fractions from amplitudes and solve the equation on α.
The same method also can be used for the B→ρρ system

Another point is adding the B→ρπ analysis This is a completely different analysis:
The time-dependent Dalitz plot analysis of the decays of the neutral B allows one to infer the value of α without any dependence on the hadronic parameter.



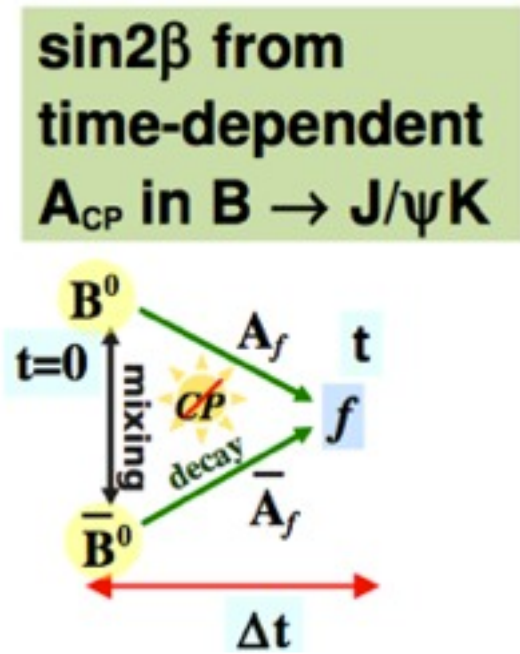
$$\alpha = (90.7 \pm 7.4)^\circ$$

Phys. Rev. D76 (2007) 014015
PRL 65 (1990) 3381



Beta results

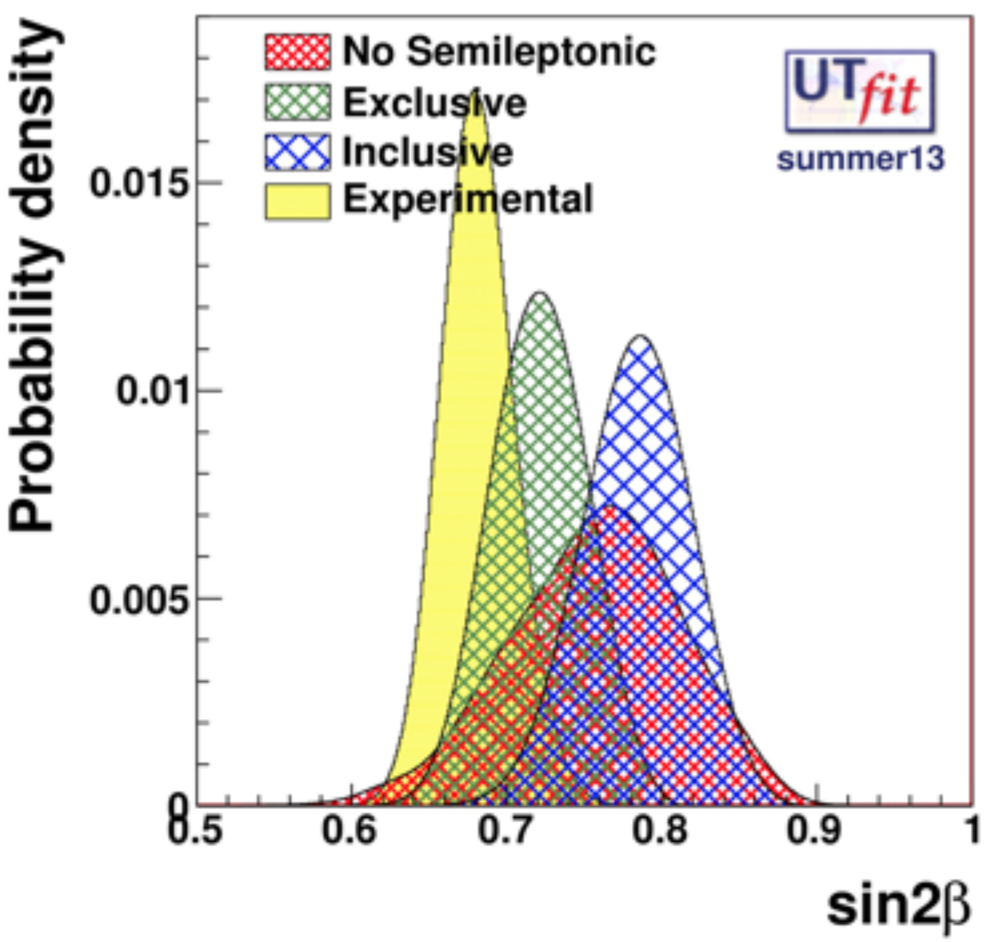
$B^0 \to J/\Psi K^0$



$$a_{f_{CP}}(t) = \frac{\mathrm{Prob}(B^0(t) \to f_{CP}) - \mathrm{Prob}(\overline{B^0}(t) \to f_{CP})}{\mathrm{Prob}(\overline{B^0}(t) \to f_{CP}) + \mathrm{Prob}(B^0(t) \to f_{CP})} = C_f \cos\Delta m_d t + S_f \sin\Delta m_d t$$

The decay is dominated by a single (tree level) amplitude, thus a can be simplified:

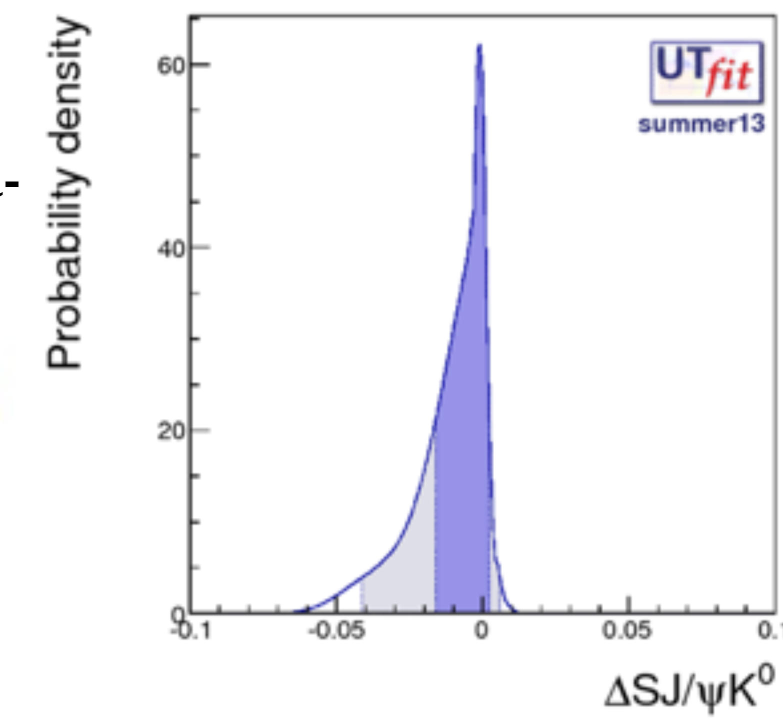
$$\boxed{a_{f_{CP}}(t) = -\eta_{CP} \sin\Delta m_d \Delta t \sin 2\beta}$$



We also analise $\bar{B}^0 \to J/\psi\pi^0$ to obtain the theoretical uncertainty related to the penguin polution in data-driven way. This gives us an additional correction:

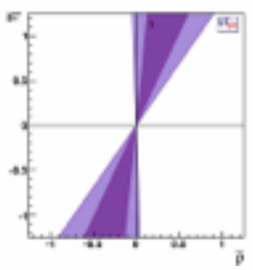
data-driven theoretical uncertainty

$\Delta S \in [-0.02, 0.00]$ at 68% prob.



$$\sin(2\beta) = (0.680 \pm 0.023)$$

Phys. Rev. Lett. 95, 221804 (2005)



We use the available information coming from the three methods:

- GLW (M. Gronau, D. London, D. Wyler, PLB253,483 (1991); PLB 265, 172 (1991))
- ADS (D. Atwood, I. Dunietz and A. Soni, PRL 78, 3357 (1997))
- GGSZ (A. Giri, Yu. Grossman, A. Soffer, J. Zupan, PRD 68, 054018(2003))

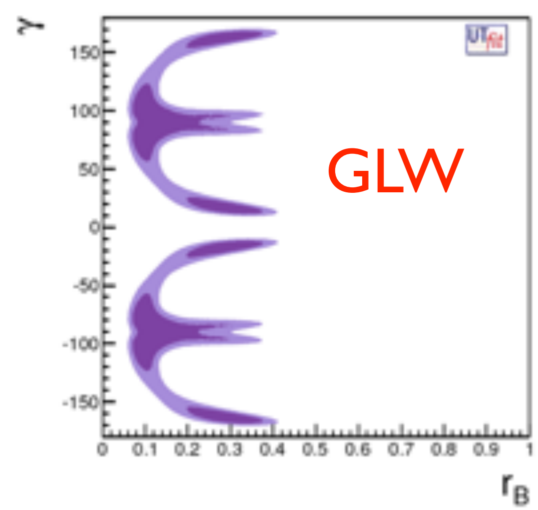
For the decays: $B^+ \to D^{(*)}K^{(*)+}$ and $B^0 \to D^{(*)}K^{(*)0}$

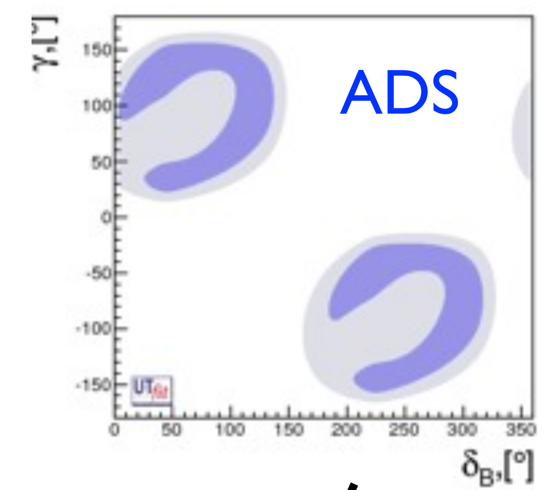
The combination is performed starting from the HFAG averages. The main problem is treatment of the nontrivial likelihoods for $\{\gamma, \delta_B, r_B\}$ observables.

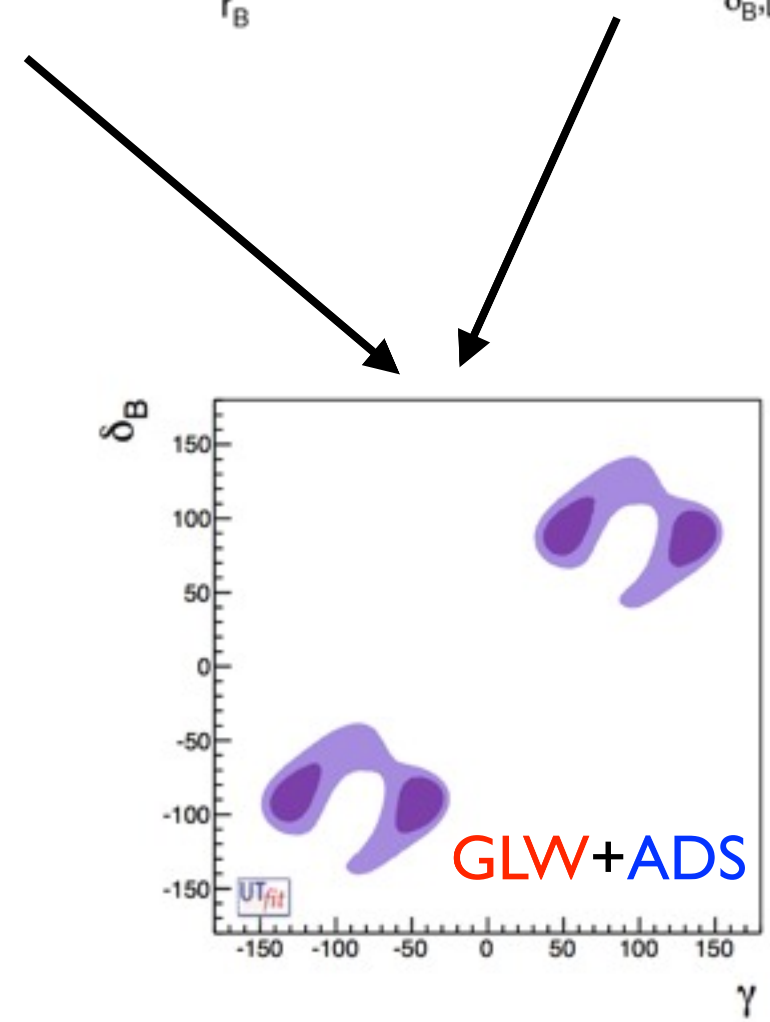
δ_B is the strong phase of the decay; r_B is the amplitude ratio

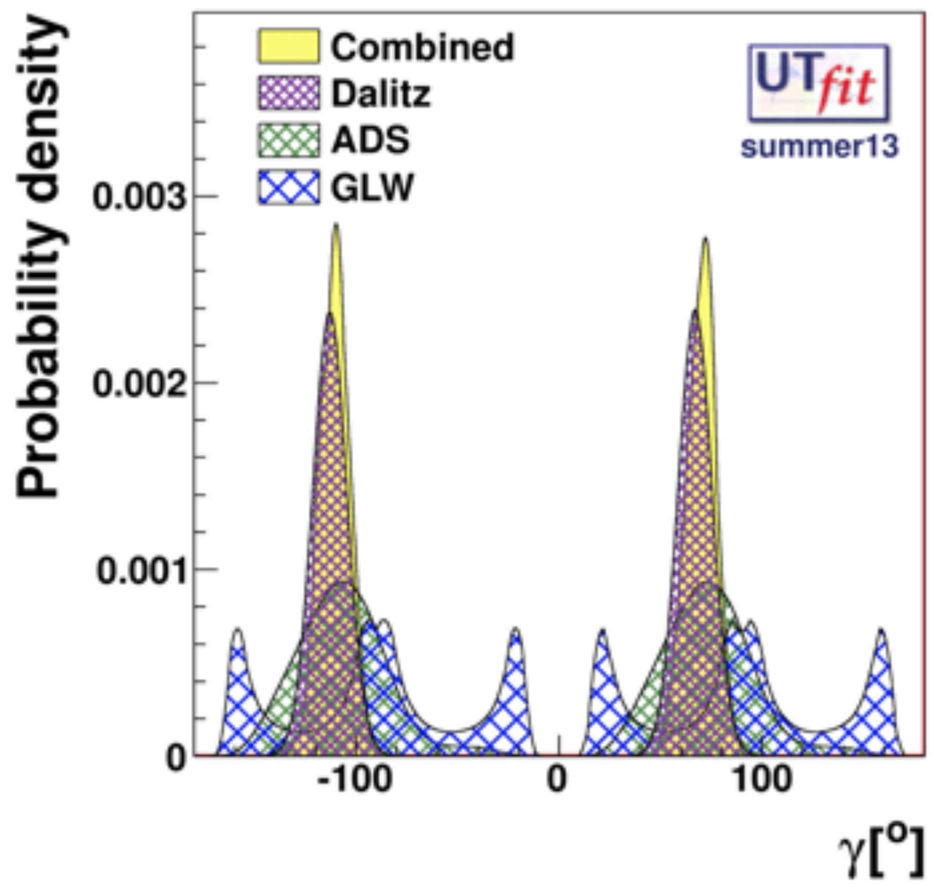
We also use CLEOc results in the ADS reconstruction.

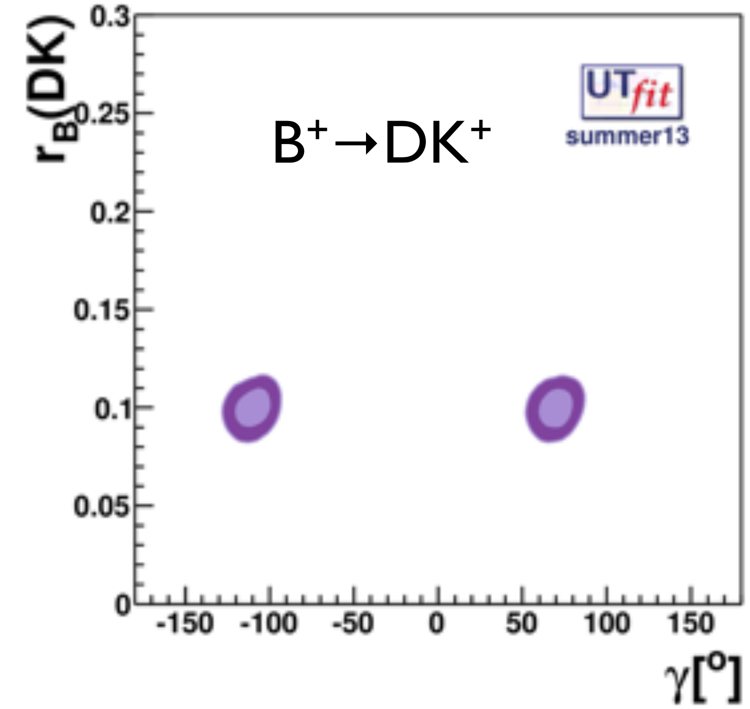
Currently, we do not include D^0 mixing in the combination, as the effect is small in B→DK system

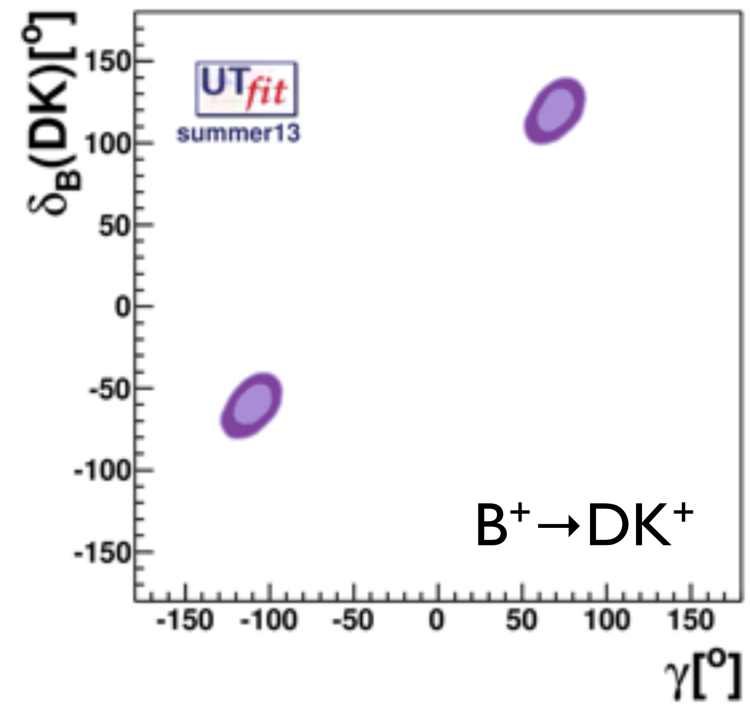












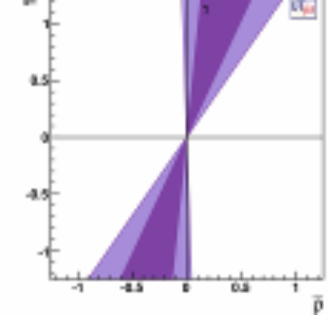
$\gamma = (70.1 \pm 7.1)^\circ$

The results show gaussian behaviour in the most precise channel $B^+ \to DK^+$

With new results in B^0 system, we are able to have the combined value more than 4 sigmas away from 0.

	DK^+	D^*K^+	DK^{*+}	DK^{*0}
δ_B	$(120.2 \pm 8.2)^\circ$	$(-51 \pm 13)^\circ$	$(124 \pm 34)^\circ$	$(-55 \pm 44)^\circ$
r_B	(0.100 ± 0.006)	(0.118 ± 0.018)	(0.13 ± 0.06)	(0.26 ± 0.06)

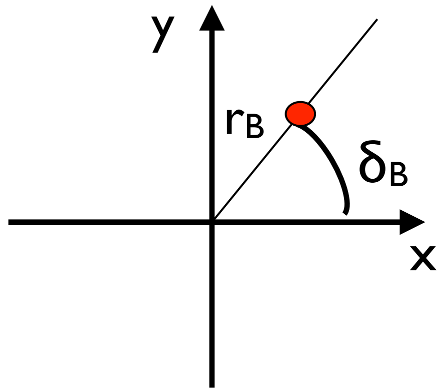
It is very important to understand that constructing predictions observables out of values of $\{\gamma, \delta_B, r_B\}$ requires a similar likelihood analysis (for example, asymmetries will not be gaussian).



Gamma combination: prior studies and strong phases

We have tested the behavior of the gamma average for different priors including:

- Flat cartesian coordinates {x;y}:
- Jeffreys prior on r_B (weight ~ $1/\sqrt{r_B}$)



The results are stable against all the reasonable priors and do not give more than 1 degree difference in central values. This value scales down with statistical error on gamma.

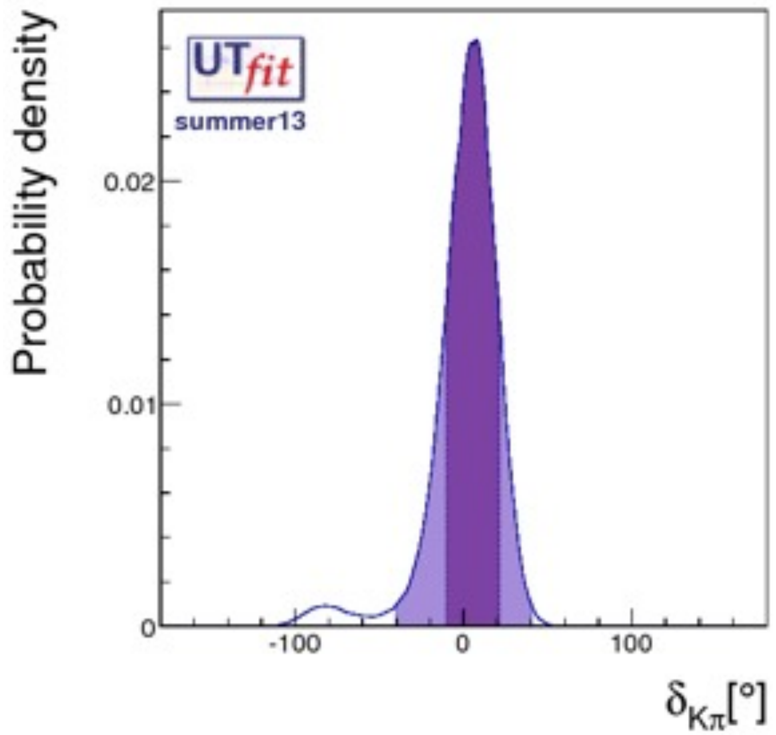
Another important result is that we are able to measure the strong phase $\delta_{D\to K\pi}$.

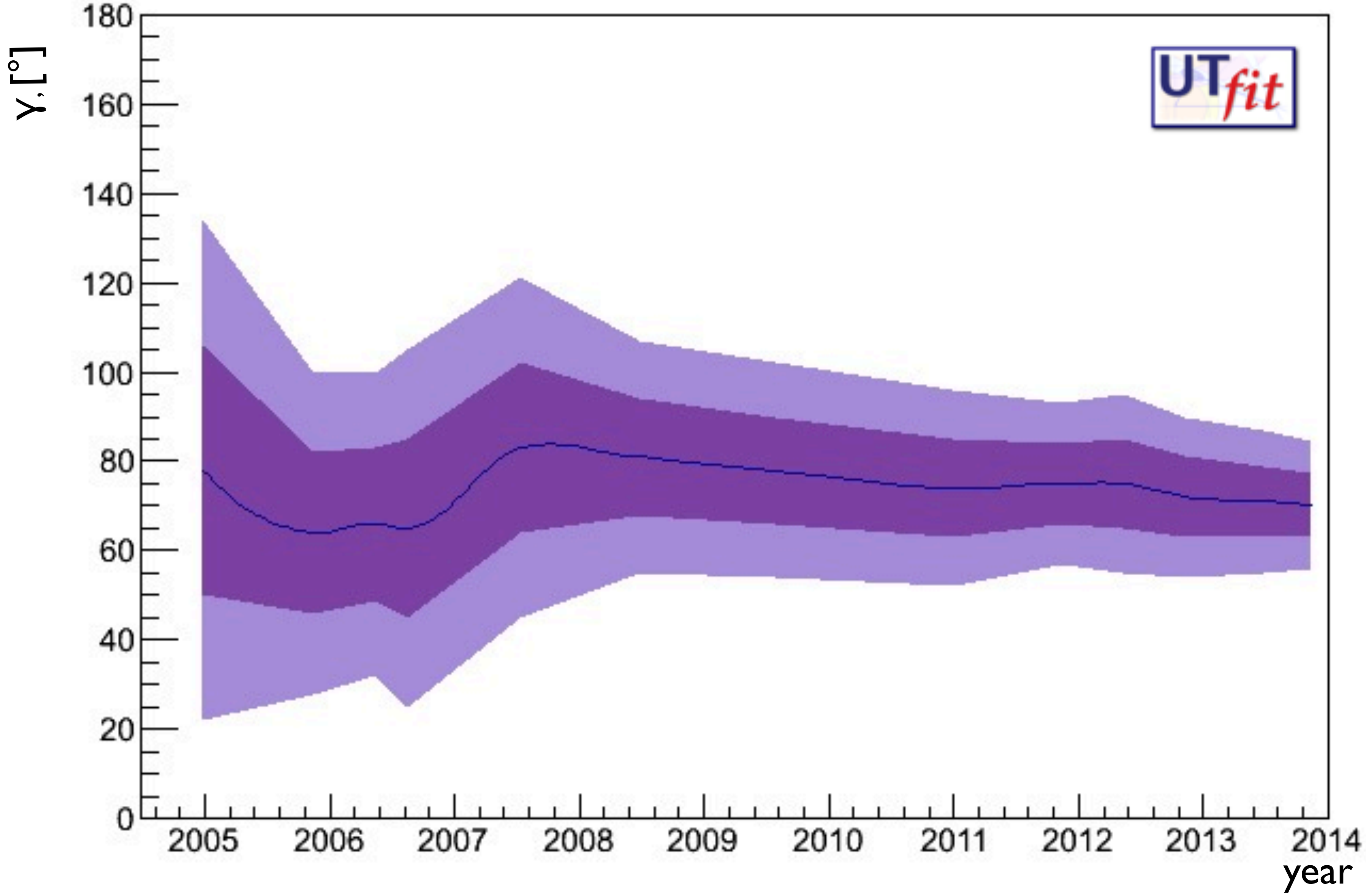
at 68.27% prob [-10,21]
at 95.45% prob [-40,40]

The results are consistent with our mixing studies and with most recent BES III results:

$$\delta_D = (18^{+11}_{-17})^\circ$$

Removing CLEOc information inflates the errors on the combination by 0.5 degrees



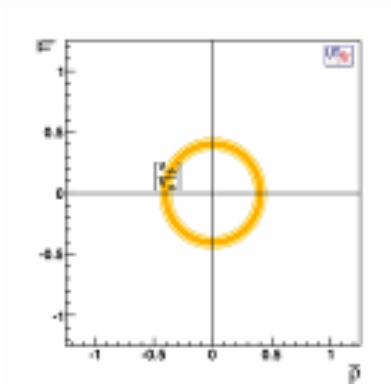


The world average uncertainty has decreased by a factor 3 in 10 years

https://www.utfit.org/foswiki/bin/view/UTfit/GammaFromTrees

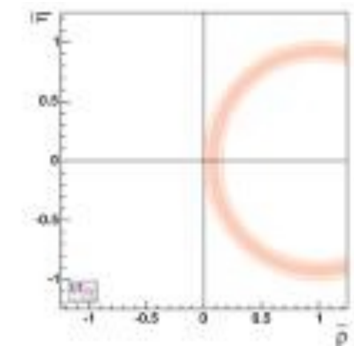
Constraints used (sides constraints)

$|V_{ub}/V_{cb}|$



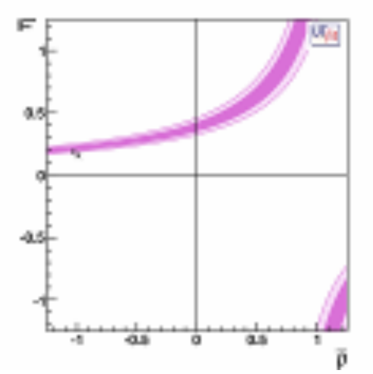
exclusive B→Dlν (B→π(ρ)lν) determination
inclusive b→c (b→u) determination

$\Delta m_d/\Delta m_s$



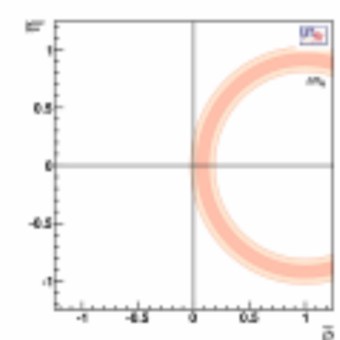
$B_{d,s}$ mixing

ε_K



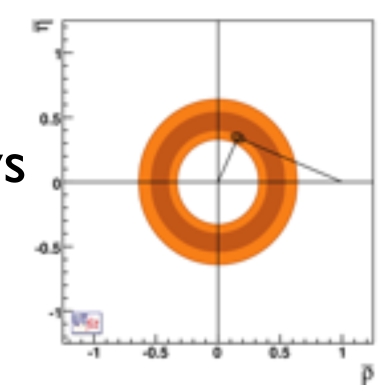
indirect *CP* violation in K_L decays

Δm_d



B_d mixing

Rare decays



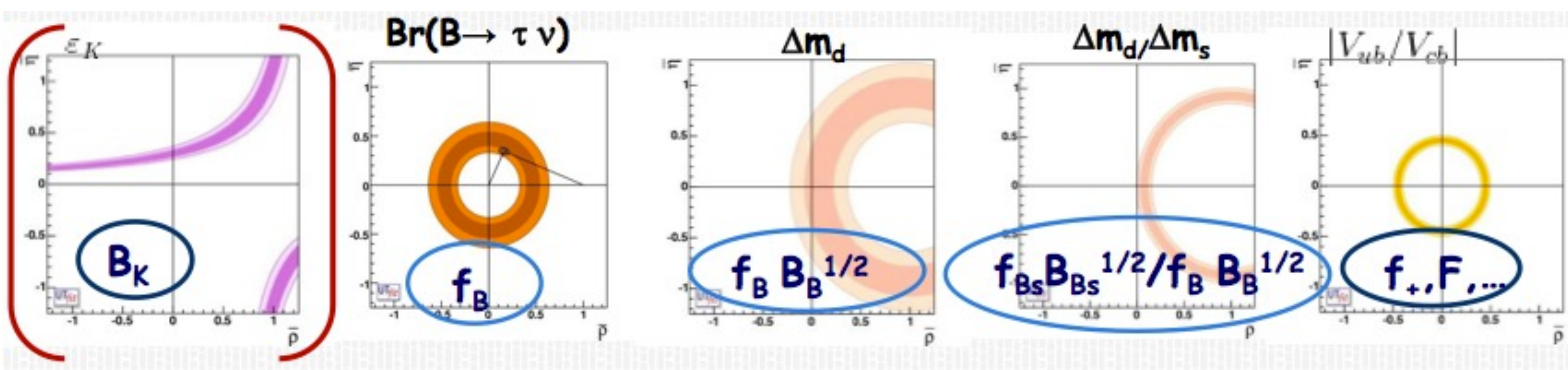
B→τν, B→μμ

For most of other CKM fit inputs we need several parameters calculated on lattice. We use:

- B-parameter in the Kaon sector
- K, D, and B mesons decay constants f_{Bs}, f_B, f_D, f_K
- Matrix elements for K, B, and D mixing
- s quark mass, V_{us}, V_{ud} (FlaviaNet values)

We take the most updated values from FLAG working group and our averages for the full basis of K-Kbar, D-Dbar and B-Bbar mixing

B_K	0.766 ± 0.010
f_{B_s}	0.2277 ± 0.0045
f_{B_s}/f_{B_d}	1.202 ± 0.022
$\hat{B}_{B_s}$	1.33 ± 0.06
$\hat{B}_{B_s}/\hat{B}_{B_d}$	1.06 ± 0.11



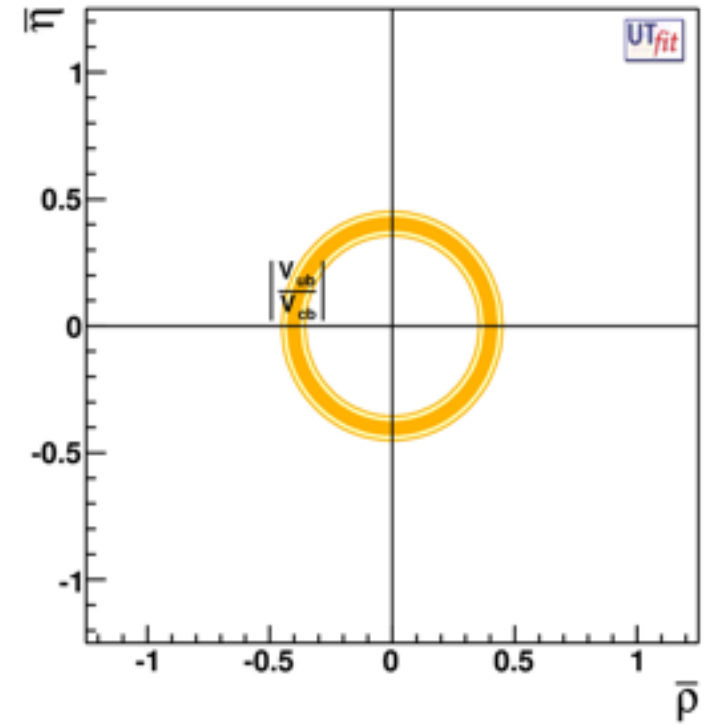
Nuovo Cim.B123:674-688,2008

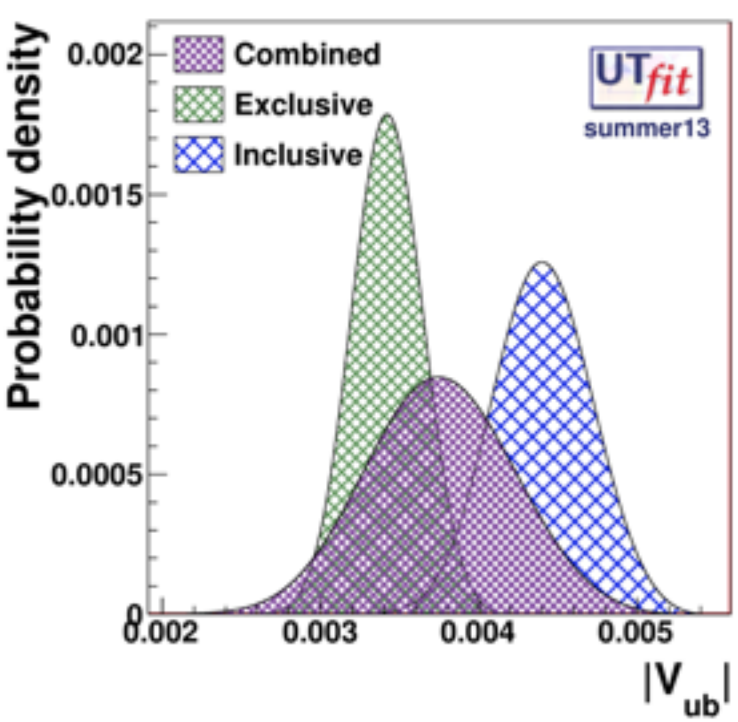
The relative ratio of CKM elements is easily calculable:

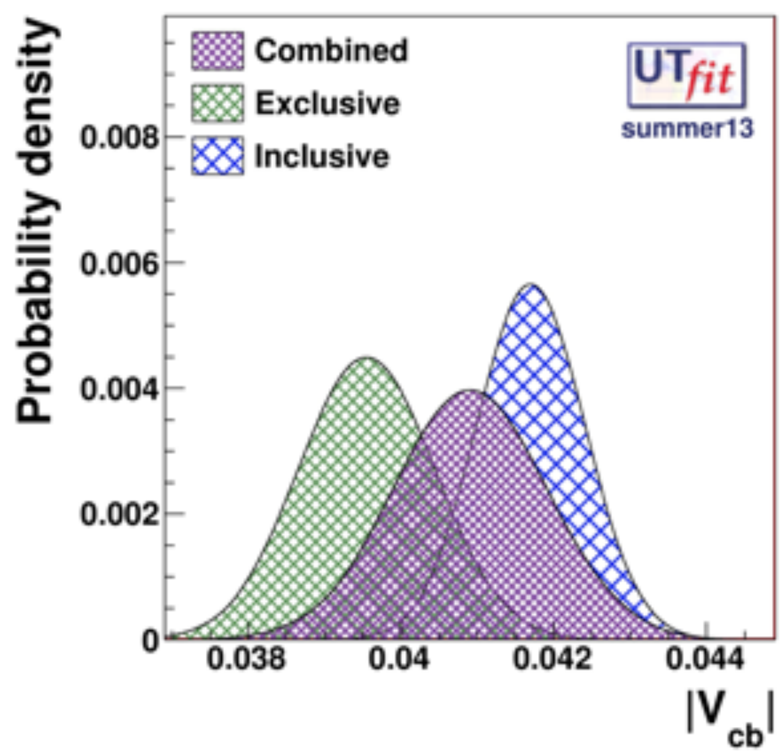
$$\left|\frac{V_{ub}}{V_{cb}}\right| = \frac{\lambda}{1 - \frac{\lambda^2}{2}}\sqrt{\bar{\rho}^2 + \bar{\eta}^2}$$

QCD corrections to be considered

- inclusive measurements: OPE
- exclusive measurements: form-factors from lattice QCD







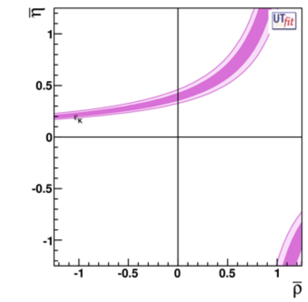
V_{ub}(excl) = (3.42 ± 0.22) 10^{-3}
V_{ub}(incl) = (4.40 ± 0.31) 10^{-3}
V_{ub} = (3.75 ± 0.46) 10^{-3}

~1.9σ discrepancy

V_{cb}(excl) = (39.55 ± 0.88) 10^{-3}
V_{cb}(incl) = (41.7 ± 0.7) 10^{-3}
V_{cb} = (40.9 ± 1.0) 10^{-3}

~2.5σ discrepancy

There is still an inconsistency between inclusive and exclusive measurements. We take this into account inflating the combined uncertainty (a-la PDG).



ε_K

Indirect CP violation in the Kaon system is usually expressed in terms of $|\varepsilon_K|$ parameter which is the fraction of CP violating component in the mass eigenstates.

$$|\varepsilon_K| = C_\varepsilon B_K A^2 \lambda^6 \bar{\eta} \{-\eta_1 S_0(x_c)(1-\lambda^2/2) + \eta_3 S_0(x_c, x_t) + \eta_2 S_0(x_t) A^2 \lambda^4 (1-\bar{\rho})\}$$

S0 - Inami-Lim functions for c-c, c-t, e t-t contributions (from perturbative calculations)

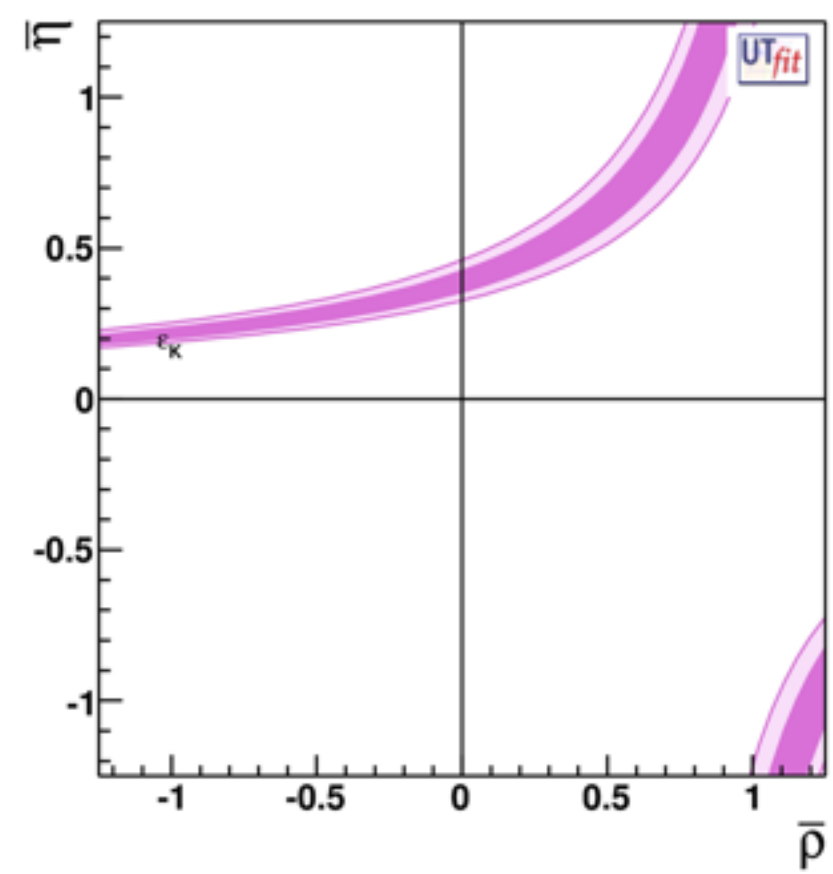
We also have a corrections for long-distance effects (Phys.Rev.D78:033005, PLB688 (2010) 309).

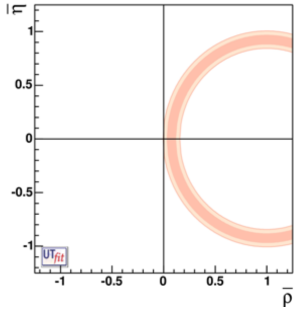
$$\epsilon_K = \sin\phi_\epsilon e^{i\phi_\epsilon}\left[\frac{\mathrm{Im}M_{12}^{(6)}}{\Delta m_K} + \rho\,\xi\right]$$

We use:

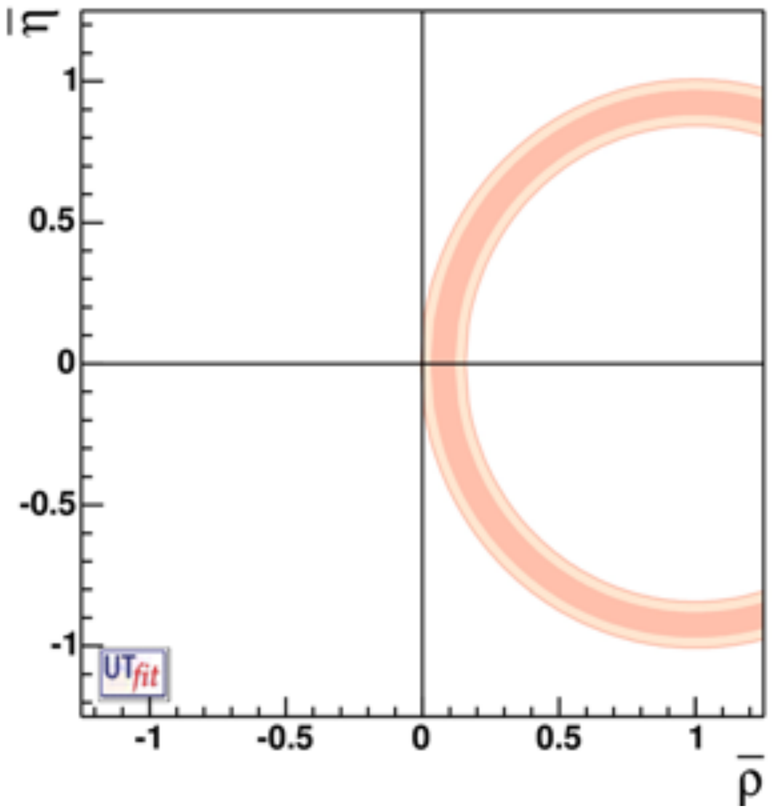
$$|\epsilon_K| = (2.23 \pm 0.11)\cdot 10^{-4}$$

Introducing the NNLO charm-top-quark contribution (from PRL108 (2012) 121801) increases the uncertainty by 0.01 and does not affect a global fit.





Δm_s or Δm_d



We include the oscillation of B_d and B_s as inputs of the fit using two observables Δm_d and $\Delta m_d/\Delta m_s$

$$\Delta m_d = \frac{G_F^2}{6\pi^2} m_W^2 \eta_b S(x_t) m_{B_d} f_{B_d}^2 \hat{B}_{B_d} |V_{tb}|^2 |V_{td}|^2 = \frac{G_F^2}{6\pi^2} m_W^2 \eta_b S(x_t) m_{B_d} f_{B_d}^2 \hat{B}_{B_d} |V_{cb}|^2 \lambda^2 ((1-\bar{\rho})^2 + \bar{\eta}^2)$$

$$\frac{\Delta m_d}{\Delta m_s} = \frac{m_{B_d} f_{B_d}^2 \hat{B}_{B_d}}{m_{B_s} f_{B_s}^2 \hat{B}_{B_s}} \frac{|V_{td}|^2}{|V_{ts}|^2} = \frac{m_{B_d} f_{B_d}^2 \hat{B}_{B_d}}{m_{B_s} f_{B_s}^2 \hat{B}_{B_s}} \left(\frac{\lambda}{1-\lambda^2/2}\right)^2 \frac{((1-\bar{\rho})^2 + \bar{\eta}^2)}{\left(1+\frac{\lambda^2}{1-\lambda^2/2}\bar{\rho}\right)^2 + \lambda^4 \bar{\eta}^2}$$

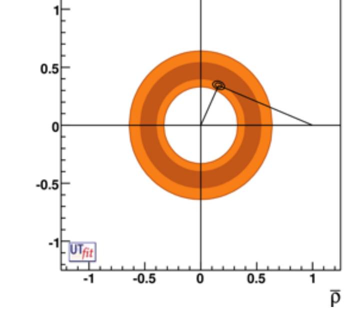
We use the following approximation

$$\Delta m_d \approx [(1-\rho)^2 + \eta^2] \frac{f_{B_s}^2 B_{B_s}}{\xi^2}$$

$$\Delta m_s \approx f_{B_s}^2 B_{B_s}$$

$$\Delta m_s = 17.768 \pm 0.024 \text{ ps}^{-1}$$

$$\Delta m_d = 0.510 \pm 0.004 \text{ ps}^{-1}$$

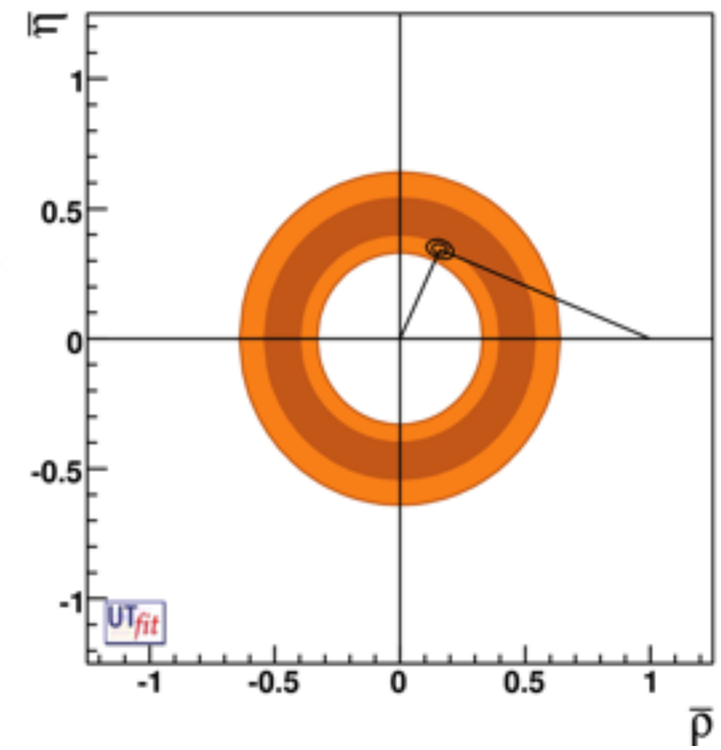


We use the combination of B→τν measurements by BaBar and Belle

$$\mathcal{B}(B \to \ell\nu) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

We use:

$$B(B \to \tau\nu) = (1.14 \pm 0.22) \cdot 10^{-4}$$

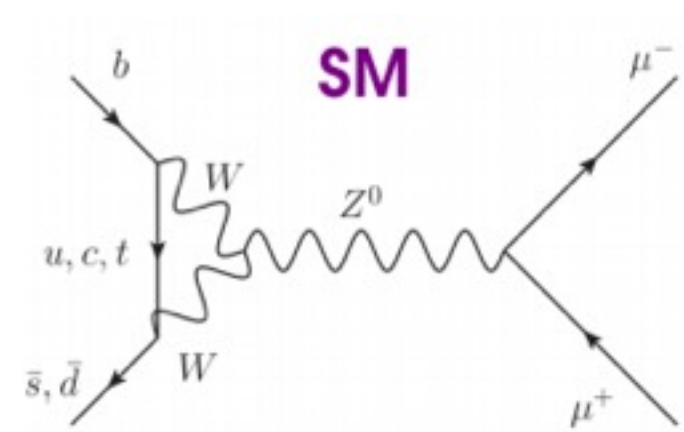


Brand new constraint from $B_{(s)}$→μμ measurements by LHCb and CMS

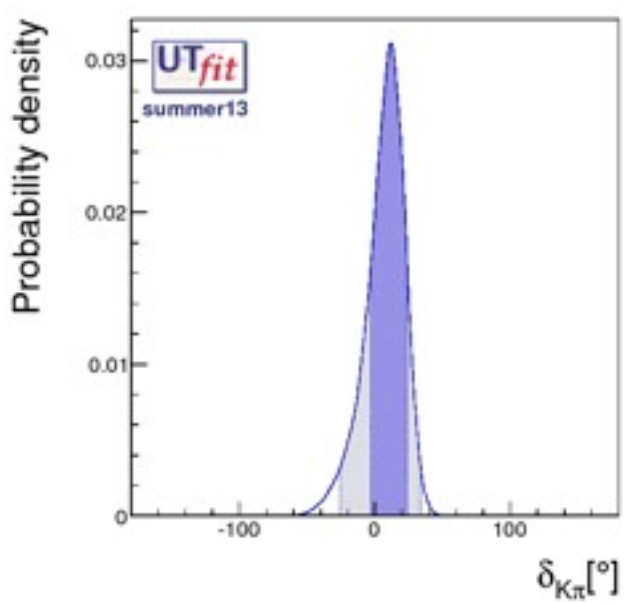
Experimental value needs to be corrected for the Bs oscillation to be compared to the theoretical predictions (see De Bruyn PRL 109, 041801 (2012))

We use LHCb+CMS combination:

$$\begin{aligned} \mathcal{B}(B_s^0 \to \mu^+\mu^-) &= (2.9 \pm 0.7) \times 10^{-9} \\ \mathcal{B}(B^0 \to \mu^+\mu^-) &= \left(3.6\,^{+1.6}_{-1.4}\right) \times 10^{-10} \end{aligned}$$



We perform a fit to the charm sector results allowing for CP violation in the singly-Cabibbo suppressed decays and receive the following results.



$\delta_D = (10.5 \pm 13.5)°$

$|q/p|-1 = -0.015 \pm 0.077$

$\phi = (0.3 \pm 2.6)°$

$x = (4.2 \pm 1.8) \cdot 10^{-3}$
$y = (6.4 \pm 0.8) \cdot 10^{-3}$

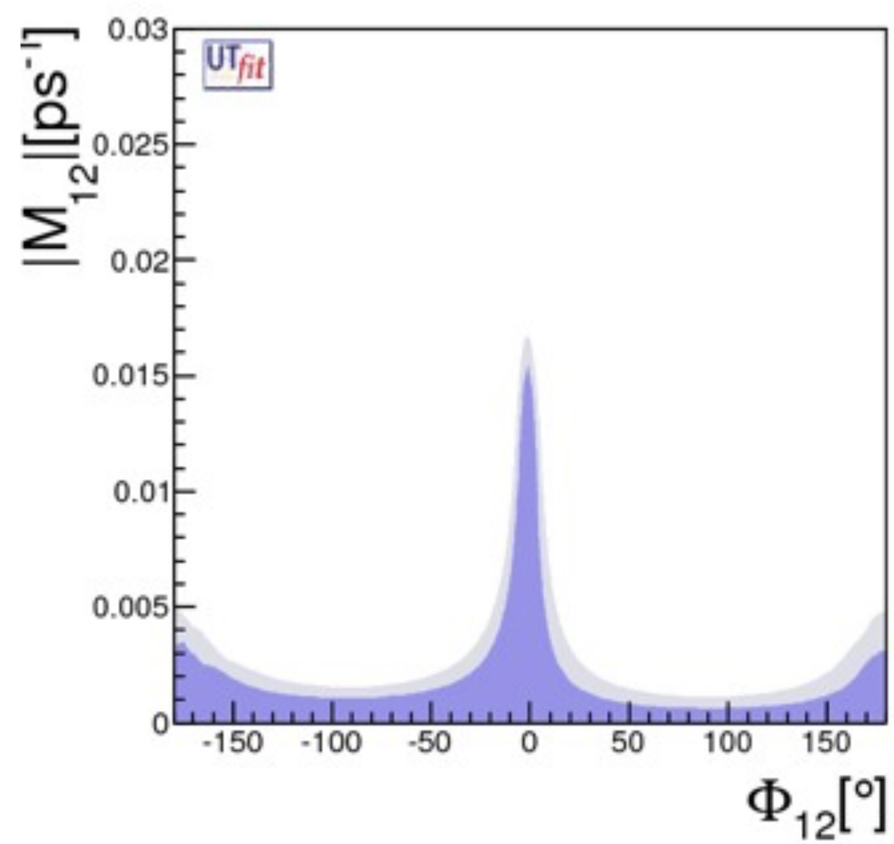
This does not include the most recent LHCb results announced at CHARM-2013

For the purpose of constraining NP, it is useful to express the fit results in terms of the $\Delta C = 2$ effective Hamiltonian matrix elements.

$$|M_{12}| = \frac{1}{\tau_D}\sqrt{\frac{x^2+\delta^2 y^2}{4(1-\delta^2)}}, \quad |\Gamma_{12}| = \frac{1}{\tau_D}\sqrt{\frac{y^2+\delta^2 x^2}{1-\delta^2}},$$

$$\sin\Phi_{12} = \frac{|\Gamma_{12}|^2 + 4|M_{12}|^2 - (x^2+y^2)|q/p|^2/\tau_D^2}{4|M_{12}\Gamma_{12}|}$$

$M_{12} = (0.005 \pm 0.002)\ \mathrm{ps}^{-1}$
$\Gamma_{12} = (0.016 \pm 0.002)\ \mathrm{ps}^{-1}$
$\phi_{12} = (2 \pm 11)°$



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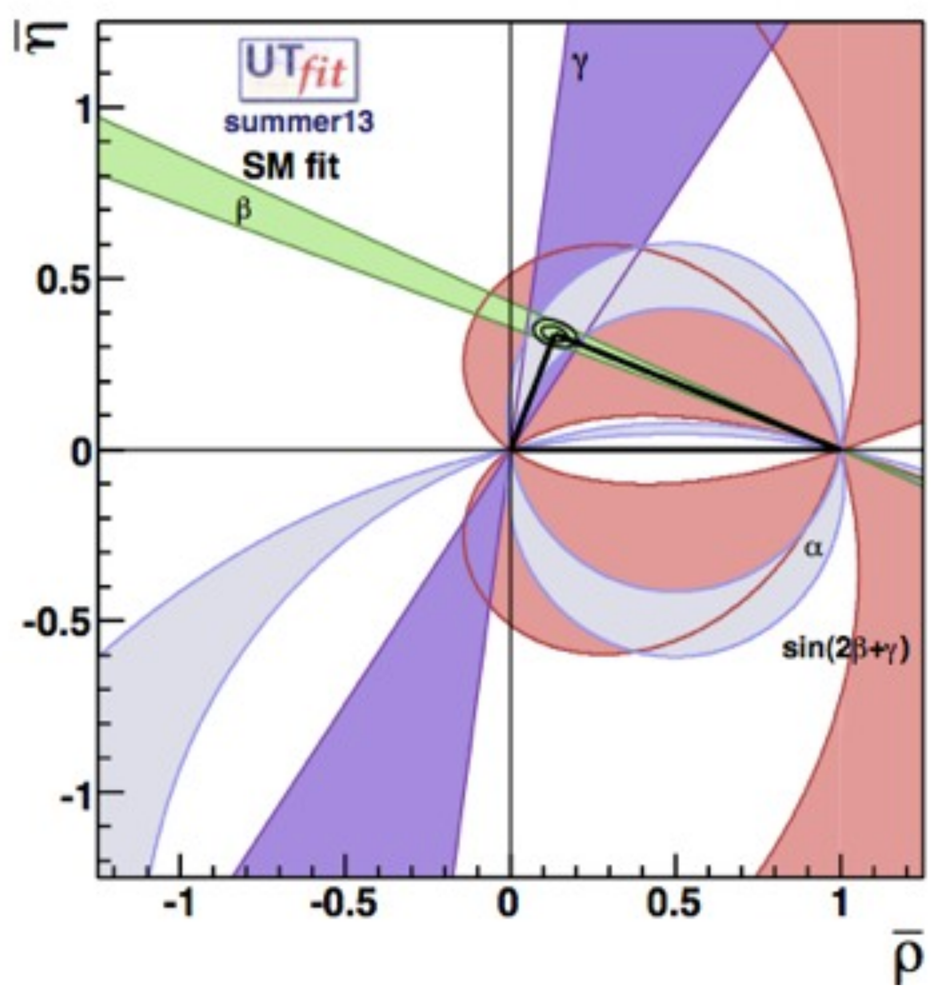
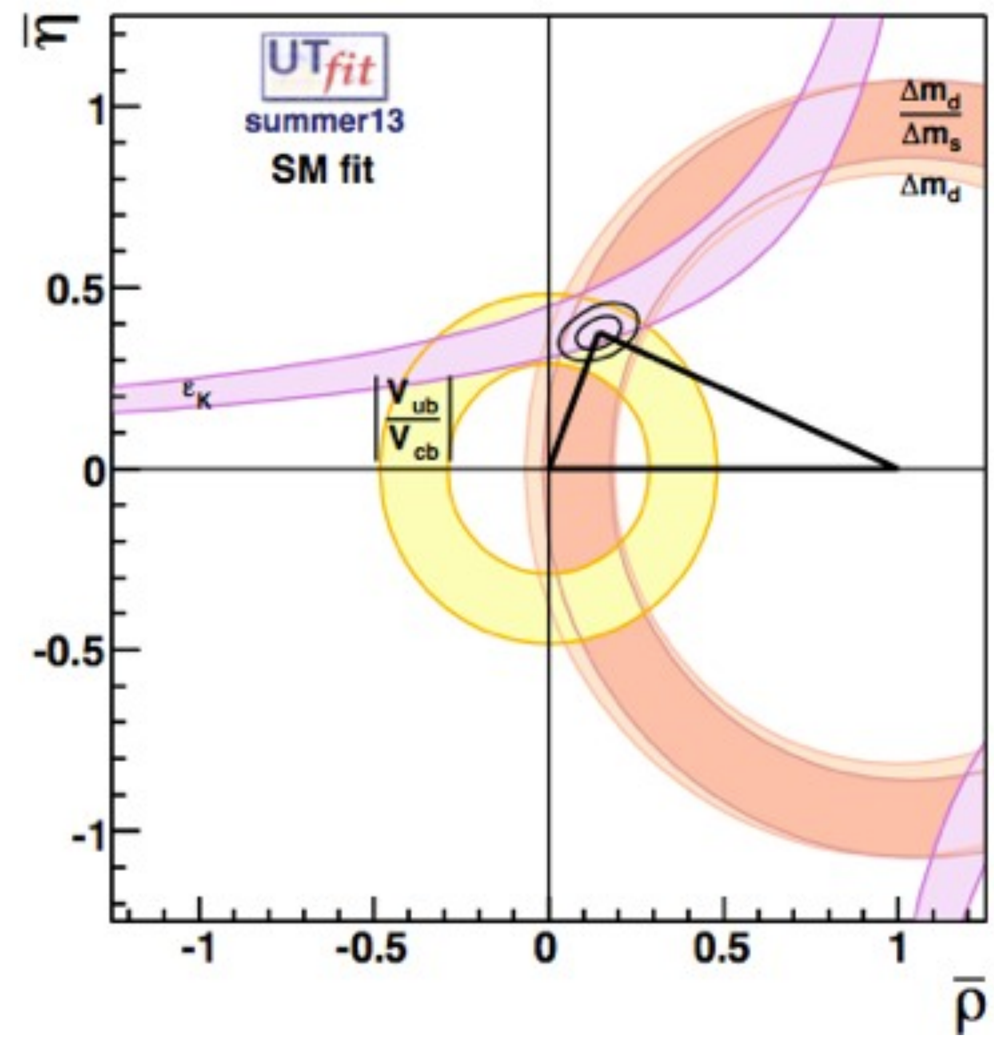
Some more results did not make it inside the talk: lifetimes, their differences and quark masses.



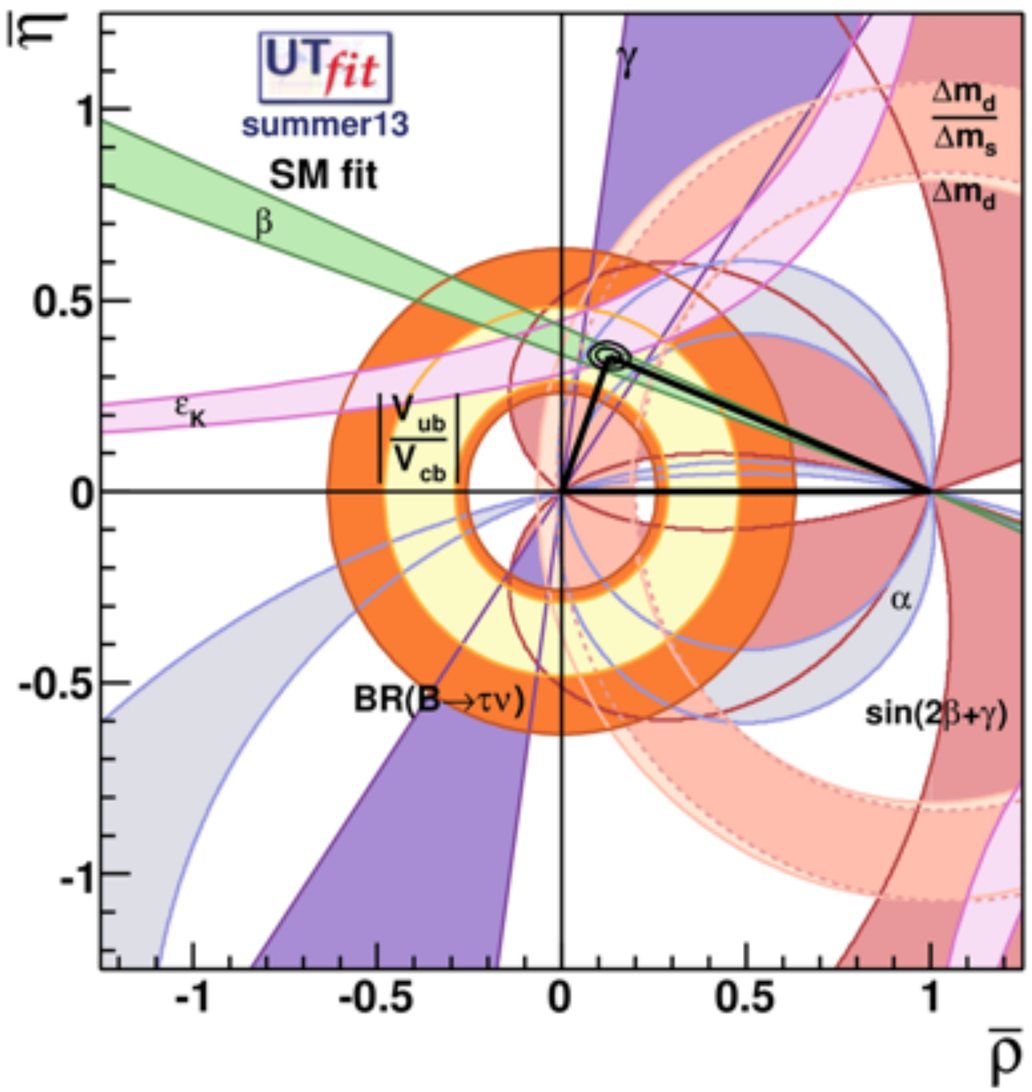
$$\bar{\rho} = 0.134 \pm 0.029$$
$$\bar{\eta} = 0.339 \pm 0.017$$

vs.



$$\bar{\rho} = 0.144 \pm 0.046$$
$$\bar{\eta} = 0.376 \pm 0.030$$

Full Fit results



$$\bar{\rho} = 0.127 \pm 0.023$$
$$\bar{\eta} = 0.353 \pm 0.014$$

	Measurement	Prediction (remove parameter from the fit)	Pull
α, °	(90.7±7.4)	(87.7±3.3)	<1
$\sin(2\beta)$	(0.680±0.023)	(0.754±0.042)	-1.5
γ , °	(70.1±7.1)	(69.8±3.9)	~0
V_{ub}, 10^{-3}	(3.75±0.46)	(3.62±0.13)	+0.3
V_{cb}, 10^{-3}	(40.9±1.0)	(42.1±0.7)	-1.0
ε_K, 10^{-3}	(2.228±0.011)	(2.04±0.19)	+1.0
Δm_s, ps^{-1}	(17.768±0.024)	(17.4±1.1)	-0.3
$B(B_u \to \tau\nu)$, 10^{-4}	(1.14±0.22)	(0.806±0.07)	-1.4
$B(B_s \to \mu\mu)$, 10^{-9}	(2.9±0.7)	(3.91±0.16)	1.3
$B(B_d \to \mu\mu)$, 10^{-9}	(0.37±0.15)	(0.115±0.007)	-1.7
β_s, rad (not in the SM fit)	(0.005±0.035)	(0.01876±0.0008)	<1

We are also able to obtain the CKM matrix

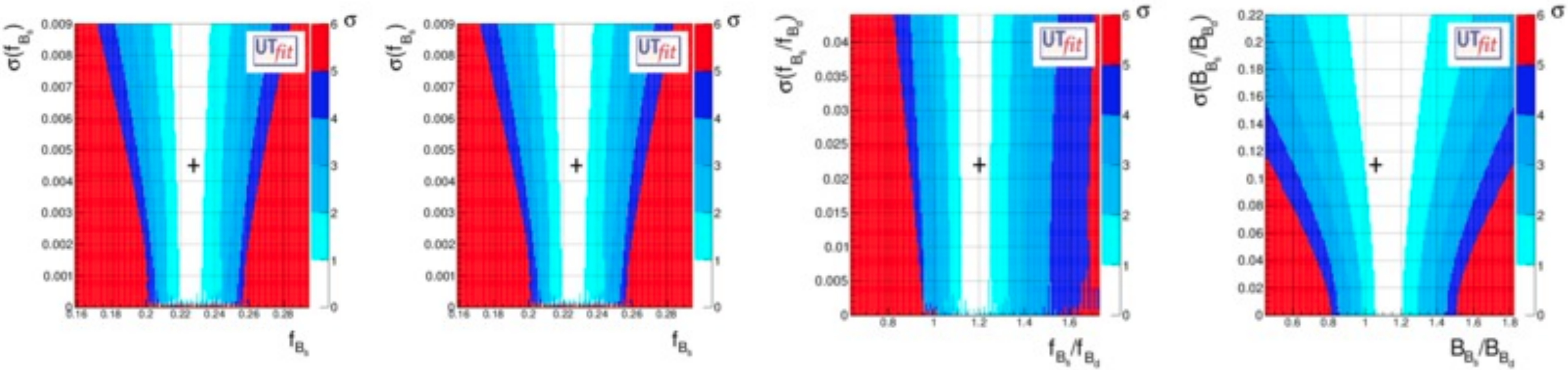
$$V_{CKM} = \begin{pmatrix} (0.97426 \pm 0.00014) & (0.22535 \pm 0.00059) & (0.00362 \pm 0.00012)e^{i(-70.2\pm3.3)^\circ} \\ (-0.22525 \pm 0.00059)e^{i(0.0352\pm0.001)^\circ} & (0.97342 \pm 0.00013)e^{i(-0.00188333\pm0.00005)^\circ} & (0.04172 \pm 0.00056) \\ (0.00884 \pm 0.00019)e^{i(-22.0\pm0.8)^\circ} & (-0.04092 \pm 0.00057)e^{i(1.071\pm0.042)^\circ} & (0.999121 \pm 0.000021) \end{pmatrix}$$

summer 13 results

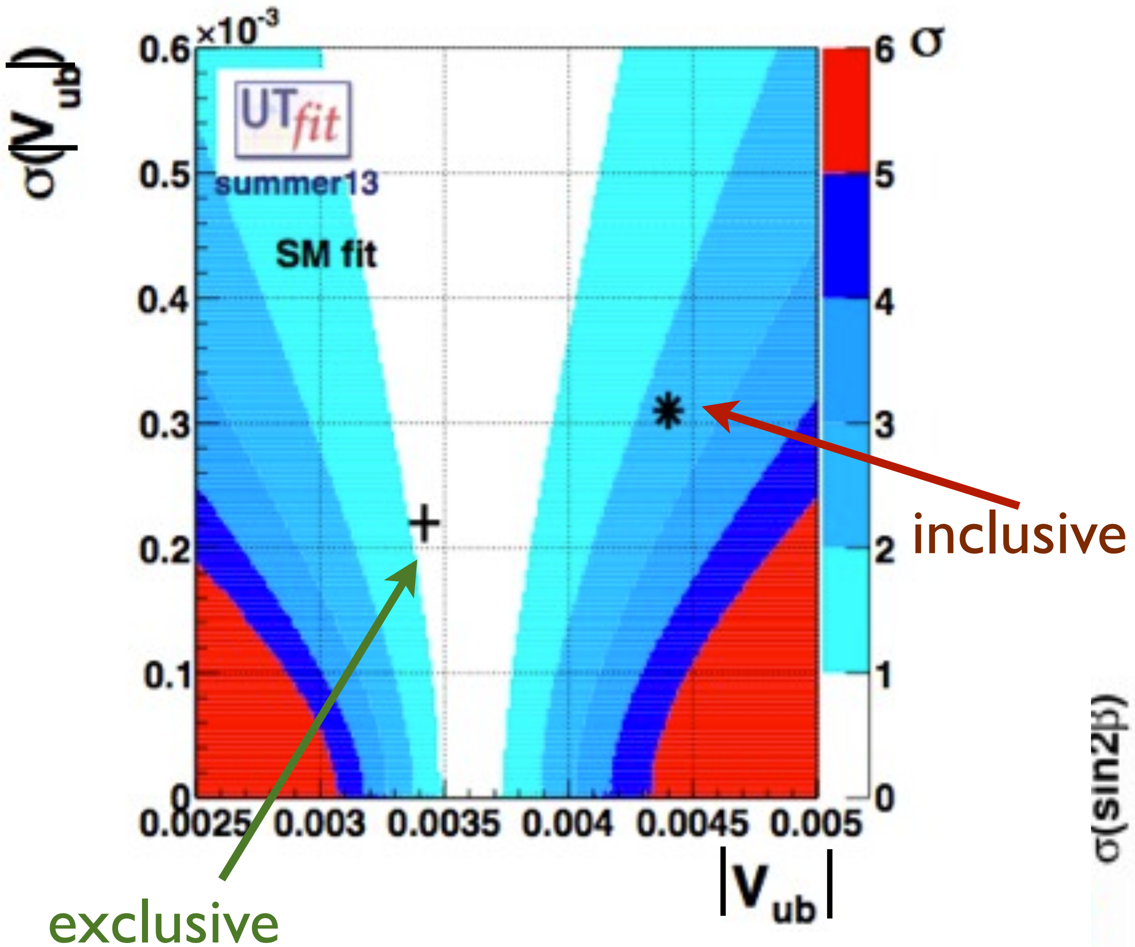
Lattice in the Full Fit

Observables	Measurement	Prediction	Pull (#σ)
B_K	0.766 ± 0.010	0.841 ± 0.078	0.9
f_{Bs}	0.2277 ± 0.0045	0.2270 ± 0.0065	< 0.5
f_{Bs}/f_{Bd}	1.202 ± 0.022	1.19 ± 0.06	< 0.5
B_{Bs}	0.875 ± 0.040	0.879 ± 0.045	< 0.5
B_{Bs}/B_{Bd}	1.06 ± 0.11	1.137 ± 0.076	0.5

Color code: agreement between the predicted values and the measurements at better than 1, 2, ...nσ.
The cross has the coordinates (x,y) =(central value, error) of the direct measurement.

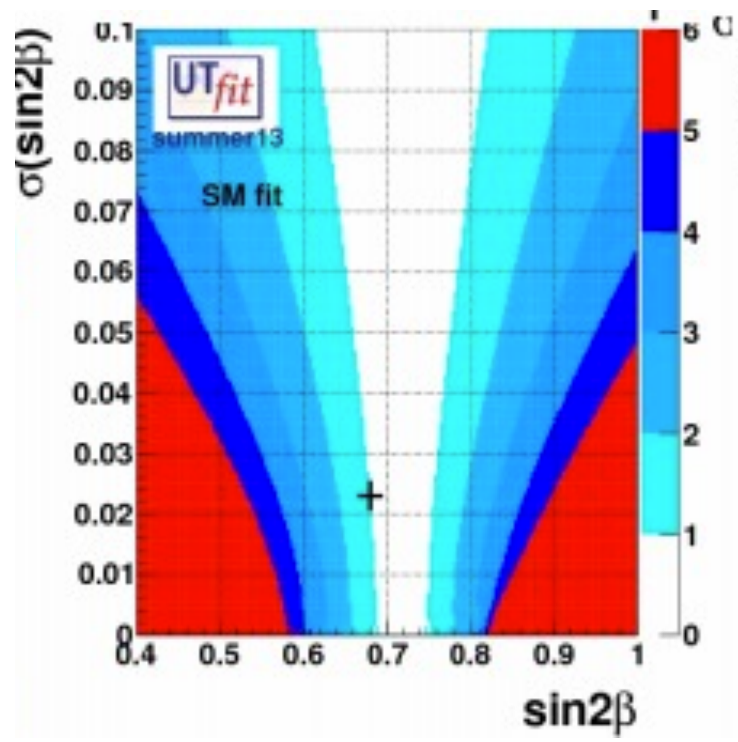


Combined $|V_{ub}|$ and $|V_{cb}|$ have two components: exclusive and inclusive. We perform the fits with only inclusive and only exclusive components to test the pulls. This have some influence to the connected observables.

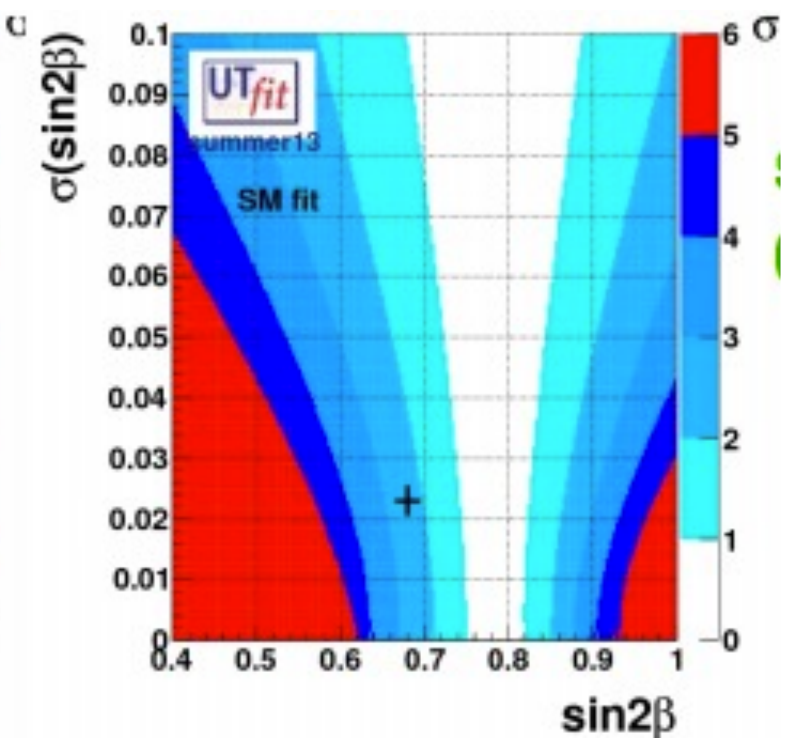


Also affects $B(B_u \to \tau\nu)$ and ε_K.

exclusive



inclusive



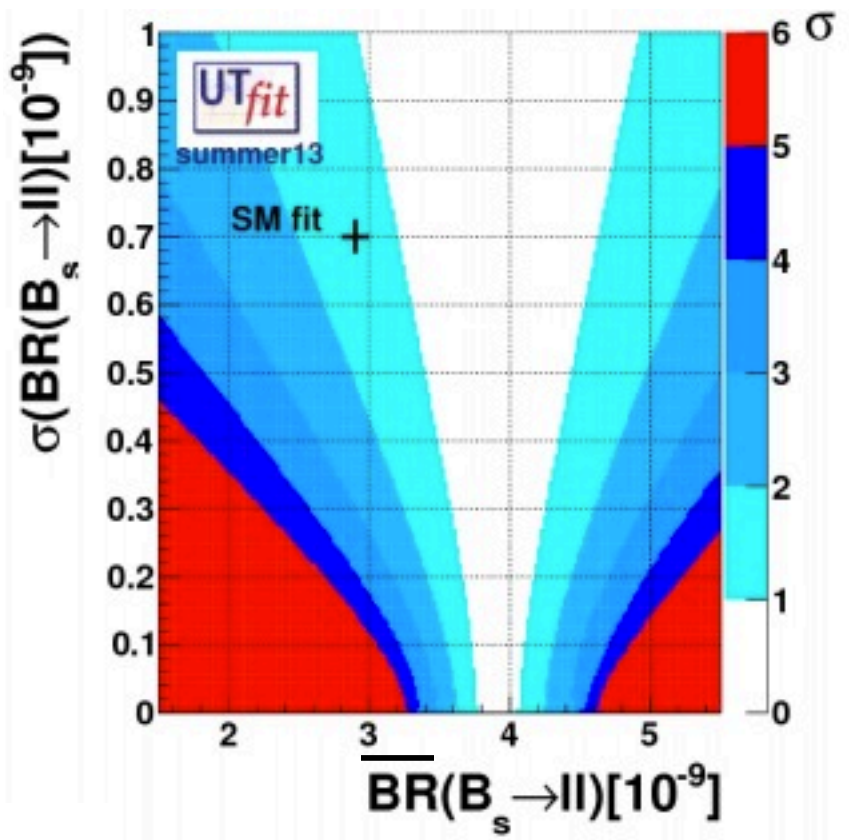
prediction: $\sin 2\beta = 0.720 \pm 0.031$

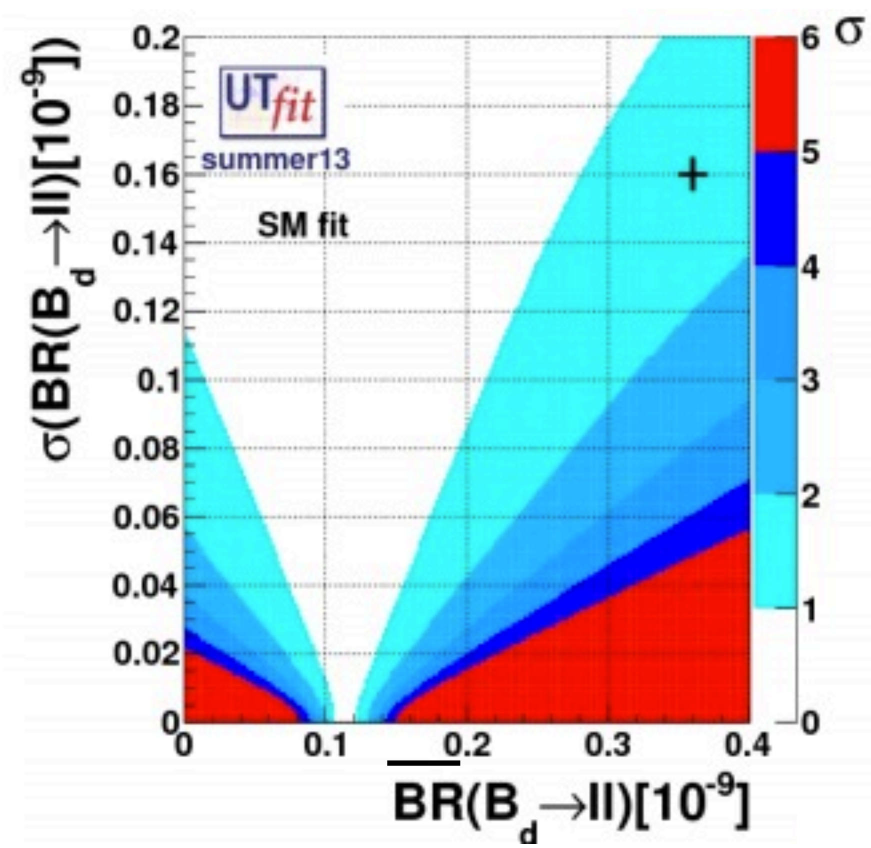
$\sin 2\beta = 0.782 \pm 0.035$

Experimental values

$BR(B_s \to \mu\mu) = (2.9 \pm 0.7)10^{-9}$

$BR(B_d \to \mu\mu) = (3.7 \pm 1.5)10^{-10}$





indirect determinations from UT

$BR(Bs \to ll) = (3.92 \pm 0.16)10^{-9}$

$BR(B_d \to ll) = (1.15 \pm 0.07)10^{-10}$

time-integration included

Generic NP parameterization

Since the fit is over constrained, we can introduce new parameters added in order to parameterize generic NP ΔF=2 processes in all sectors

B_d and B_s mixing amplitudes (2+2 real parameters):

$$A_q e^{2i\phi_q} = C_{B_q} e^{2i\phi_{B_q}} A_q^{SM} e^{2i\phi_q^{SM}} = \left(1+\frac{A_q^{NP}}{A_q^{SM}} e^{2i(\phi_q^{NP}-\phi_q^{SM})}\right) A_q^{SM} e^{2i\phi_q^{SM}}$$

In case of absence of NP effects, $C_i=1$, $\varphi_i=0$

Observables:

$$\Delta m_{q/K} = C_{B_q/\Delta m_K} (\Delta m_{q/K})^{SM} \qquad \varepsilon_K = C_\varepsilon \varepsilon_K^{SM}$$

$$A_{CP}^{B_d \to J/\psi K_s} = \sin 2(\beta + \phi_{B_d}) \qquad A_{CP}^{B_s \to J/\psi \phi} \sim \sin 2(-\beta_s + \phi_{B_s})$$

$$A_{SL}^q = \mathrm{Im}\left(\Gamma_{12}^q / A_q\right) \qquad \Delta\Gamma^q/\Delta m_q = \mathrm{Re}\left(\Gamma_{12}^q / A_q\right)$$

		ρ, η	C_d	φ_d	C_s	φ_s	$C_{\varepsilon K}$
Tree processes	γ (DK)	X					
	V_{ub}/V_{cb}	X					
1↔3 family	Δm_d	X	X				
	ACP (J/Ψ K)	X		X			
	ACP (Dπ(ρ),DKπ)	X		X			
	A_{SL}		X	X			
	α (ρρ,ρπ,ππ)	X		X			
	A_{CH}		X	X	X	X	
2↔3 family	τ(Bs), $\Delta\Gamma_s/\Gamma_s$				X	X	
	Δm_s				X		
	ASL(Bs)				X	X	
	ACP (J/Ψ φ)	~X				X	
1↔2 familiy	ε_K	X					X

semileptonic asymmetries:
sensitive to NP effects in both size and phase

$$A_{SL}^s \equiv \frac{\Gamma(\bar{B}_s \to \ell^+ X) - \Gamma(B_s \to \ell^- X)}{\Gamma(\bar{B}_s \to \ell^+ X) + \Gamma(B_s \to \ell^- X)} = \mathrm{Im}\left(\frac{\Gamma_{12}^s}{A_s^{\mathrm{full}}}\right)$$

$A_{SL}(B_d)[10^{-3}] = 3.2 \pm 2.9$, $A_{SL}(B_s)[10^{-3}] = -4.8 \pm 5.2$

B factories,
CDF + D0 + LHCb

same-side dilepton charge asymmetry:
admixture of B_s and B_d so sensitive to NP effects in both systems

$A_{\mu\mu}[10^{-3}] = -7.9 \pm 2.0$

D0 arXiv:1106.6308

$$A_{SL}^{\mu\mu} = \frac{f_d \chi_{d0} A_{SL}^d + f_s \chi_{s0} A_{SL}^s}{f_d \chi_{d0} + f_s \chi_{s0}}$$

lifetime τ^{FS} in flavour-specific final states:
average lifetime is a function to the width and the width difference (independent data sample)

$\tau^{FS} = 1.417 \pm 0.042$

HFAG

$$\tau_{B_s}^{FS} = \frac{1}{\Gamma_s} \frac{1 - \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}{1 + \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}$$

$\varphi_s = 2\beta_s$ vs $\Delta\Gamma_s$ from $B_s \to J/\psi\varphi$

angular analysis as a function of proper time and b-tagging. Additional sensitivity from the $\Delta\Gamma$s terms φ

φ s: LHCb: Gaussian
$\Delta\Gamma$s: average: Gaussian

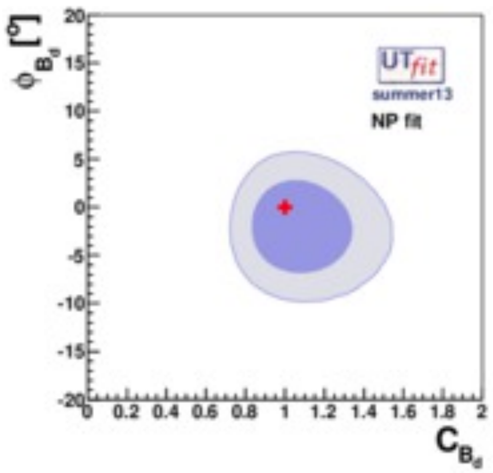
We thus obtain the following results.

SM:

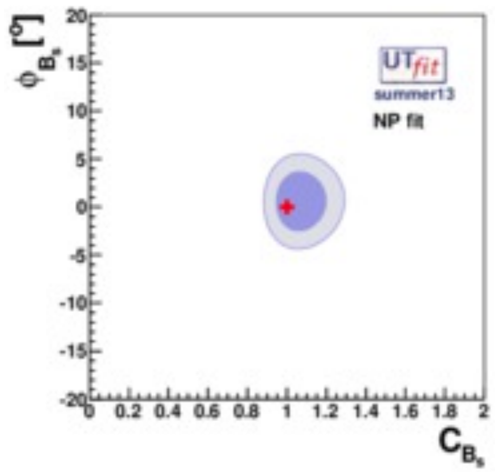
$$\bar{\rho} = 0.127 \pm 0.023$$
$$\bar{\eta} = 0.353 \pm 0.014$$

NP:

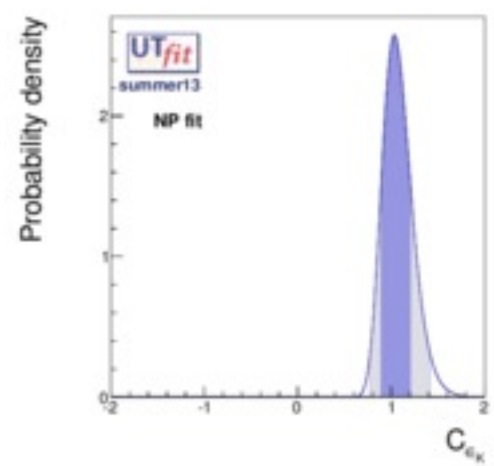
$$\bar{\rho} = 0.147 \pm 0.045$$
$$\bar{\eta} = 0.368 \pm 0.048$$



C_{Bd} = 1.10 ± 0.17
φ_{Bd} = (-2.1 ± 3.2)°



C_{Bs} = 1.08 ± 0.09
φ_{Bs} = (0.6 ± 2.0)°



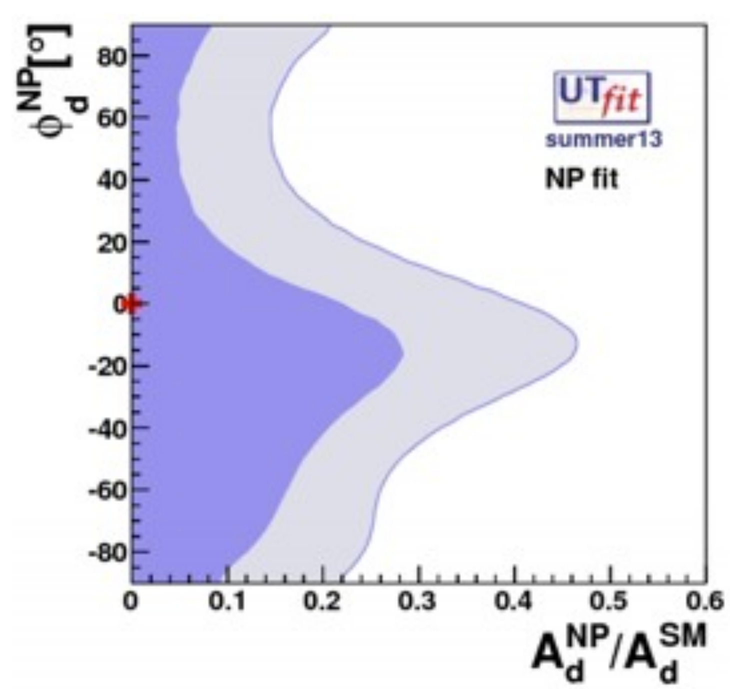
$C_{\varepsilon K}$ = 1.08 ± 0.16

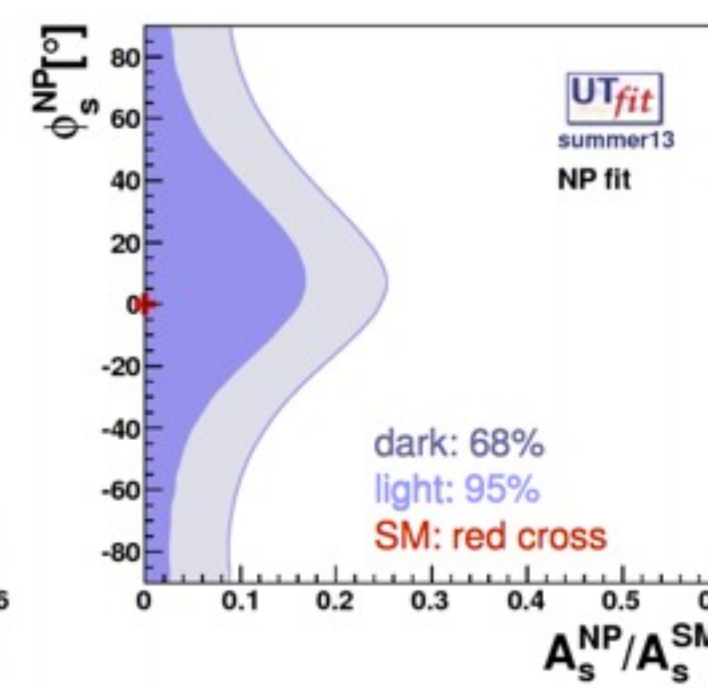
The uncertainty in d-sector is larger than that in c-sector.

This can be interpreted using different observables:

$$A_q = \left(1 + \frac{A_q^{NP}}{A_q^{SM}} e^{2i(\varphi_q^{NP} - \varphi_q^{SM})}\right) A_q^{SM} e^{2i\varphi_q^{SM}}$$

No real tension in any place





Scale Analysis

Starting from previous results, we can try to put the limits to the generic New physics scenarios. The most general effective Hamiltonians for ΔF = 2 processes beyond the SM have the form. NP effects are in the Wilson Coefficients C_i.

$$\mathcal{H}_{\text{eff}}^{\Delta S=2} = \sum_{i=1}^{5} C_i\, Q_i^{sd} + \sum_{i=1}^{3} \tilde{C}_i\, \tilde{Q}_i^{sd}$$

$$\mathcal{H}_{\text{eff}}^{\Delta C=2} = \sum_{i=1}^{5} C_i\, Q_i^{cu} + \sum_{i=1}^{3} \tilde{C}_i\, \tilde{Q}_i^{cu}$$

$$\mathcal{H}_{\text{eff}}^{\Delta B=2} = \sum_{i=1}^{5} C_i\, Q_i^{bq} + \sum_{i=1}^{3} \tilde{C}_i\, \tilde{Q}_i^{bq}$$

C_i in general can be presented as:

$$C_i(\Lambda) = \frac{F_i L_i}{\Lambda^2}$$

where

$$Q_1^{q_i q_j} = \bar{q}_{jL}^{\alpha}\gamma_\mu q_{iL}^{\alpha}\bar{q}_{jL}^{\beta}\gamma^\mu q_{iL}^{\beta} ,$$

$$Q_2^{q_i q_j} = \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha}\bar{q}_{jR}^{\beta} q_{iL}^{\beta} ,$$

$$Q_3^{q_i q_j} = \bar{q}_{jR}^{\alpha} q_{iL}^{\beta}\bar{q}_{jR}^{\beta} q_{iL}^{\alpha} ,$$

$$Q_4^{q_i q_j} = \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha}\bar{q}_{jL}^{\beta} q_{iR}^{\beta} ,$$

$$Q_5^{q_i q_j} = \bar{q}_{jR}^{\alpha} q_{iL}^{\beta}\bar{q}_{jL}^{\beta} q_{iR}^{\alpha} .$$

Fi : function of the NP flavour couplings
L_i: loop factor (in NP models with no tree-level FCNC)
Λ: NP scale (typical mass of new particles mediating ΔF=2 transitions)

The dependence of C on Λ changes with flavour structure.
We can consider different flavour scenarios:

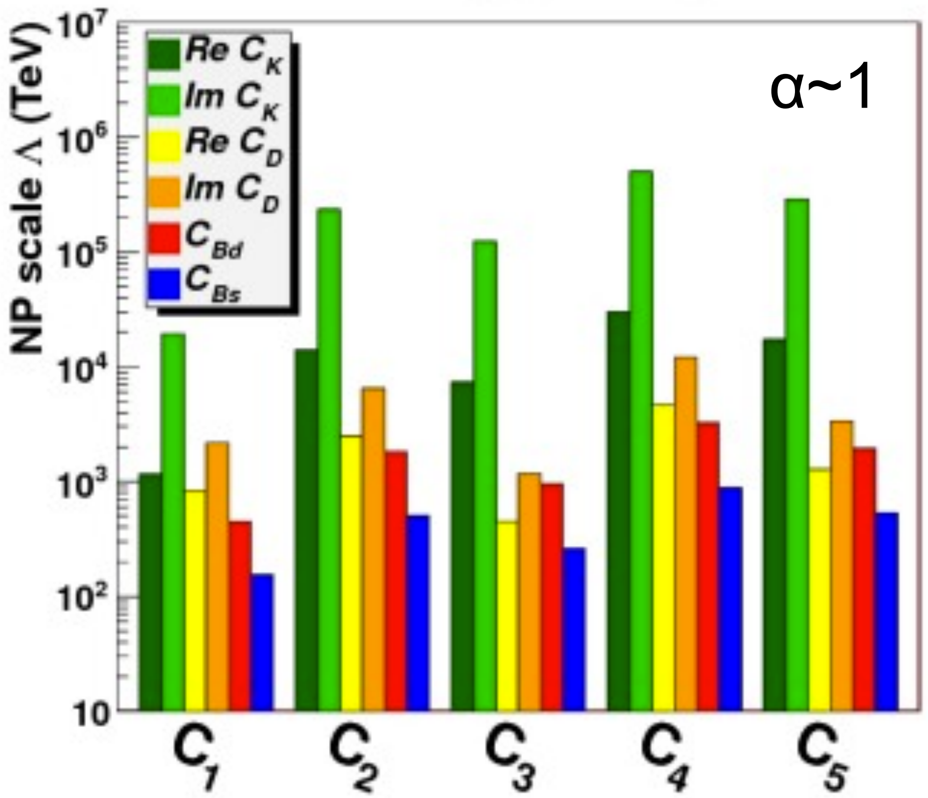
- Generic: $C(\Lambda) = \alpha/\Lambda^2$; $F_i \sim 1$, arbitrary phase
- NMFV: $C(\Lambda) = \alpha\times|F_{SM}|/\Lambda^2$; $F_i\sim|F_{SM}|$, arbitrary phase

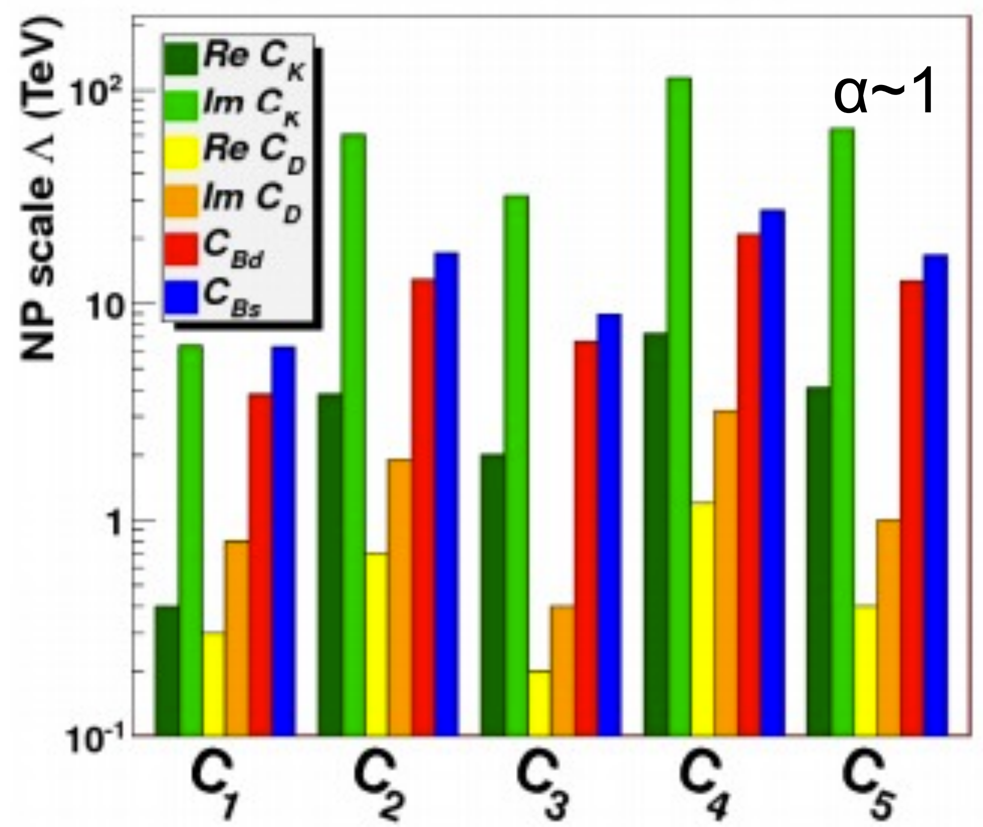
To obtain the PDF for the Wilson coefficients Ci(Λ) at the new-physics scale, we switch on one coefficient at a time in each sector and calculate its value from the result of the NP analysis.

JHEP 0803:049,2008
arXiv:0707.0636

Generic $C(\Lambda) = \alpha/\Lambda^2$, $F_i \sim 1$

NMFV $C(\Lambda) = \alpha \times |F_{SM}|/\Lambda^2$





To obtain the lower bound for loop-mediated contributions, one simply multiplies the bounds by α_s (~0.1) or by α_W (~0.03).

$\alpha \sim \alpha_W$ in case of loop coupling through weak interactions

NP in α_W (~ 0.1) loops $\Lambda > 1.5\ 10^4$ TeV

Non-perturbative NP $\Lambda > 5.0\ 10^5$ TeV

NP in α_W (~ 0.1) loops $\Lambda > 3.4$ TeV

Non-perturbative NP $\Lambda > 113$ TeV

JHEP 0803:049,2008
arXiv:0707.0636

Conclusions

- SM analysis displays good overall consistency

- Still open discussion on semileptonic inclusive vs exclusive

- UTA provides determination also of NP contributions to

- $\Delta F=2$ amplitudes. It currently leaves space for NP at the level of 15-20%

- Scale analysis points to high scales for the generic scenario and even above L HC reach for weak coupling.

- Indirect searches become essential.