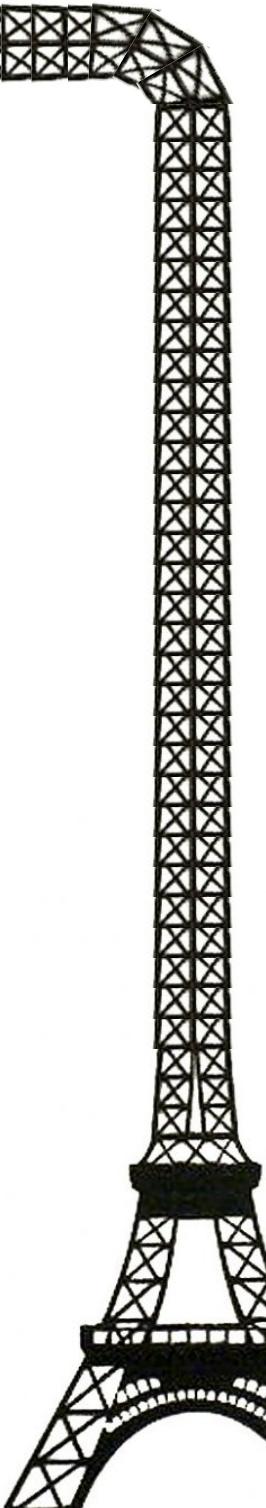
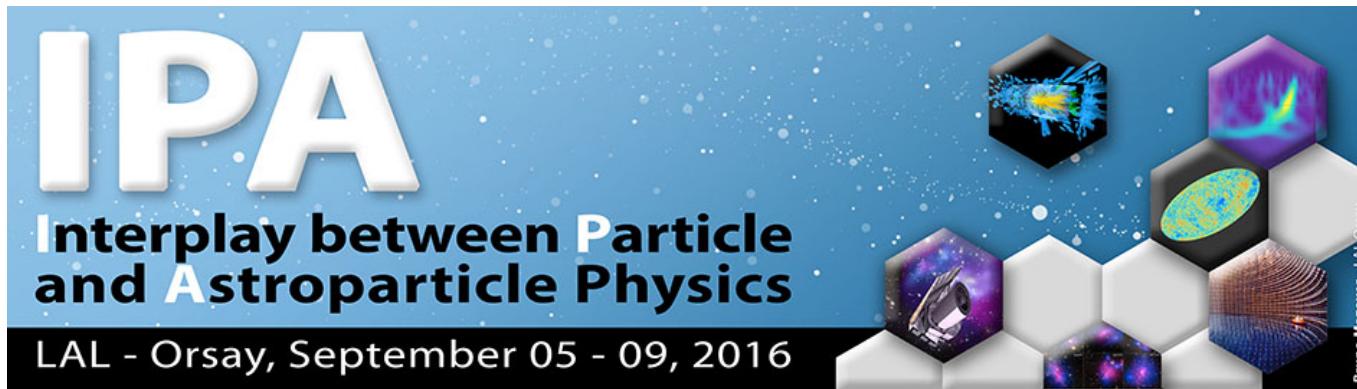


Unitarity Triangle analysis in the Standard Model and beyond from UTfit



Marcella Bona
QMUL



Unitarity Triangle analysis in the SM

- SM UT analysis:

- provide the best determination of CKM parameters
- test the consistency of the SM (“*direct*” vs “*indirect*” determinations)
- provide predictions (from data..) for SM observables

.. and beyond

- NP UT analysis:

- model-independent analysis
- provides limit on the allowed deviations from the SM
- obtain the NP scale



www.utfit.org

C. Alpigiani, A. Bevan, M.B., M. Ciuchini,
D. Derkach, E. Franco, V. Lubicz, G. Martinelli,
F. Parodi, M. Pierini, C. Schiavi, L. Silvestrini,
A. Stocchi, V. Sordini, C. Tarantino and V. Vagnoni

Other UT analyses exist, by:

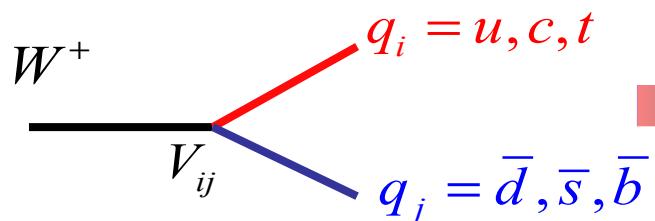
CKMfitter (<http://ckmfitter.in2p3.fr/>),

Laiho&Lunghi&Van de Water (<http://latticeaverages.org/>)

Lunghi&Soni (1010.6069)

CKM matrix and Unitarity Triangle

Quarks vertices in weak interactions:



$$V = \begin{pmatrix} & d & s & b \\ u & \text{blue square} & \text{blue square} & \cdot \\ c & \text{blue square} & \text{blue square} & \cdot \\ t & \cdot & \cdot & \text{blue square} \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Relative magnitudes

We parameterise the couplings V_{ij} in the CKM matrix:

$$V = \begin{pmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A\lambda^3(\bar{\rho} - i\bar{\eta}) \\ -\lambda & 1 - \frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1 - \bar{\rho} - i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix}$$

Buras-Wolfenstein parameterisation

$$\begin{aligned} \bar{\rho} &= \rho (1 - \lambda^2/2) \\ \bar{\eta} &= \eta (1 - \lambda^2/2) \end{aligned}$$

4 SM fundamental parameters extracted from various observables:

$$\lambda = 0.2253 \pm 0.0008 \text{ [or } V_{us} \text{, from K to } \pi l\nu]$$

$$A, \rho, \text{ and } \eta \text{ from global fits: } A = 0.833 \pm 0.012$$

CKM matrix and Unitarity Triangle

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

many observables
functions of $\bar{\rho}$ and $\bar{\eta}$:
overconstraining

$$\alpha = \pi - \beta - \gamma$$

normalized:

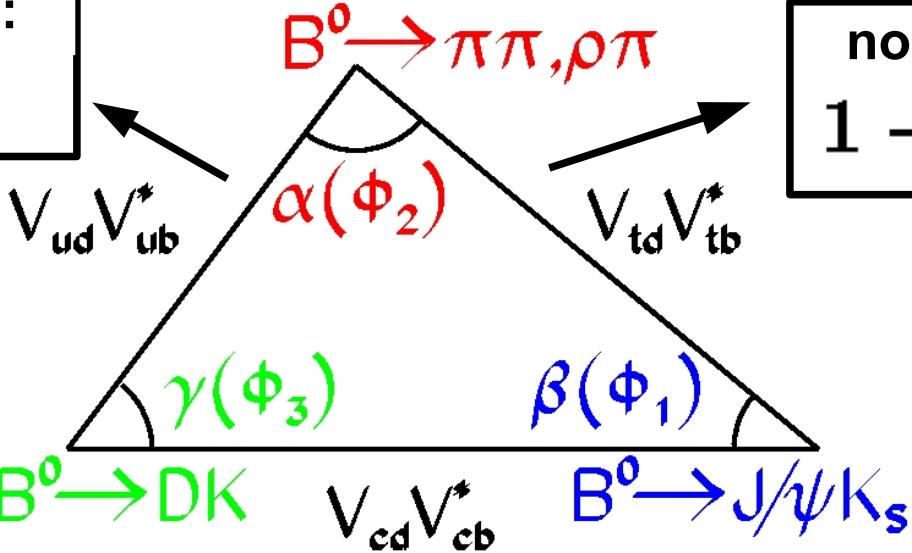
$$\bar{\rho} + i\bar{\eta}$$

normalized:

$$1 - \bar{\rho} - i\bar{\eta}$$

$$\gamma = \text{atan} \left(\frac{\bar{\eta}}{\bar{\rho}} \right)$$

$$\beta = \text{atan} \left(\frac{\bar{\eta}}{(1 - \bar{\rho})} \right)$$



the method and the inputs:

$$f(\bar{\rho}, \bar{\eta}, X | c_1, \dots, c_m) \sim \prod_{j=1,m} f_j(\mathcal{C} | \bar{\rho}, \bar{\eta}, X) * \prod_{i=1,N} f_i(x_i) f_0(\bar{\rho}, \bar{\eta})$$

Bayes Theorem

$$X \equiv x_1, \dots, x_n = m_t, B_K, F_B, \dots$$

$$\mathcal{C} \equiv c_1, \dots, c_m = \epsilon, \Delta m_d / \Delta m_s, A_{CP}(J/\psi K_S), \dots$$

$$(b \rightarrow u)/(b \rightarrow c)$$

$$\bar{\rho}^2 + \bar{\eta}^2$$

$$\bar{\Lambda}, \lambda_1, F(1), \dots$$

$$\epsilon_K$$

$$\bar{\eta}[(1 - \bar{\rho}) + P]$$

$$B_K$$

$$\Delta m_d$$

$$(1 - \bar{\rho})^2 + \bar{\eta}^2$$

$$f_B^2 B_B$$

$$\Delta m_d / \Delta m_s$$

$$(1 - \bar{\rho})^2 + \bar{\eta}^2$$

$$\xi$$

$$A_{CP}(J/\psi K_S)$$

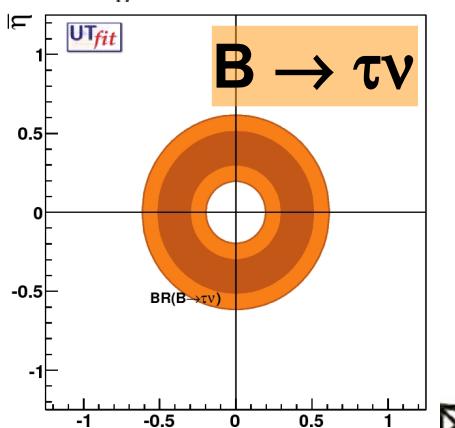
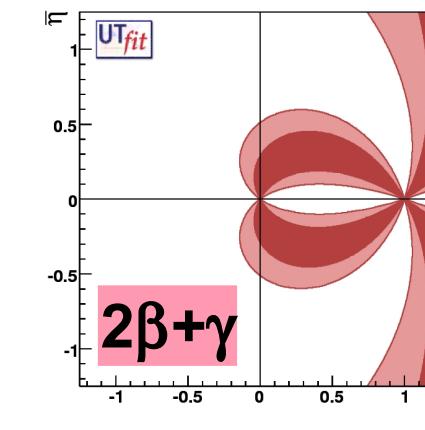
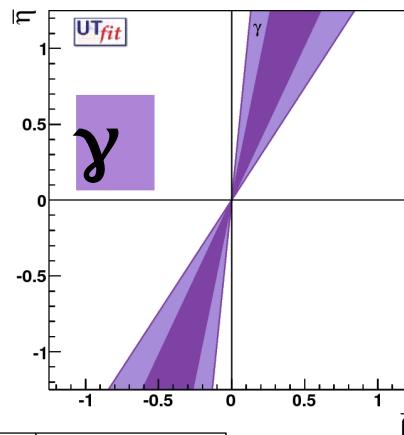
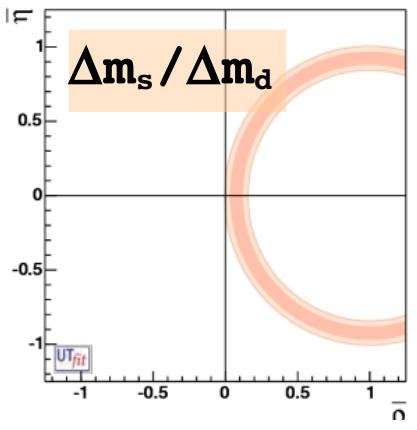
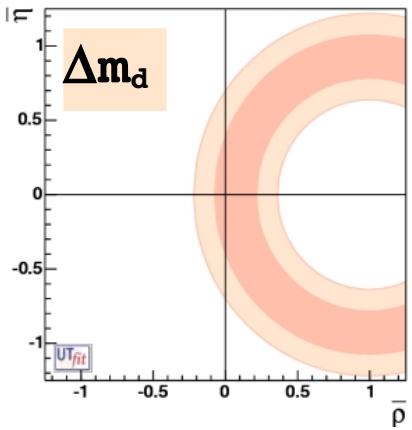
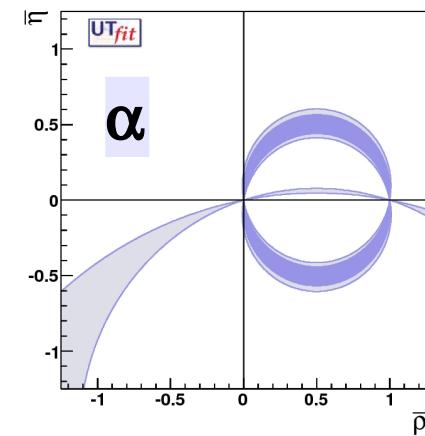
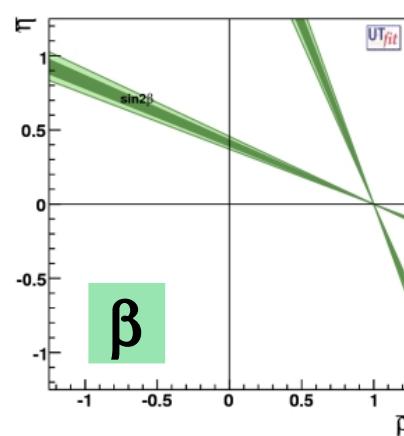
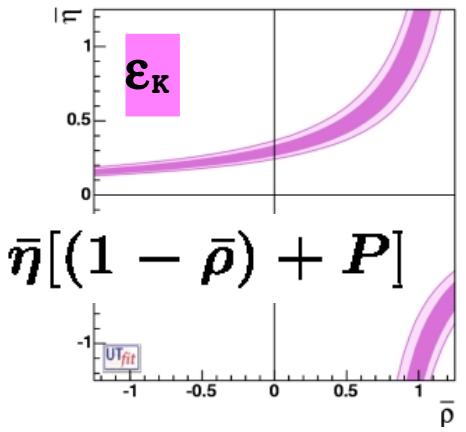
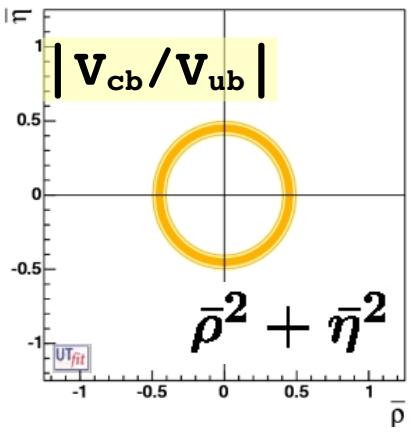
$$\sin 2\beta$$

Standard Model +
OPE/HQET/
Lattice QCD
to go
from quarks
to hadrons

m_t

M. Bona *et al.* (UTfit Collaboration)
JHEP 0507:028,2005 hep-ph/0501199
M. Bona *et al.* (UTfit Collaboration)
JHEP 0603:080,2006 hep-ph/0509219

Unitarity Triangle analysis in the SM:



$\sin 2\alpha (\phi_2)$ from charmless B decays: $\pi\pi$, $\rho\rho$, $\pi\rho$

Interference between box mixing and tree diagrams results in an asymmetry that is sensitive to α in $B \rightarrow hh$ decays: $h = \pi, \rho$

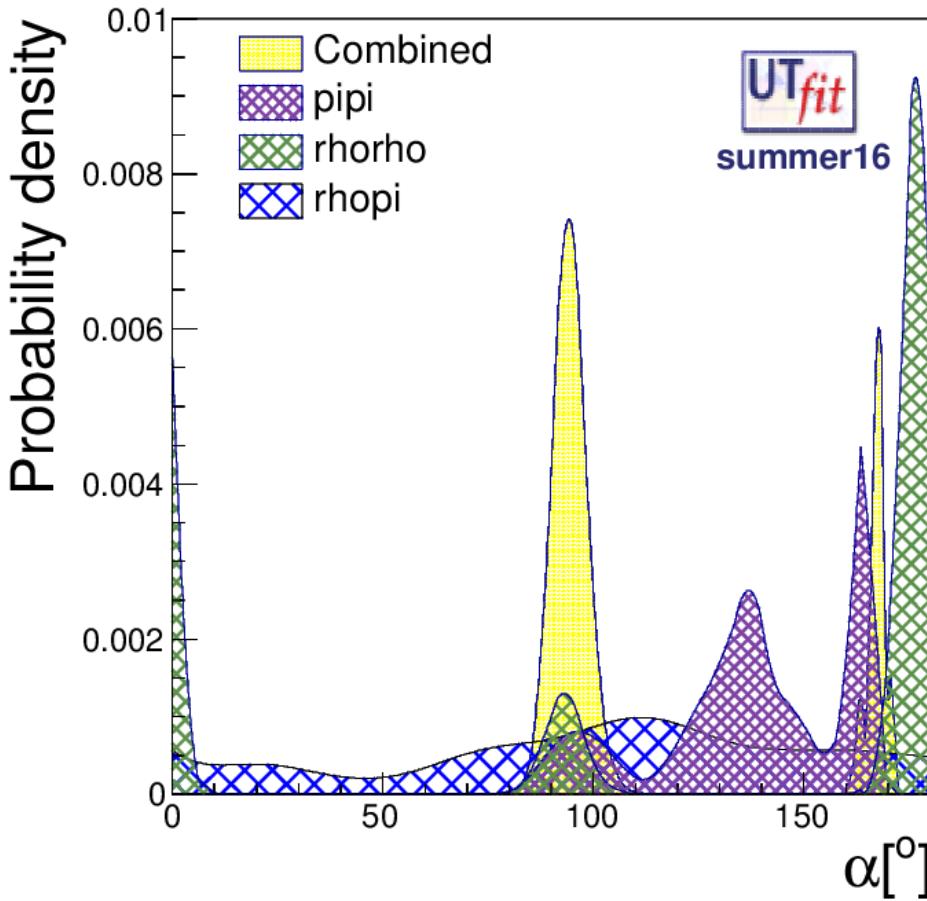
Unlike for β , loop (penguin diagrams) corrections are not negligible for α

Need Isospin analysis including all modes (B of all charges and flavours) to obtain the α estimate

Updated for ICHEP16

α from $\pi\pi$, $\rho\rho$, $\pi\rho$ decays:
combined: $(94.2 \pm 4.5)^\circ$

UTfit prediction: $(90.9 \pm 2.5)^\circ$



γ and DK trees

B to $D^{(*)}K^{(*)}$ decays: from BRs and BR ratios, no time-dependent analysis, just rates.

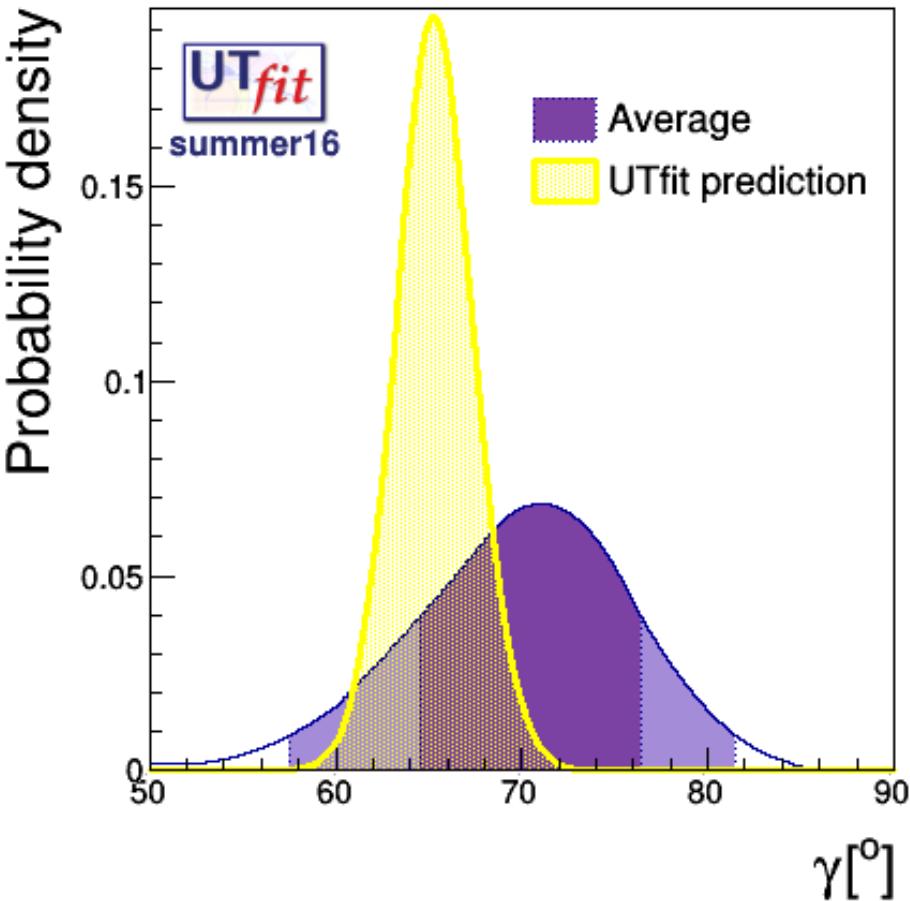
the phase γ is measured exploiting interferences between $b \rightarrow c$ and $b \rightarrow u$ transitions: two amplitudes leading to the same final states some rates can be really small:
 $\sim 10^{-7}$

need to combine all the possible modes and analysis methods.

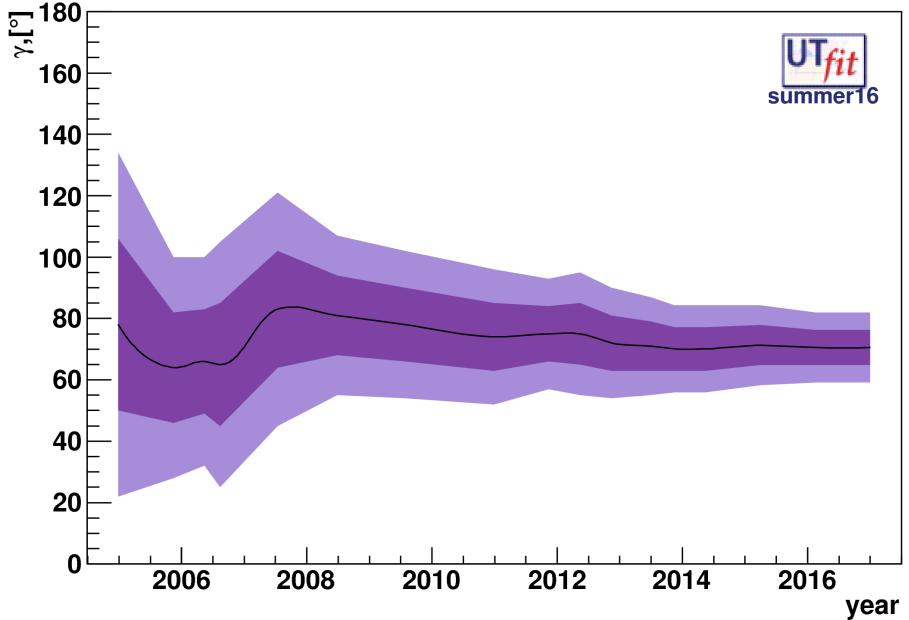
Updated for ICHEP16

combined: $(70.5 \pm 5.7)^\circ$

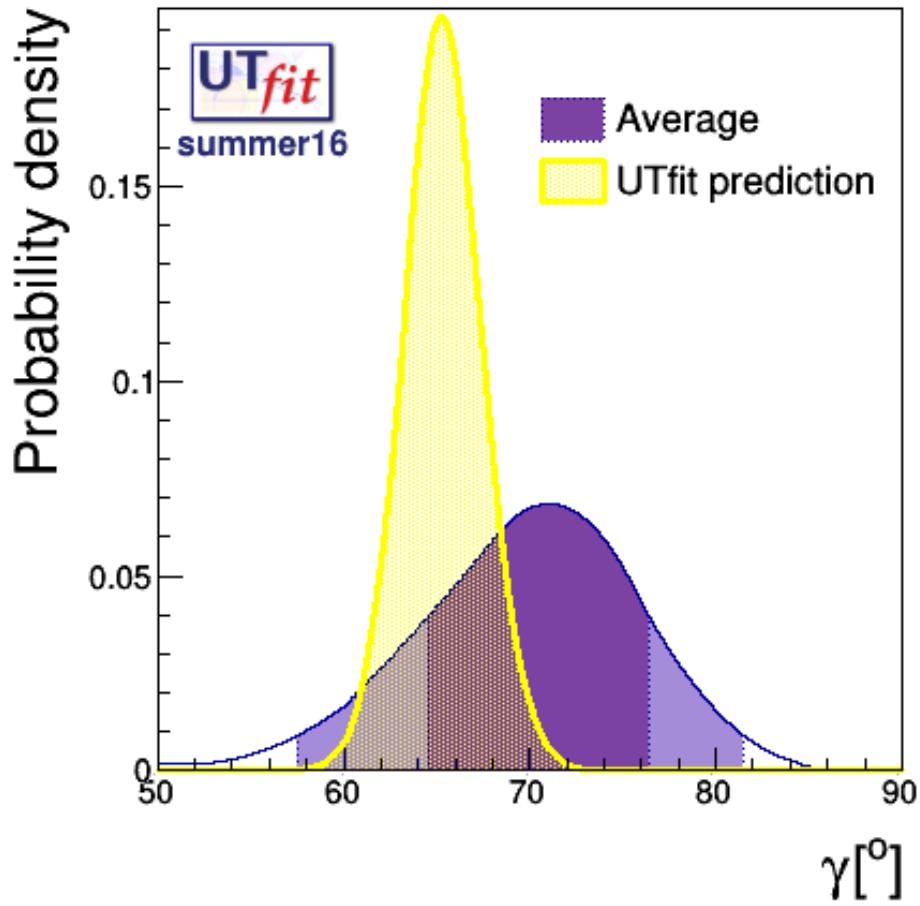
UTfit prediction: $(65.4 \pm 2.1)^\circ$



γ and DK trees



After a decade of analyses and almost 50 papers published, the world average uncertainty has decreased by a factor 3



combined: $(70.5 \pm 5.7)^\circ$

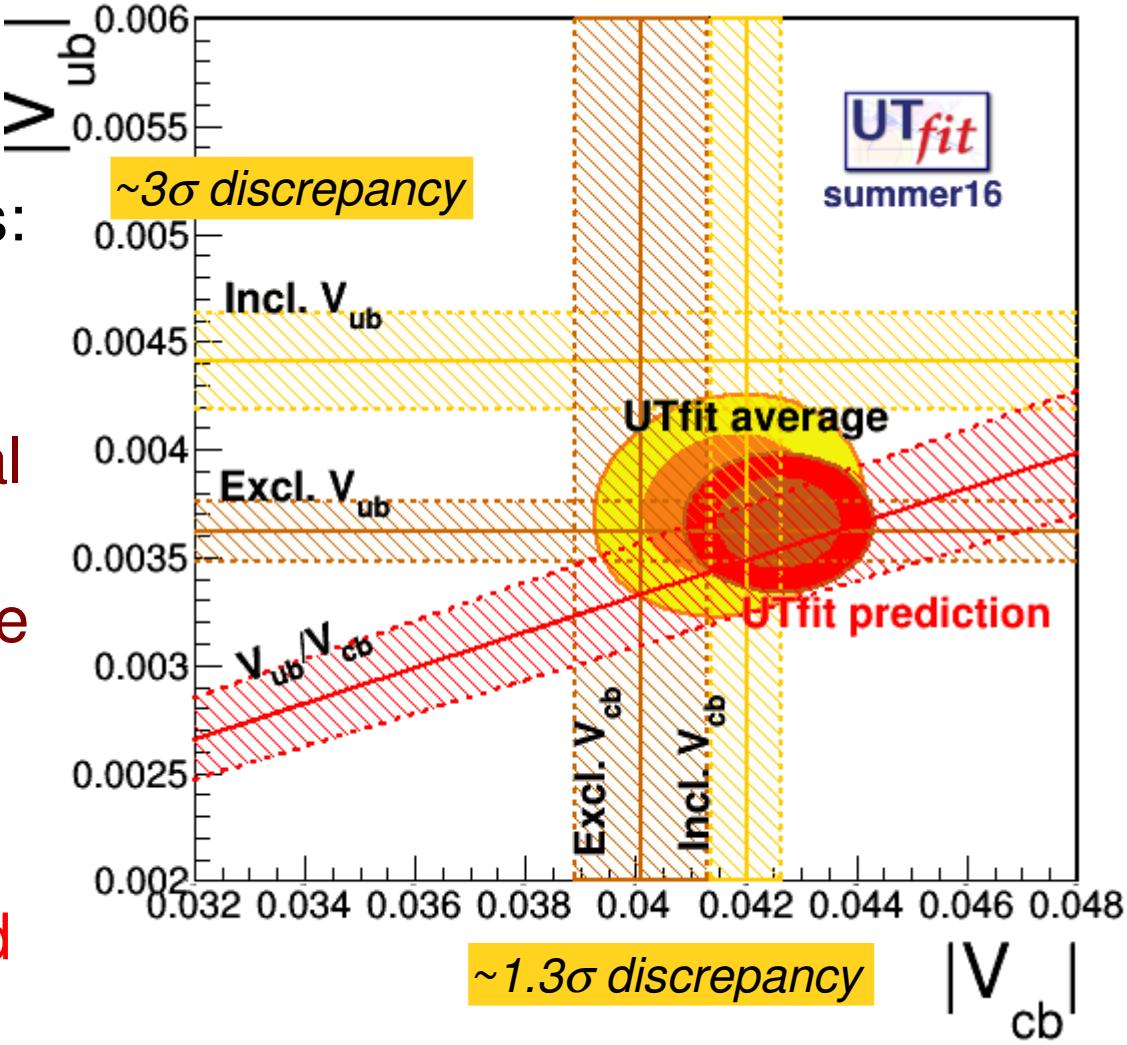
UTfit prediction: $(65.4 \pm 2.1)^\circ$

V_{cb} and V_{ub}

From tree level processes:
semileptonic B decays
 $B \rightarrow X_{u,c} l\nu$

Use theory to relate partial branching fractions to V_{cb} for a given region of phase space.

Can study modes exclusively or inclusively:
different experimental and theoretical issues.



V_{cb} and V_{ub}

2D average inspired by D'Agostini skeptical procedure (hep-ex/9910036) with $\sigma=1$. Very similar results obtained from a 2D a la PDG procedure.

$$|V_{cb}| = (41.7 \pm 1.0) 10^{-3}$$

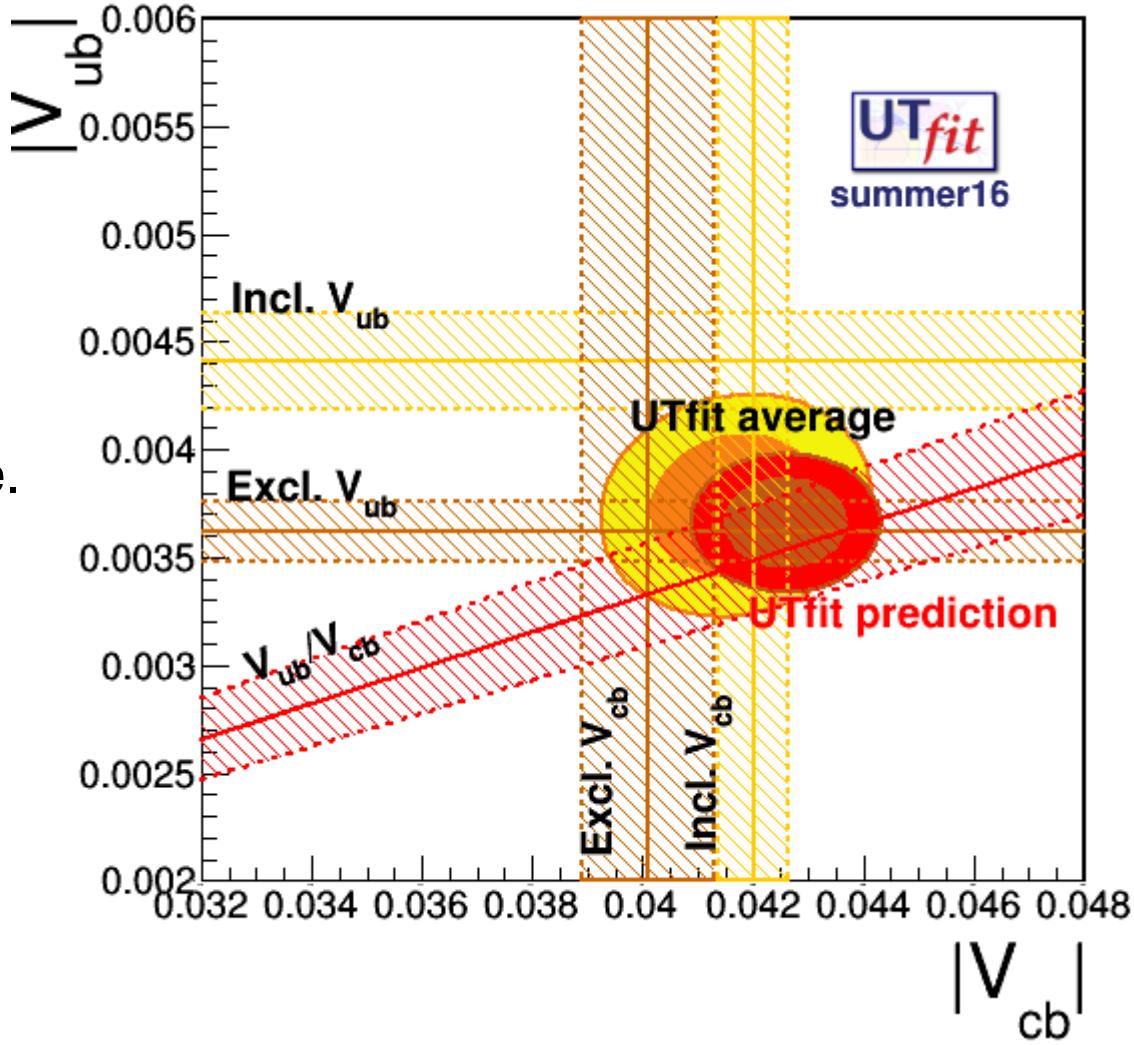
uncertainty $\sim 2.4\%$

$$|V_{ub}| = (3.74 \pm 0.21) 10^{-3}$$

uncertainty $\sim 5.6\%$

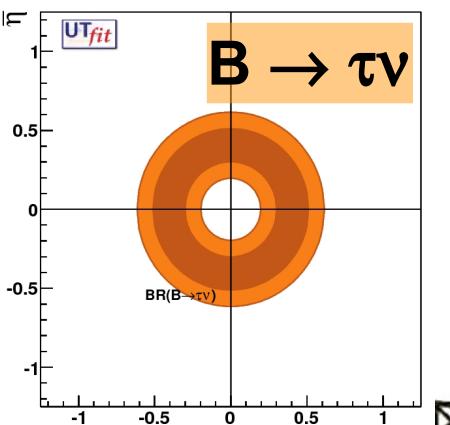
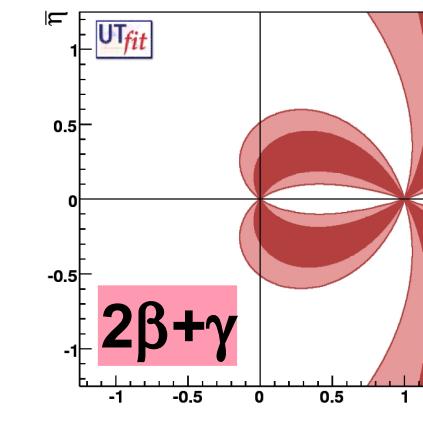
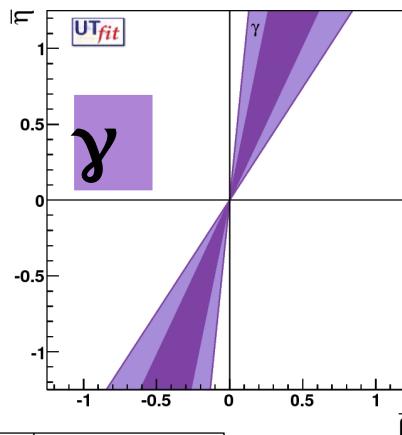
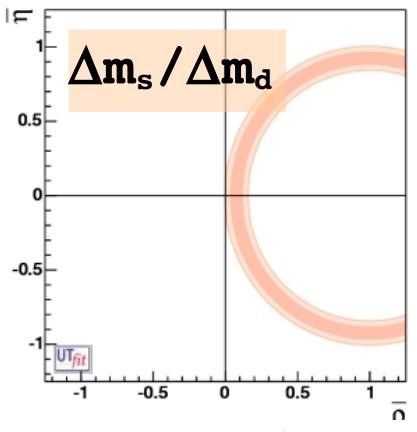
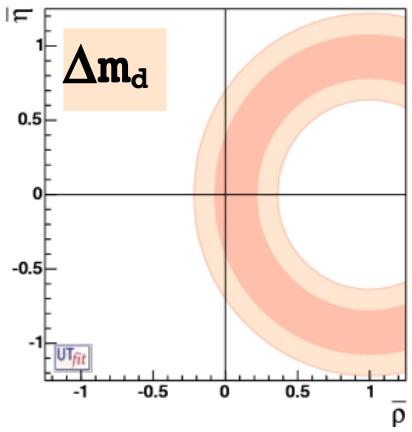
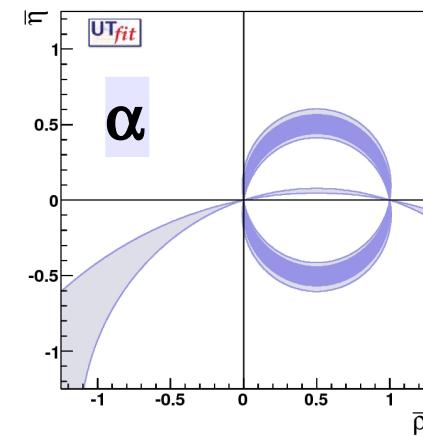
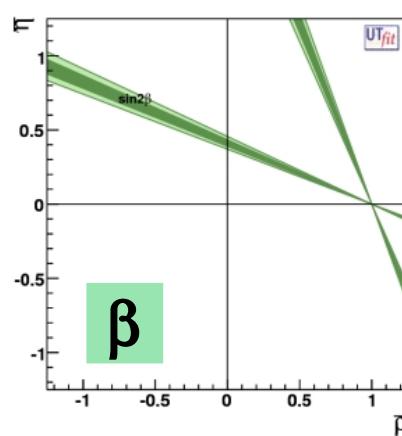
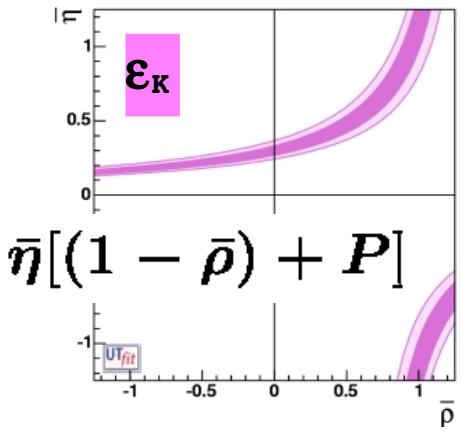
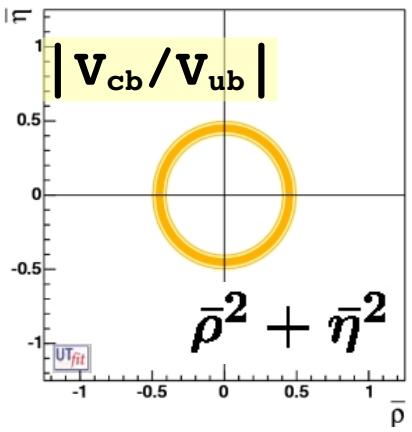
Updated
for ICHEP16

$$\begin{aligned} |V_{cb}| &= (42.6 \pm 0.7) 10^{-3} \\ |V_{ub}| &= (3.66 \pm 0.13) 10^{-3} \end{aligned}$$

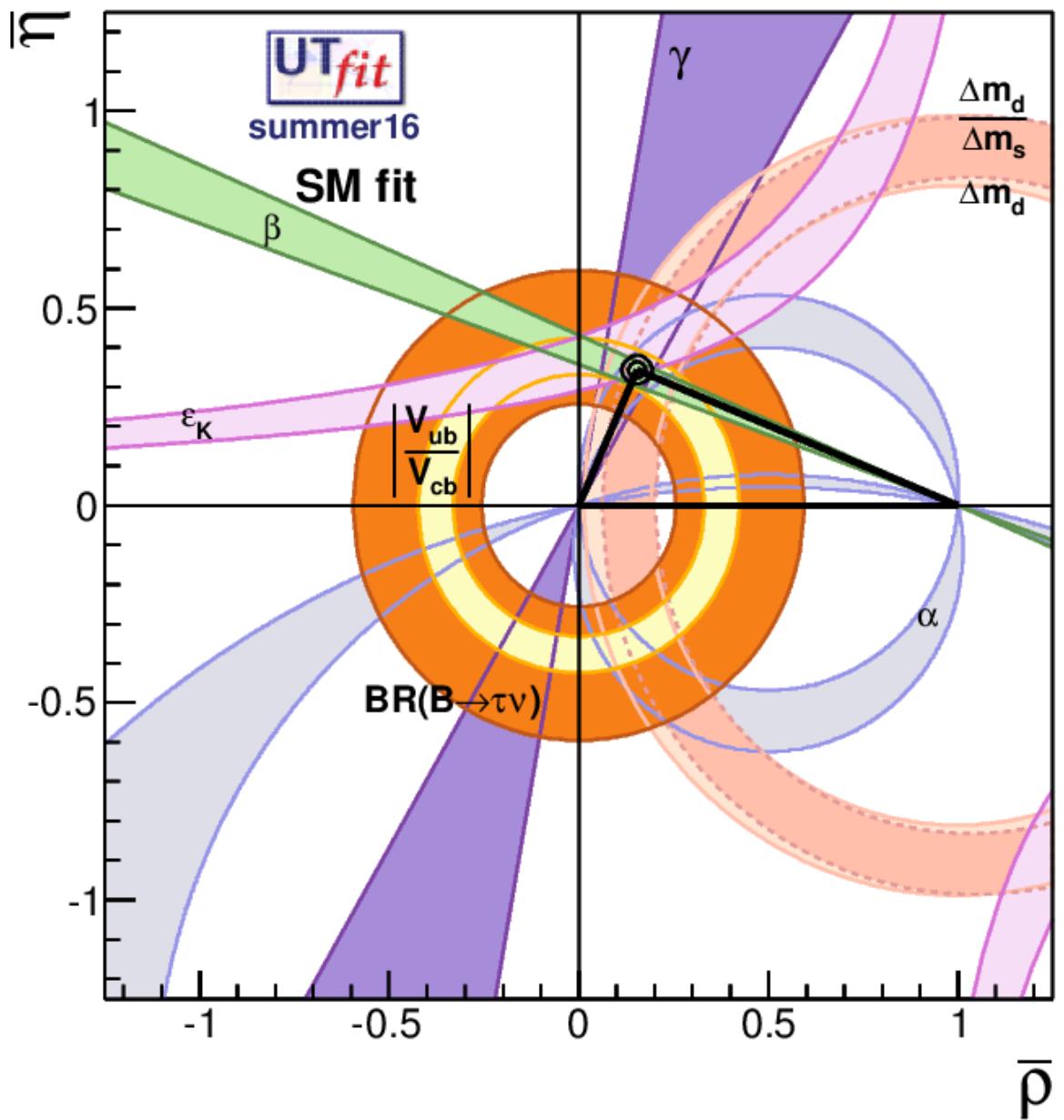


UTfit predictions

Unitarity Triangle analysis in the SM:



Unitarity Triangle analysis in the SM:



levels @
95% Prob

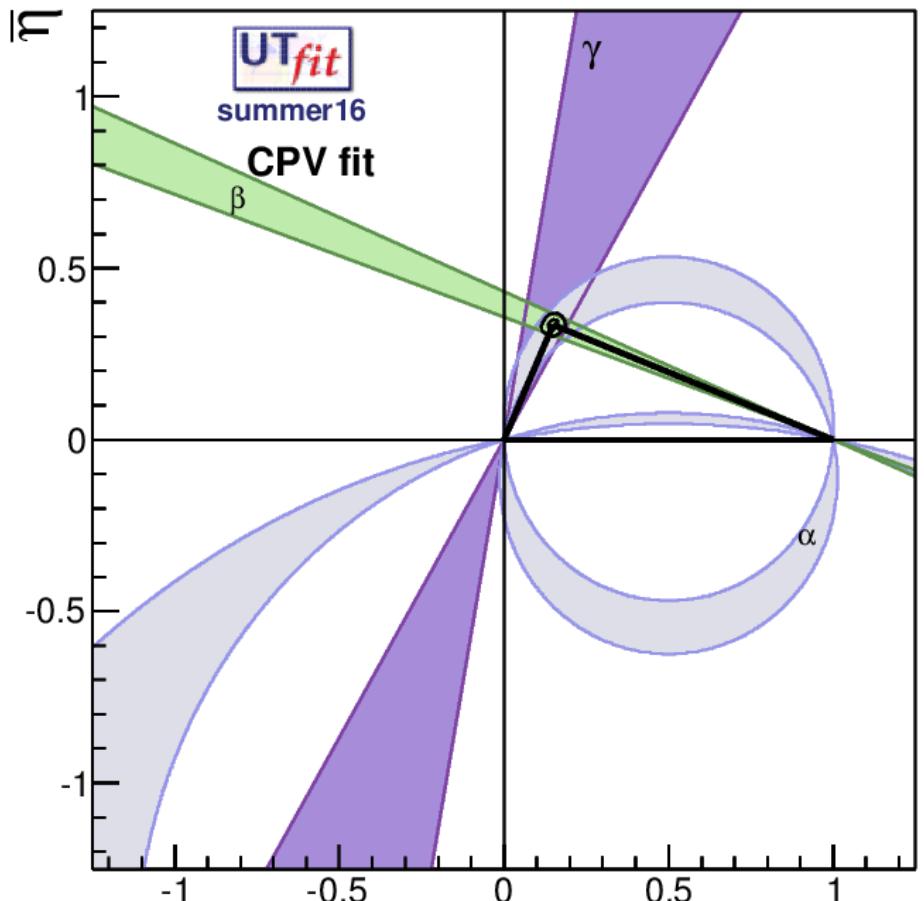
~10 %

$$\begin{aligned}\bar{\rho} &= 0.154 \pm 0.015 \\ \bar{\eta} &= 0.344 \pm 0.013\end{aligned}$$

~4%

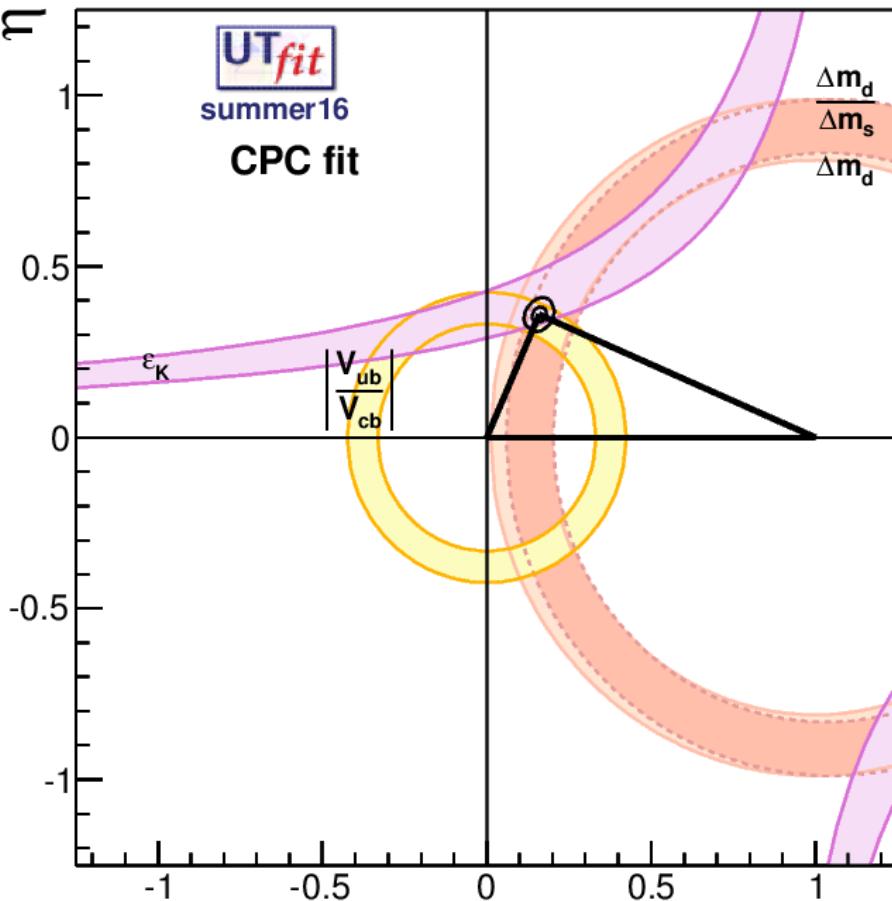
Angles vs sides+ ε_K

levels @
95% Prob



$$\bar{\rho} = 0.147 \pm 0.022$$

$$\bar{\eta} = 0.333 \pm 0.016$$



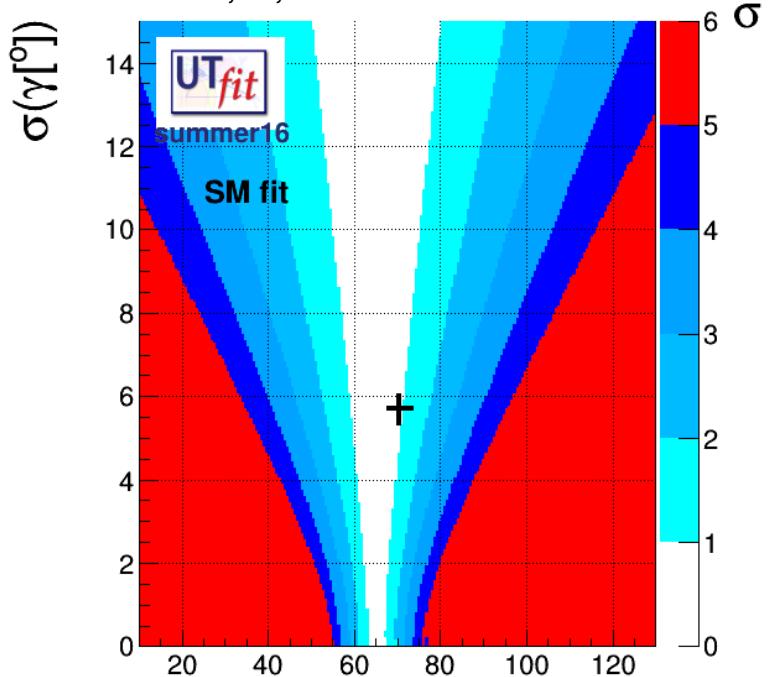
$$\bar{\rho} = 0.160 \pm 0.018$$

$$\bar{\eta} = 0.359 \pm 0.021$$

compatibility plots

A way to “measure” the agreement of a single measurement with the indirect determination from the fit using all the other inputs: test for the SM description of the flavour physics

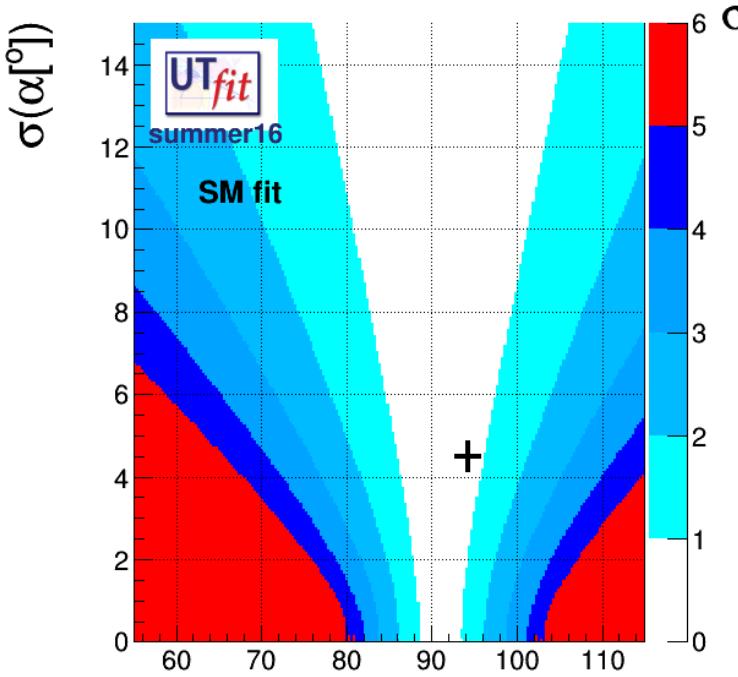
Color code: agreement between the predicted values and the measurements at better than 1, 2, ... $n\sigma$



$$\gamma_{\text{exp}} = (70.5 \pm 5.7)^\circ \quad \gamma^\circ$$

$$\gamma_{\text{UTfit}} = (65.4 \pm 2.1)^\circ$$

The cross has the coordinates $(x,y)=(\text{central value}, \text{error})$ of the direct measurement

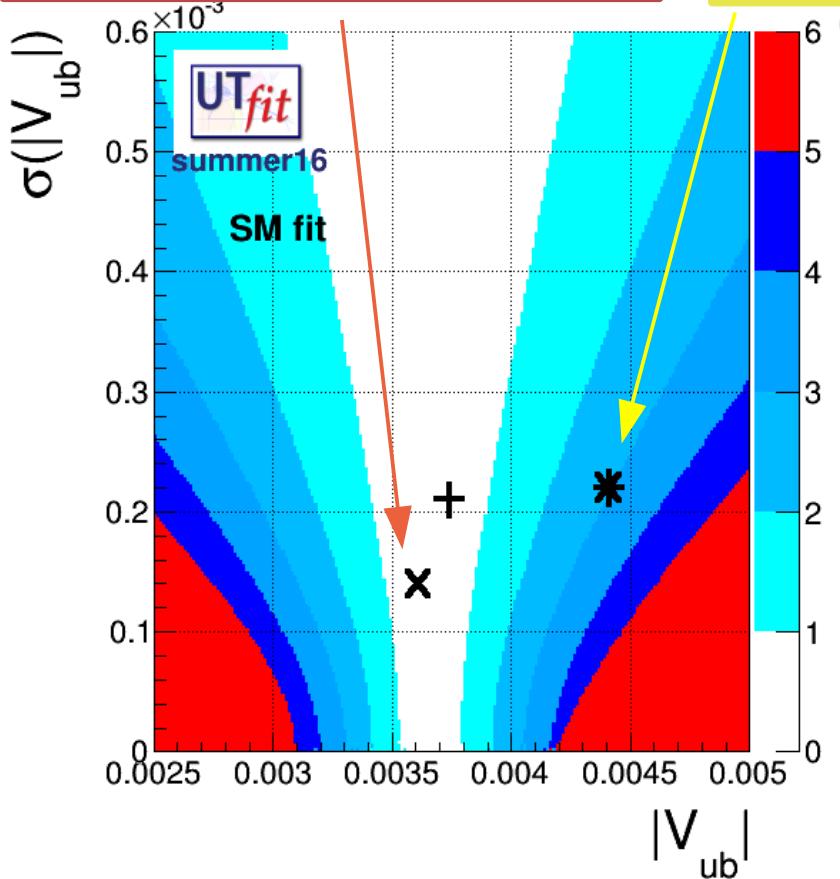


$$\alpha_{\text{exp}} = (94.2 \pm 4.5)^\circ \quad \alpha^\circ$$

$$\alpha_{\text{UTfit}} = (90.9 \pm 2.5)^\circ$$

tensions? not really.. still that V_{ub} inclusive

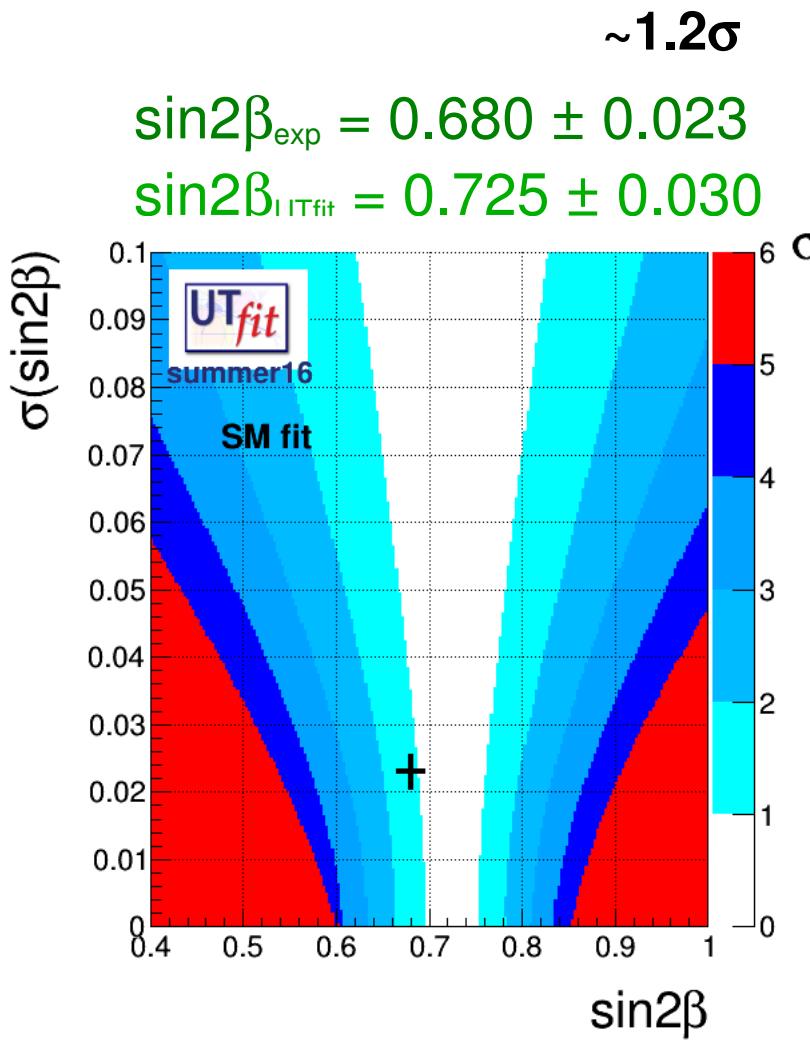
$$V_{ub} \text{ (excl)} = (3.62 \pm 0.14) \cdot 10^{-3}$$



$$V_{ub\text{exp}} = (3.74 \pm 0.21) \cdot 10^{-3}$$

$$V_{ub\text{UTfit}} = (3.66 \pm 0.11) \cdot 10^{-3}$$

$$V_{ub} \text{ (incl)} = (4.41 \pm 0.22) \cdot 10^{-3}$$



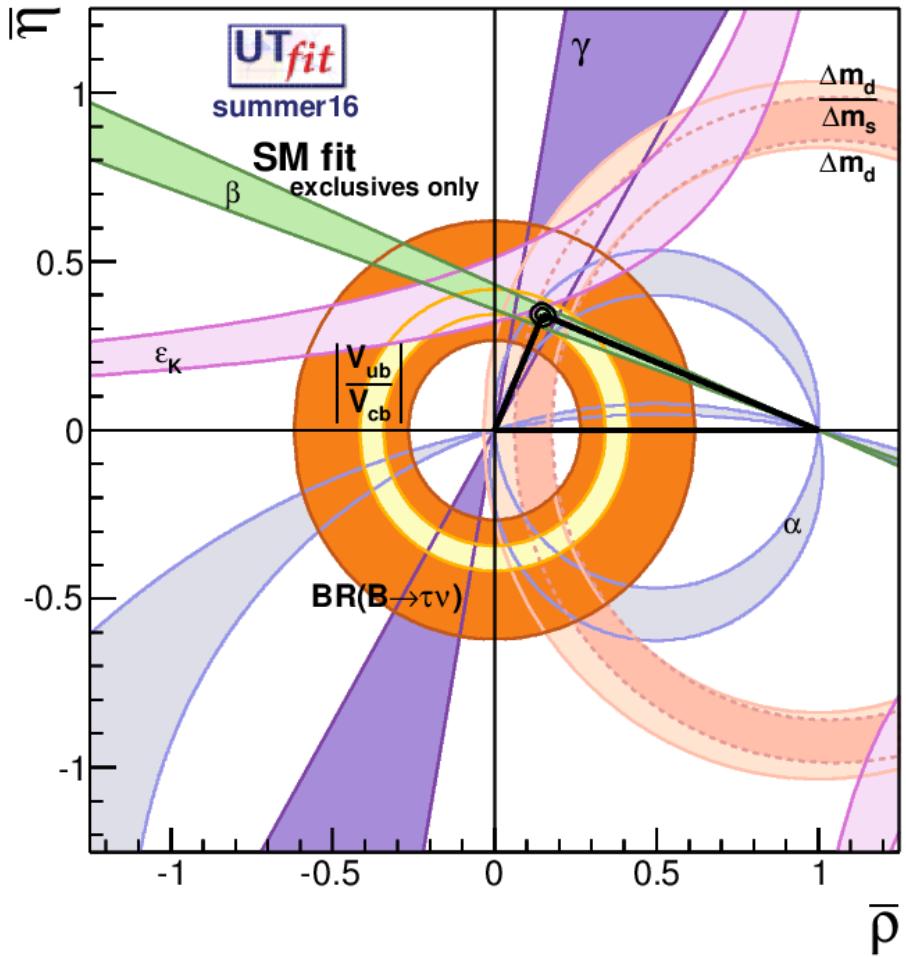
Unitarity Triangle analysis in the SM:

obtained excluding
the given constraint
from the fit

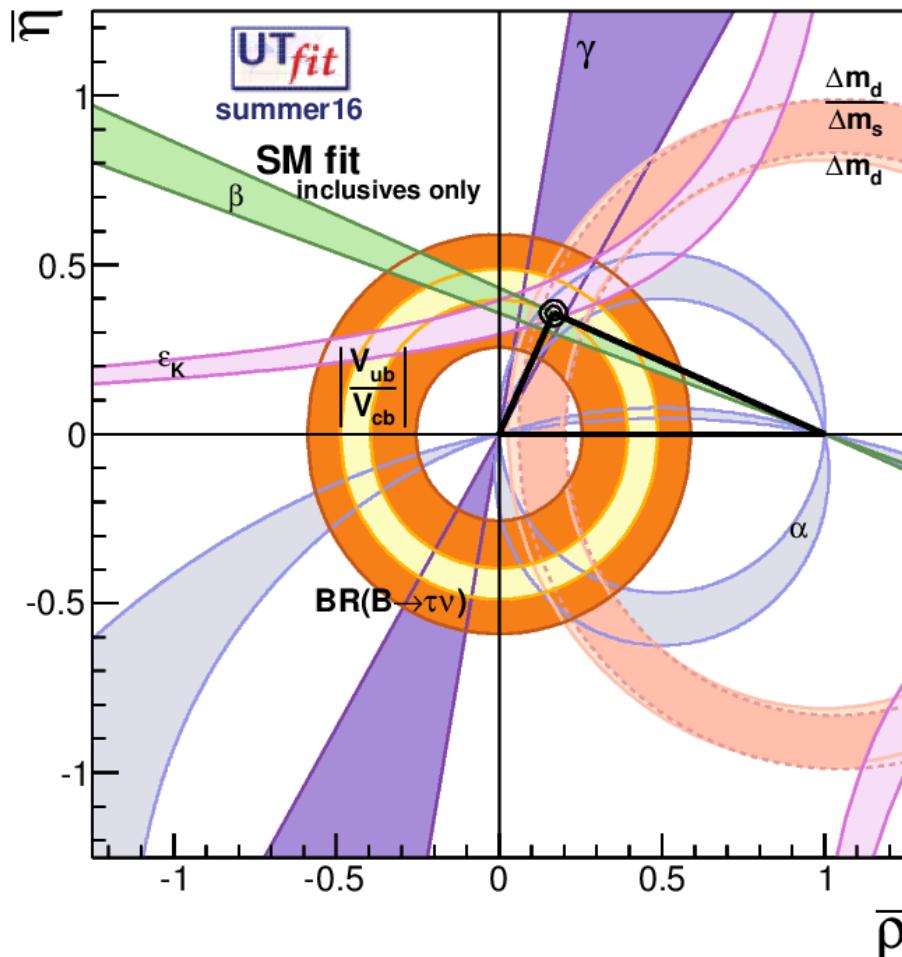
Observables	Measurement	Prediction	Pull (# σ)
$\sin 2\beta$	0.680 ± 0.023	0.725 ± 0.030	~ 1.2
γ	70.5 ± 5.7	65.4 ± 2.1	< 1
α	94.2 ± 4.5	90.9 ± 2.5	< 1
$ V_{ub} \cdot 10^3$	3.74 ± 0.21	3.66 ± 0.11	< 1
$ V_{ub} \cdot 10^3$ (incl)	4.41 ± 0.22	-	~ 2.9 ←
$ V_{ub} \cdot 10^3$ (excl)	3.62 ± 0.14	-	< 1
$ V_{cb} \cdot 10^3$	41.7 ± 1.0	42.6 ± 0.7	< 1
β_s	0.97 ± 0.94	1.05 ± 0.04	< 1
$BR(B \rightarrow \tau\nu)[10^{-4}]$	1.06 ± 0.20	0.81 ± 0.06	~ 1.2
$A_{SL}^d \cdot 10^3$	0.2 ± 2.0	-0.283 ± 0.024	< 1
$A_{SL}^s \cdot 10^3$	1.7 ± 3.0	0.013 ± 0.001	< 1

exclusives vs inclusives

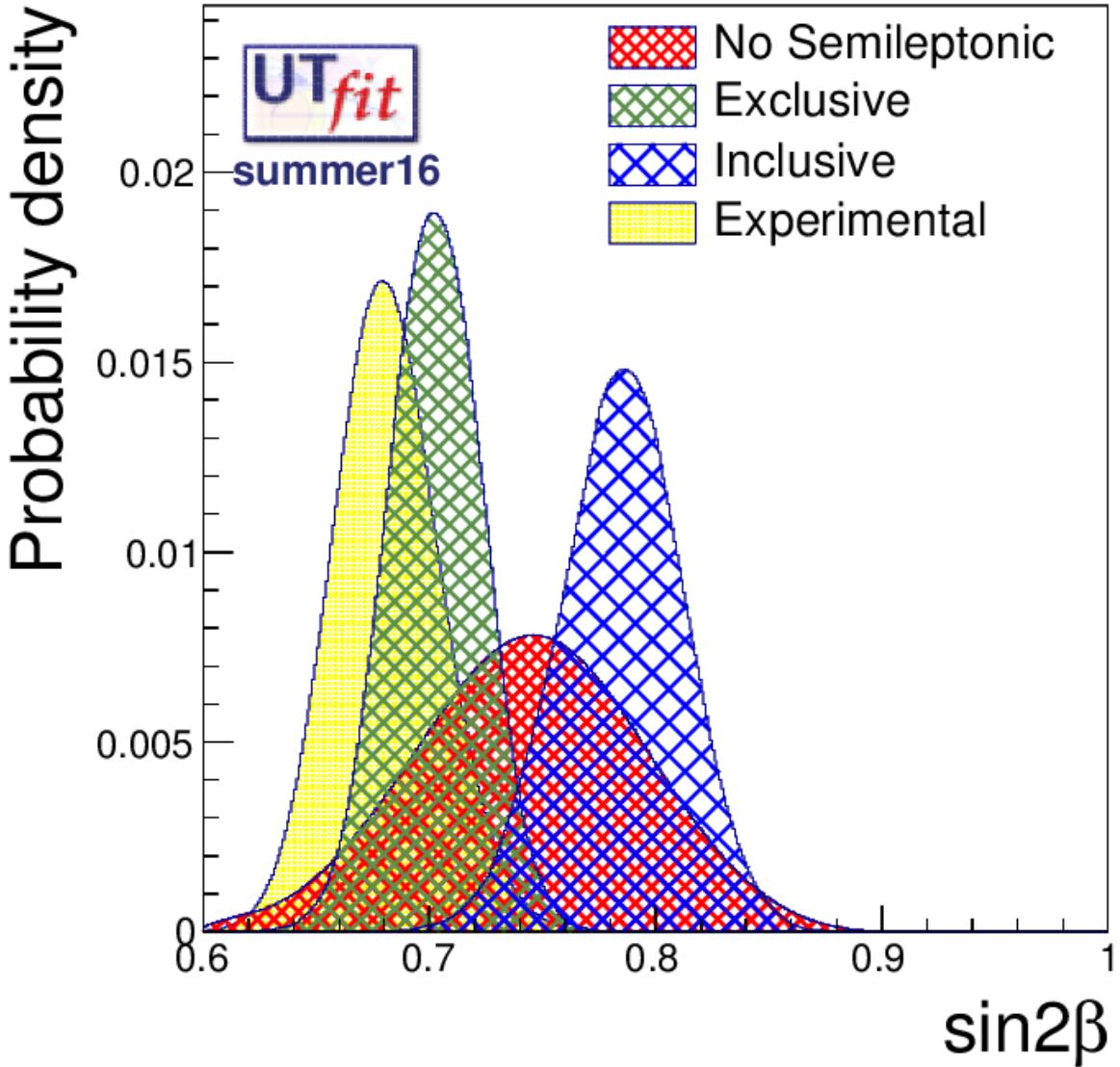
only exclusive values



only inclusive values



exclusives vs inclusives



$$\sin 2\beta_{\text{exp}} = 0.745 \pm 0.050$$

$$\sin 2\beta_{\text{exp}} = 0.703 \pm 0.021$$

$$\sin 2\beta_{\text{exp}} = 0.784 \pm 0.027$$

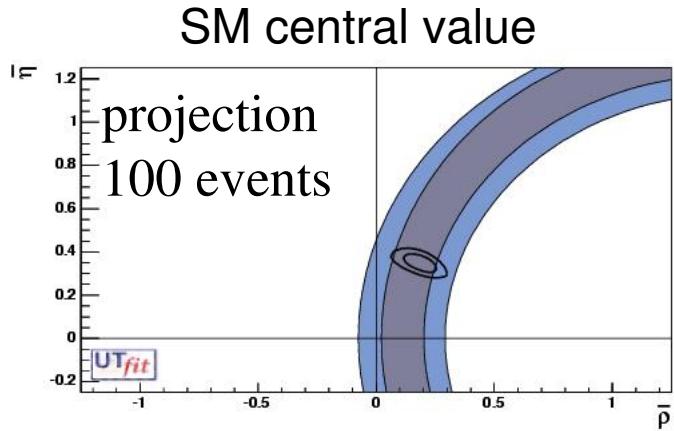
$$\sin 2\beta_{\text{exp}} = 0.680 \pm 0.023$$

$$\sin 2\beta_{\text{UTfit}} = 0.725 \pm 0.030$$

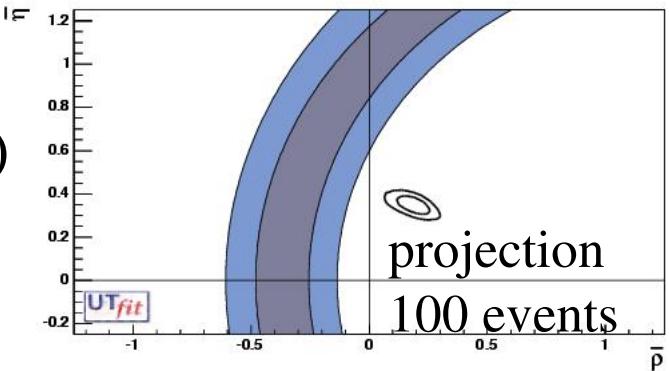
some old plots coming back to fashion:

As NA62 and KOTO are approaching
data taking:

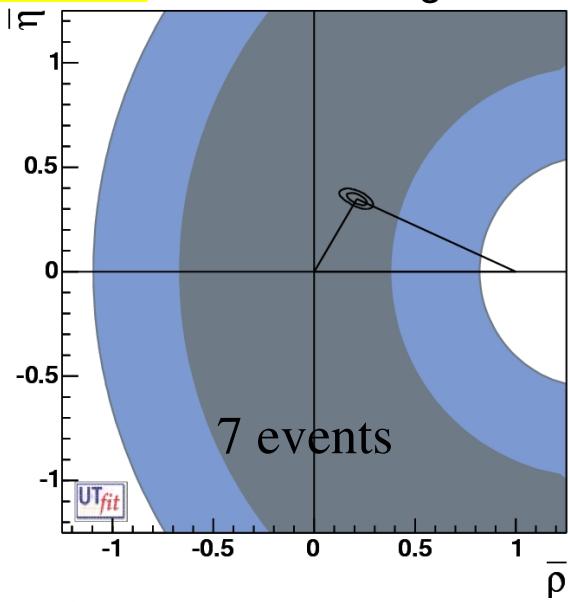
$\text{BR}(K^+ \rightarrow \pi^+ \bar{v}v)$



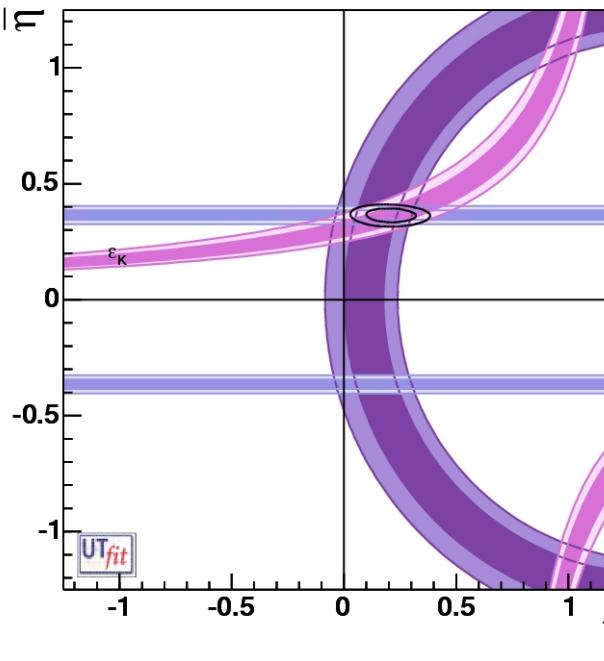
E949 central value



2007 global fit area



including
 $\text{BR}(K^0 \rightarrow \pi^0 \bar{v}v)$
SM central value



UT analysis including new physics

fit simultaneously for the CKM and the NP parameters (generalized UT fit)

- ▶ add most general loop NP to all sectors
- ▶ use all available experimental info
- ▶ find out NP contributions to $\Delta F=2$ transitions

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

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

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

$$A_{CP}^{B_d \rightarrow J/\psi K_s} = \sin 2(\beta + \varphi_{B_d})$$

$$A_{SL}^q = \text{Im} \left(\Gamma_{12}^q / A_q \right)$$

$$\varepsilon_K = C_\varepsilon \varepsilon_K^{SM}$$

$$A_{CP}^{B_s \rightarrow J/\psi \varphi} \sim \sin 2(-\beta_s + \varphi_{B_s})$$

$$\Delta \Gamma^q / \Delta m_q = \text{Re} \left(\Gamma_{12}^q / A_q \right)$$

new-physics-specific constraints

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

semileptonic asymmetries in B^0 and B_s : sensitive to NP effects in both size and phase. From 2D average done by HFAG for A_{SL}^s and A_{SL}^d 1.5 σ discrepancy in B_s wrt the SM prediction..

BaBar, Belle,
CDF + D0 + LHCb

same-side dilepton charge asymmetry:

admixture of B_s and B_d so sensitive to NP effects in both.

$$A_{\text{SL}}^{\mu\mu} \times 10^3 = -7.9 \pm 2.0$$

D0 arXiv:1106.6308

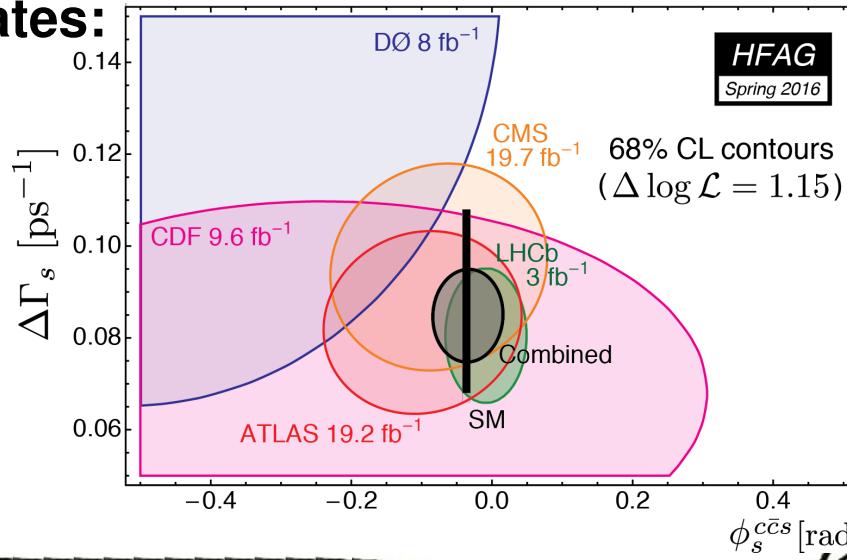
$$A_{\text{SL}}^{\mu\mu} = \frac{f_d \chi_{d0} A_{\text{SL}}^d + f_s \chi_{s0} A_{\text{SL}}^s}{f_d \chi_{d0} + f_s \chi_{s0}}$$

lifetime τ^{FS} in flavour-specific final states:

average lifetime is a function to the width and the width difference

$$\tau^{\text{FS}}(B_s) = 1.511 \pm 0.014 \text{ ps}$$

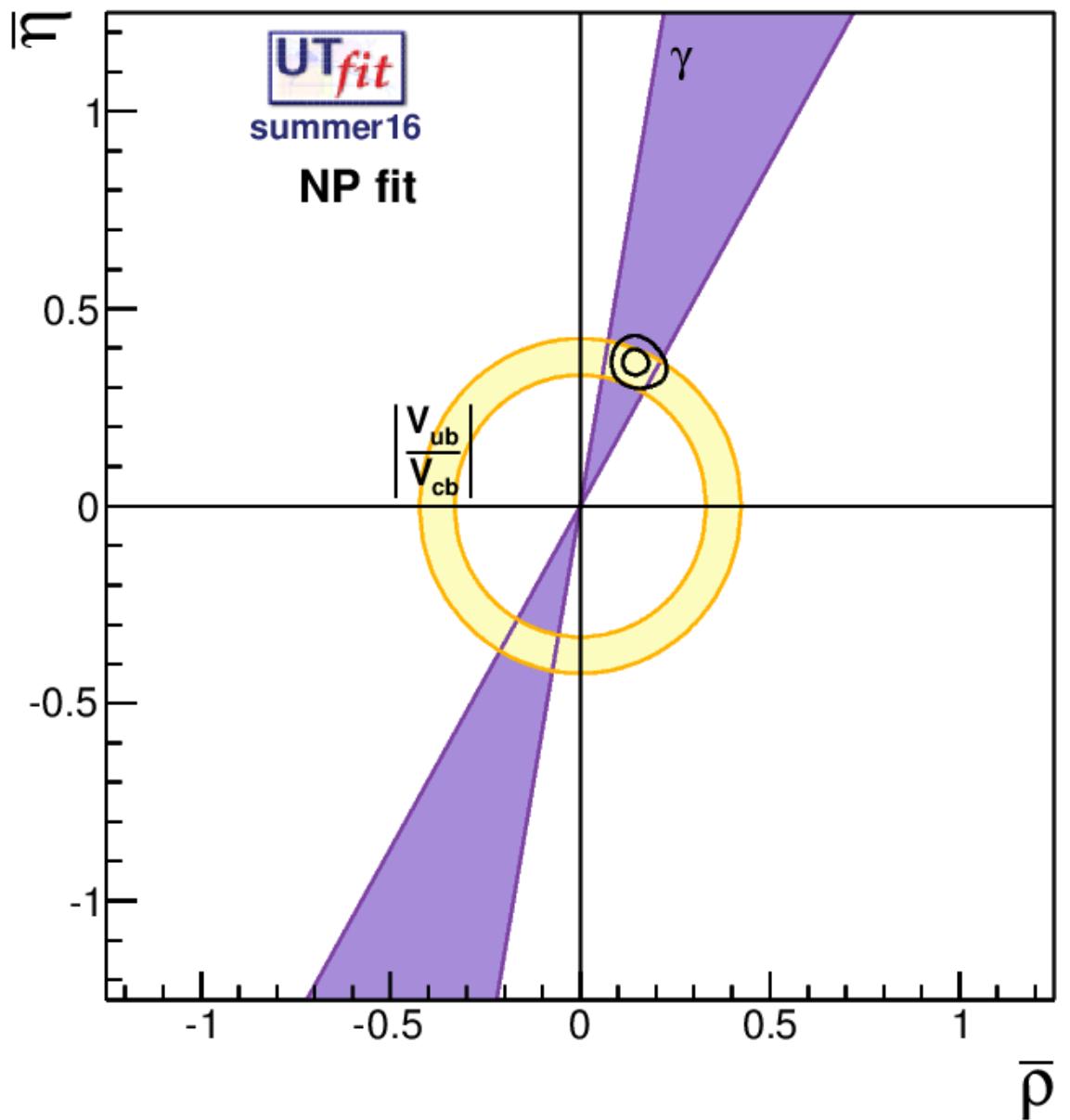
HFAG



$\phi_s = 2\beta_s$ vs $\Delta\Gamma_s$ from $B_s \rightarrow J/\psi \phi$

angular analysis as a function of proper time and b-tagging

NP analysis results

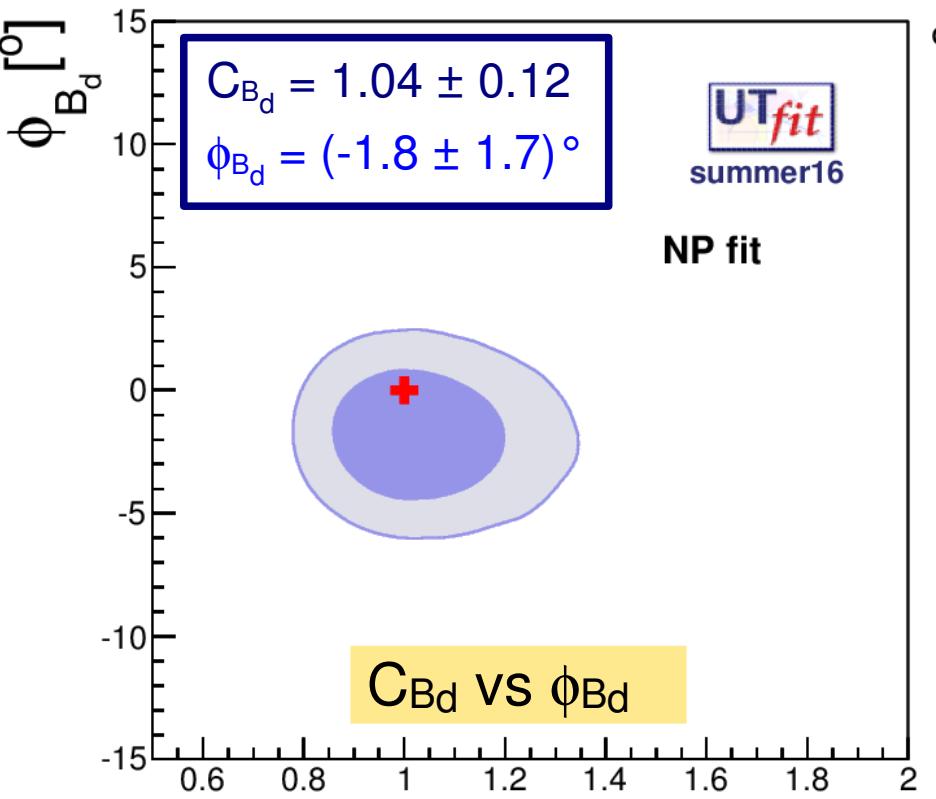


$$\bar{\rho} = 0.150 \pm 0.027$$
$$\bar{\eta} = 0.363 \pm 0.025$$

SM is

$$\bar{\rho} = 0.154 \pm 0.015$$
$$\bar{\eta} = 0.344 \pm 0.013$$

NP parameter results

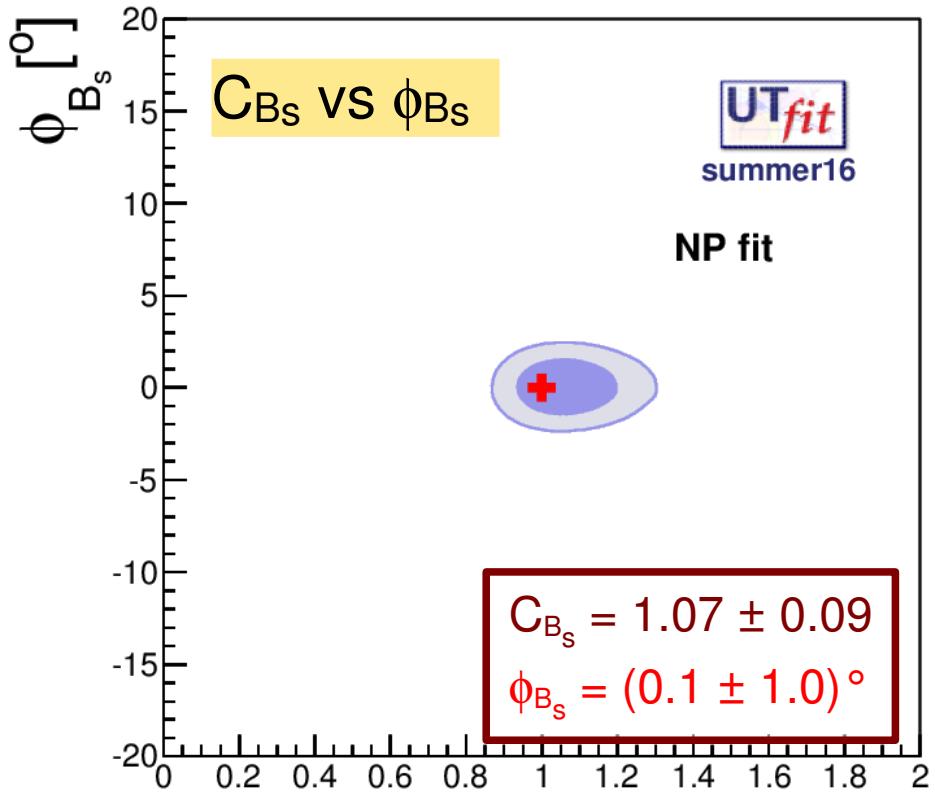


dark: 68%
light: 95%
SM: red cross

$$A_q = C_{B_q} e^{2i\varphi_{B_q}} A_q^{SM} e^{2i\varphi_q^{SM}}$$

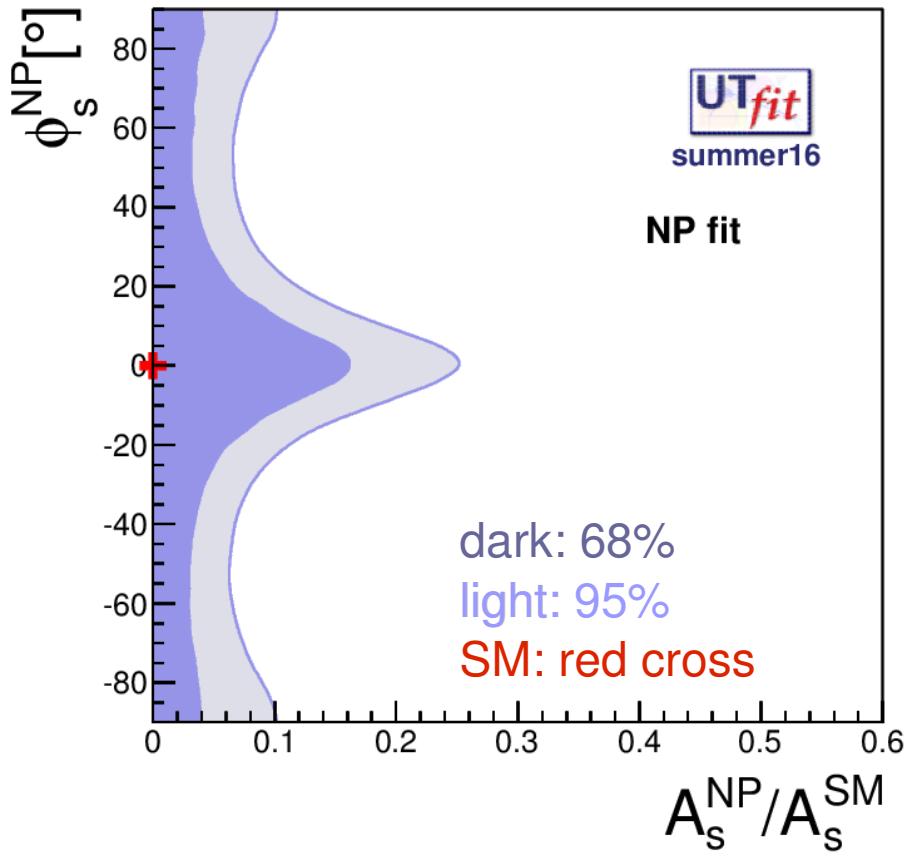
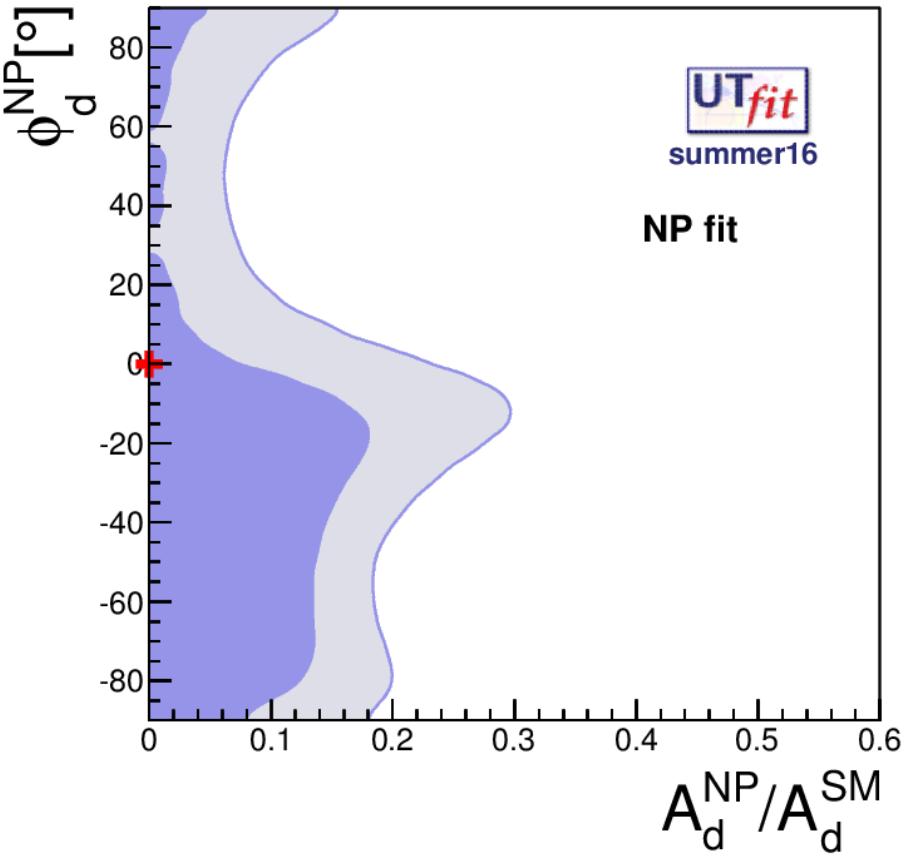
K system

$$C_{\epsilon_K} = 1.05 \pm 0.11$$



NP parameter results

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



The ratio of NP/SM amplitudes is:

< 15% @68% prob. (30% @95%) in B_d mixing

< 15% @68% prob. (25% @95%) in B_s mixing

see also Lunghi & Soni, Buras et al., Ligeti et al.

testing the new-physics scale

R
G
E

At the high scale

new physics enters according to its specific features

At the low scale

use OPE to write the most general effective Hamiltonian.
the operators have different chiralities than the SM

NP effects are in the Wilson Coefficients C

NP effects are enhanced

- up to a factor 10 by the values of the matrix elements especially for transitions among quarks of different chiralities
- up to a factor 8 by RGE

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

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

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

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

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

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

M. Bona *et al.* (UTfit)
JHEP 0803:049,2008
arXiv:0707.0636

effective BSM Hamiltonian for $\Delta F=2$ transitions

The Wilson coefficients C_i have in general the form

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

Putting bounds on the Wilson coefficients give insights into the NP scale in different NP scenarios that enter through F_i and L_i

F_i: 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 $\Delta F=2$ transitions)

testing the TeV scale

The dependence of C on Λ changes depending on the 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
- **MFV:** $C(\Lambda) = \alpha \times |F_{SM}|/\Lambda^2$ $F_1 \sim |F_{SM}|$, $F_{i \neq 1} \sim 0$, SM phase

$\alpha (L_i)$ is the coupling among NP and SM

- $\alpha \sim 1$ for strongly coupled NP
- $\alpha \sim \alpha_w (\alpha_s)$ in case of loop coupling through weak (strong) interactions

If no NP effect is seen
lower bound on NP scale Λ
if NP is seen
upper bound on NP scale Λ

F is the flavour coupling and so

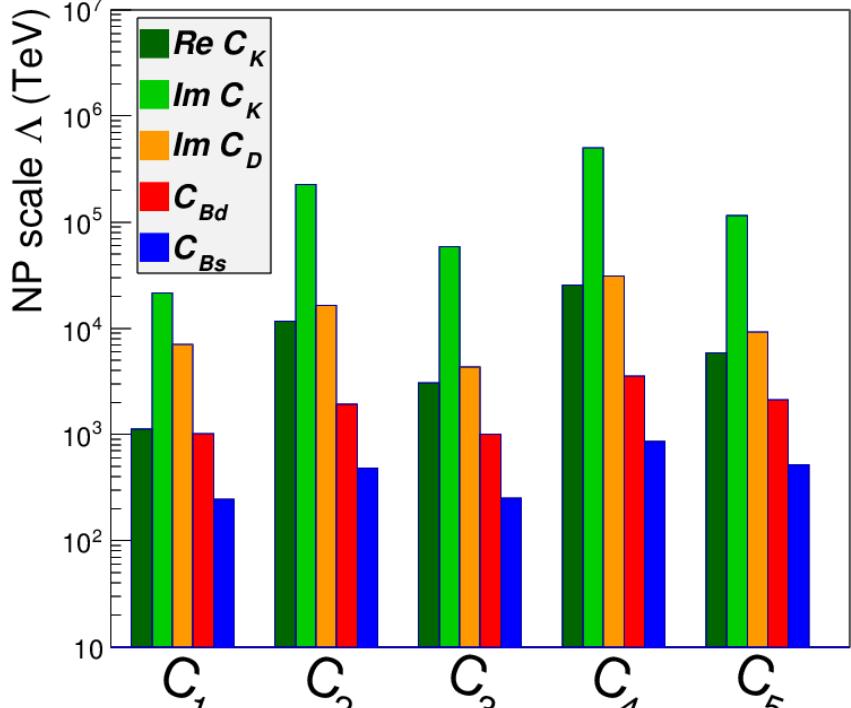
F_{SM} is the combination of CKM factors for the considered process

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

results from the Wilson coefficients

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

$\alpha \sim 1$ for strongly coupled NP



Lower bounds on NP scale
(in TeV at 95% prob.)

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

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

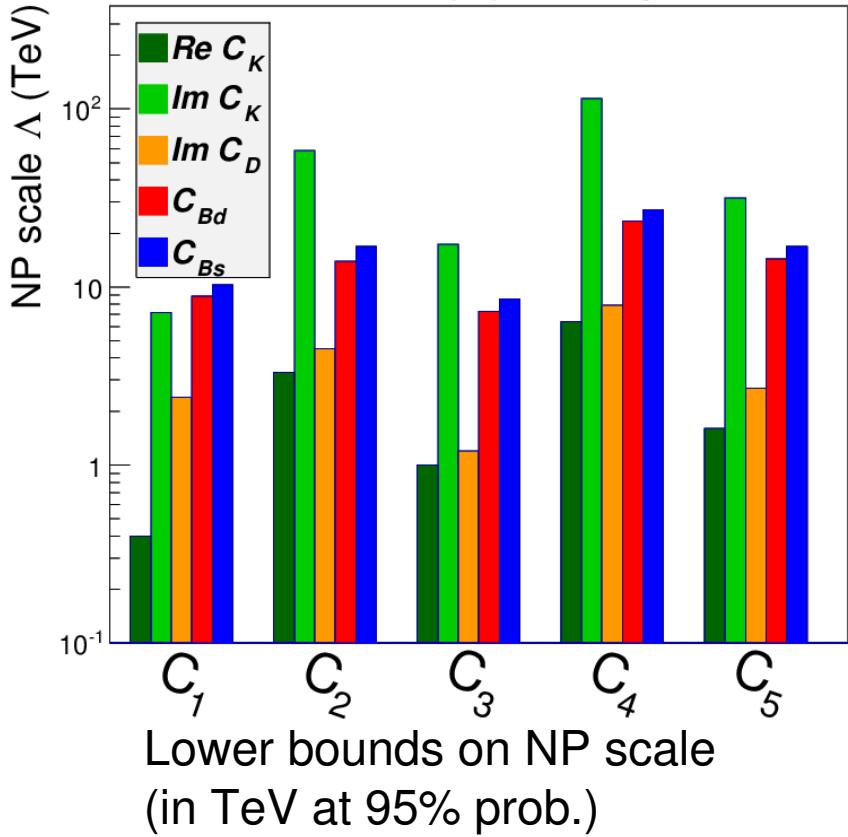
NP in α_w loops
 $\Lambda > 1.5 \times 10^4$ TeV

Best bound from ε_K
dominated by CKM error
CPV in charm mixing follows,
exp error dominant
Best CP conserving from Δm_K ,
dominated by long distance
 B_d and B_s are behind,
errors from CKM and B-pars

results from the Wilson coefficients

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

$\alpha \sim 1$ for strongly coupled NP



Non-perturbative NP
 $\Lambda > 114$ TeV

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 loops
 $\Lambda > 3.4$ TeV

If new chiral structures present,
 ε_K still leading
 $B_{(s)}$ mixing provides very stringent constraints, especially if no new chiral structures are present
Constraining power of the various sectors depends on unknown NP flavour structure.

Look at the future

In the next decade, Belle-II and LHCb upgrade will push down the exp. error on $\sin 2\beta(s)$ to less than 0.01

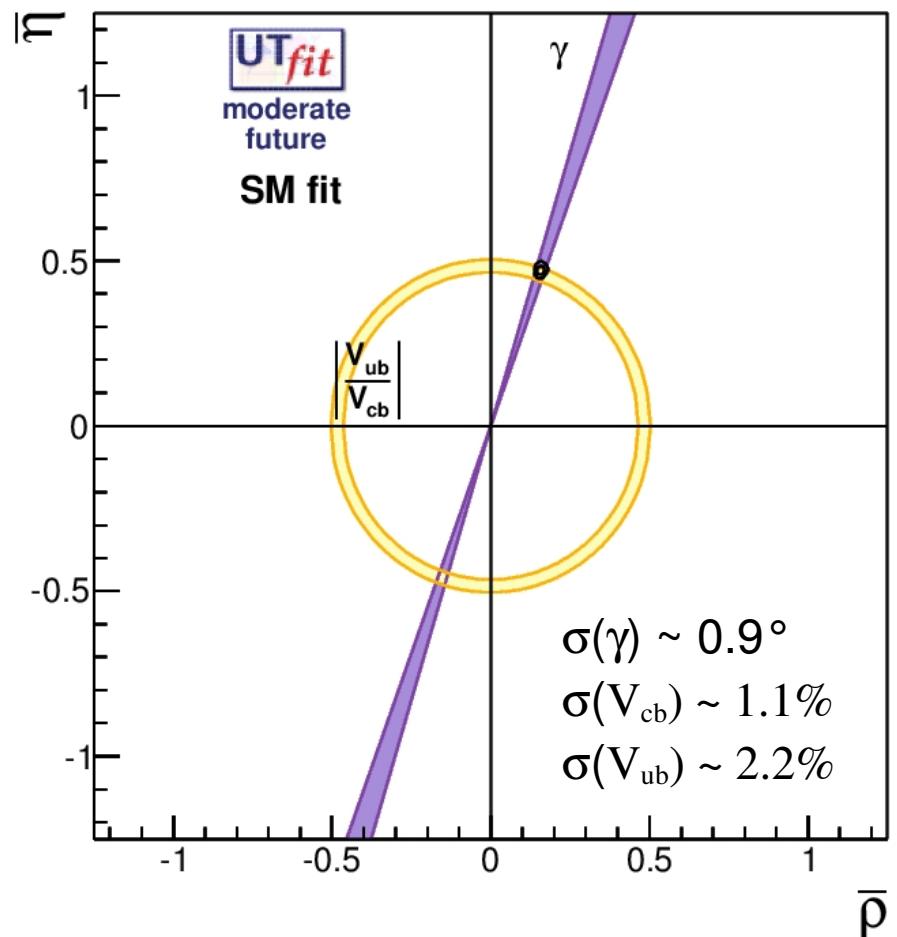
Theory error can be kept below 0.01 using control channels as $S(B \rightarrow J/\psi \pi)$

B-parameters will go below the % level, new ideas to attack long-distance in K and D

Improving γ , α and $|V_{cb}|$ & $|V_{ub}|$ crucial!

[Silvestrini@Pisa]

Look at the future

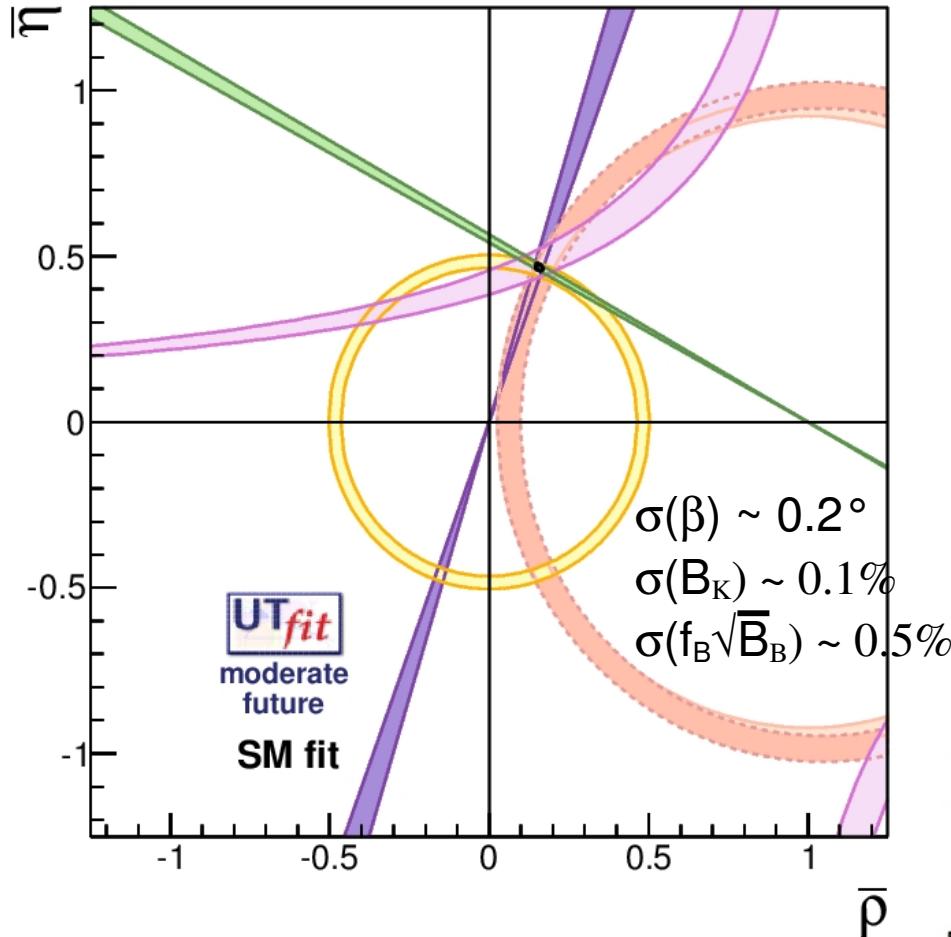


errors from tree-only fit on ρ and η :

$$\sigma(\rho) = 0.008 \text{ [currently 0.050]}$$

$$\sigma(\eta) = 0.010 \text{ [currently 0.035]}$$

errors predicted from
Belle II + LHCb upgrade



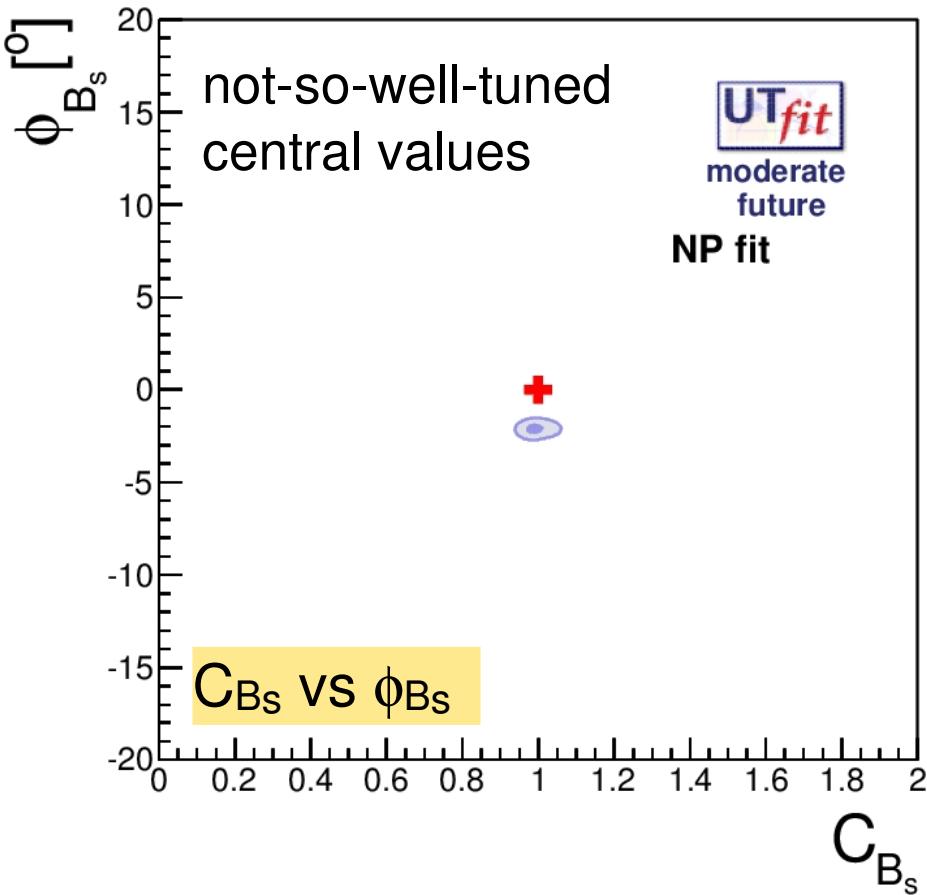
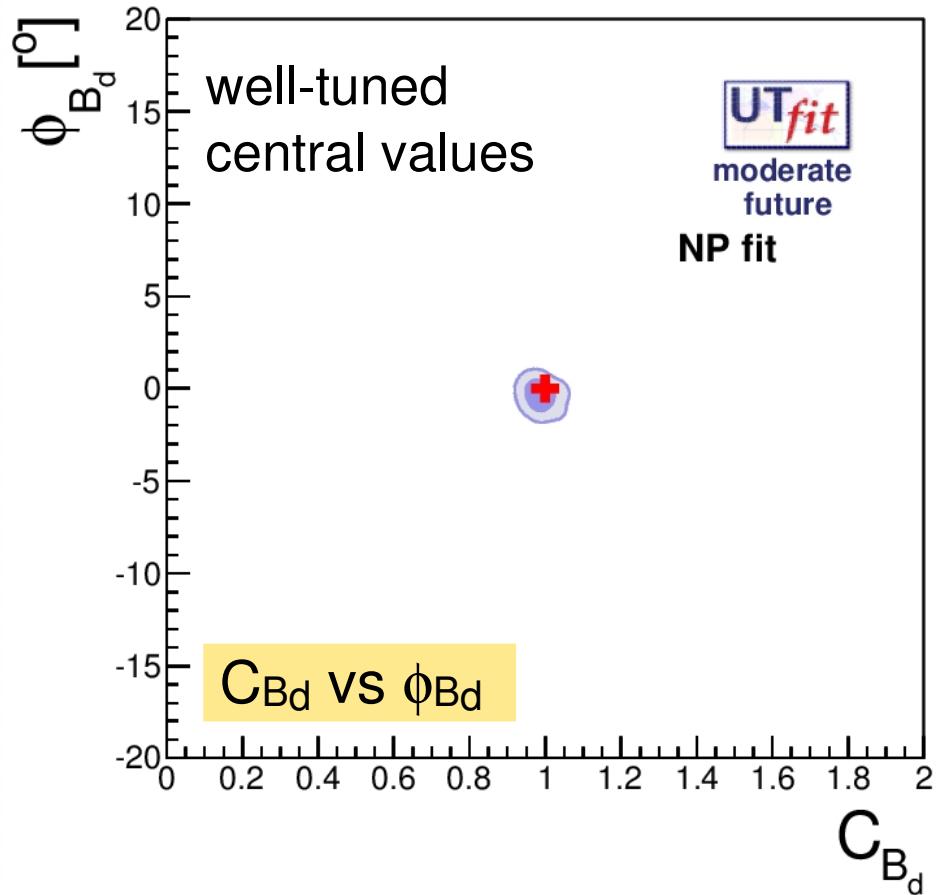
errors from 5-constraint fit on ρ and η :

$$\sigma(\rho) = 0.005 \text{ [currently 0.015]}$$

$$\sigma(\eta) = 0.004 \text{ [currently 0.013]}$$

Look at the future

errors predicted from
Belle II + LHCb upgrade



errors on general NP parameters:

$$\sigma(C_{B_d}) = 0.03 \text{ [currently 0.12]}$$

$$\sigma(\phi_{B_d}) = 0.7 \text{ [currently 1.7]}$$

$$\sigma(C_{B_s}) = 0.03 \text{ [currently 0.09]}$$

$$\sigma(\phi_{B_s}) = 0.3 \text{ [currently 1.0]}$$

conclusions

- ▶ SM analysis displays very good overall consistency
- ▶ Still open discussion on semileptonic inclusive vs exclusive
- ▶ UTA provides determination of NP contributions to $\Delta F=2$ amplitudes. It currently leaves space for NP at the level of 25-30%
- ▶ So the scale analysis points to high scales for the generic scenario and at the limit of LHC reach for weak coupling. Indirect searches are complementary to direct searches.
- ▶ Even if we don't see relevant deviations in the down sector, we might still find them in the up sector.

Back up slides

$\sin 2\alpha (\phi_2)$ from charmless B decays: $\pi\pi$, $\rho\rho$, $\pi\rho$

$\pi^0\pi^0$ from Belle at CKM14

to be updated soon (?)

$$\text{BR}(\pi^0\pi^0) = (1.17 \pm 0.13) 10^{-6}$$

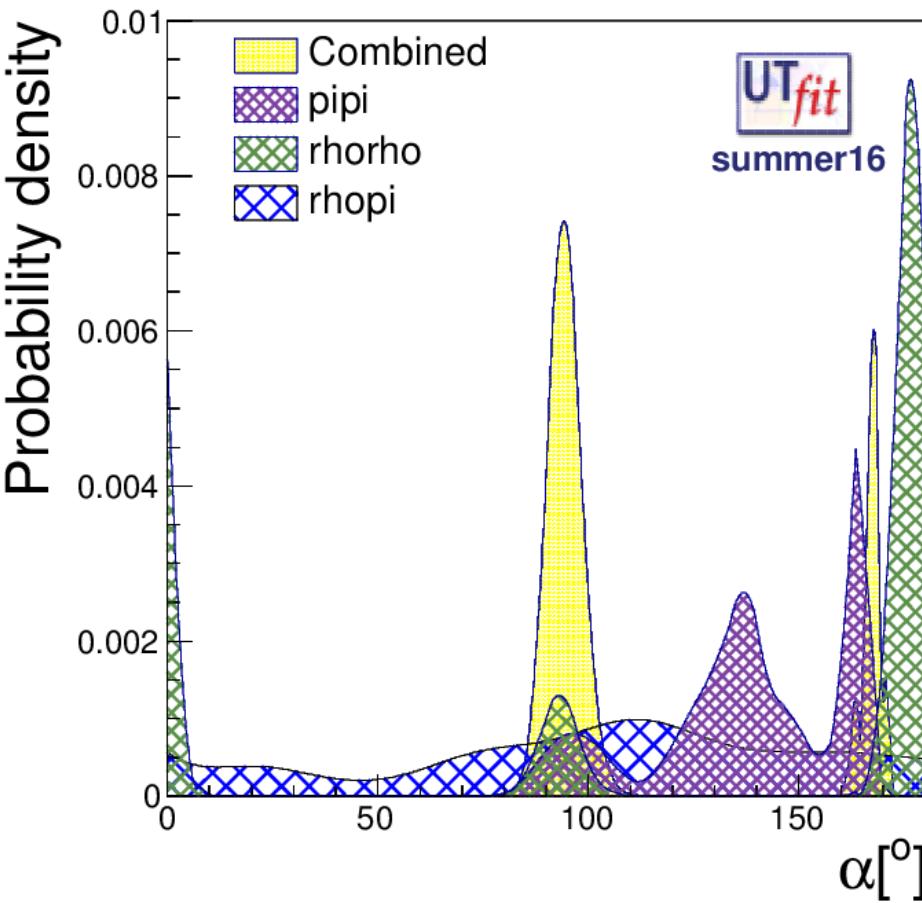
HFAG 2014

a \bar{a} la PDG average would give
an inflated uncertainty of 0.41

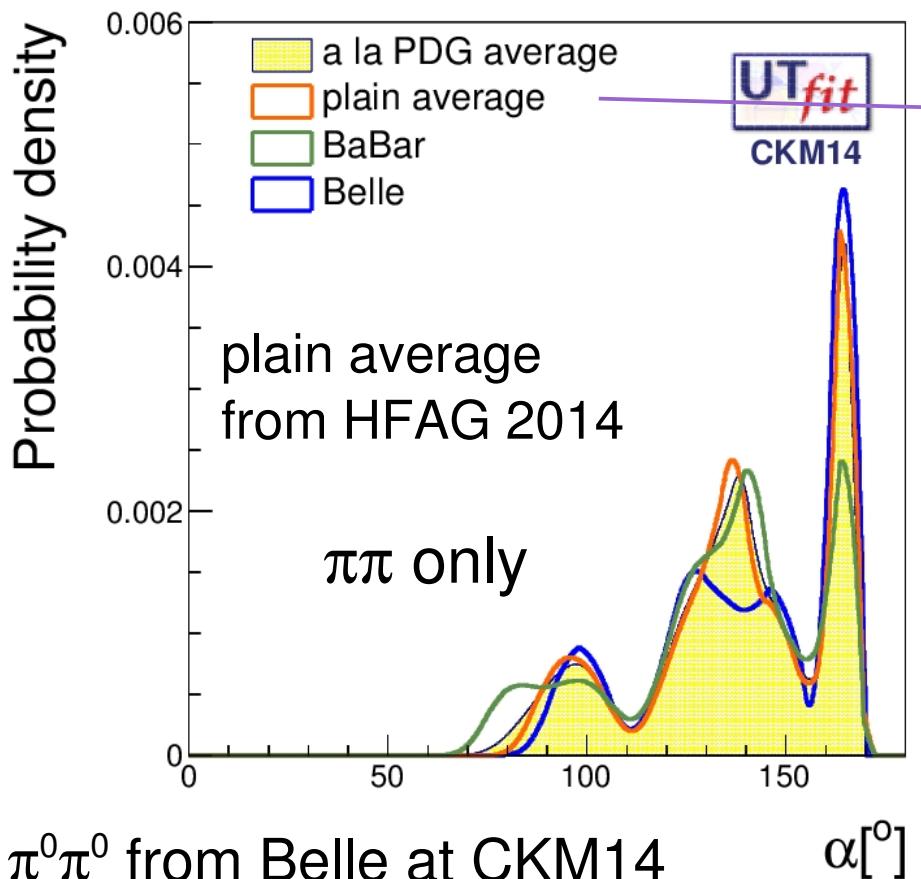
$\rho^+\rho^-$ average updated including
Belle arXiv:1510.01245

$\rho^0\rho^0$ average updated including
LHCb arXiv:1503.07770

α from $\pi\pi$, $\rho\rho$, $\pi\rho$ decays:
combined: $(94.2 \pm 4.5)^\circ$
UTfit prediction: $(90.9 \pm 2.5)^\circ$



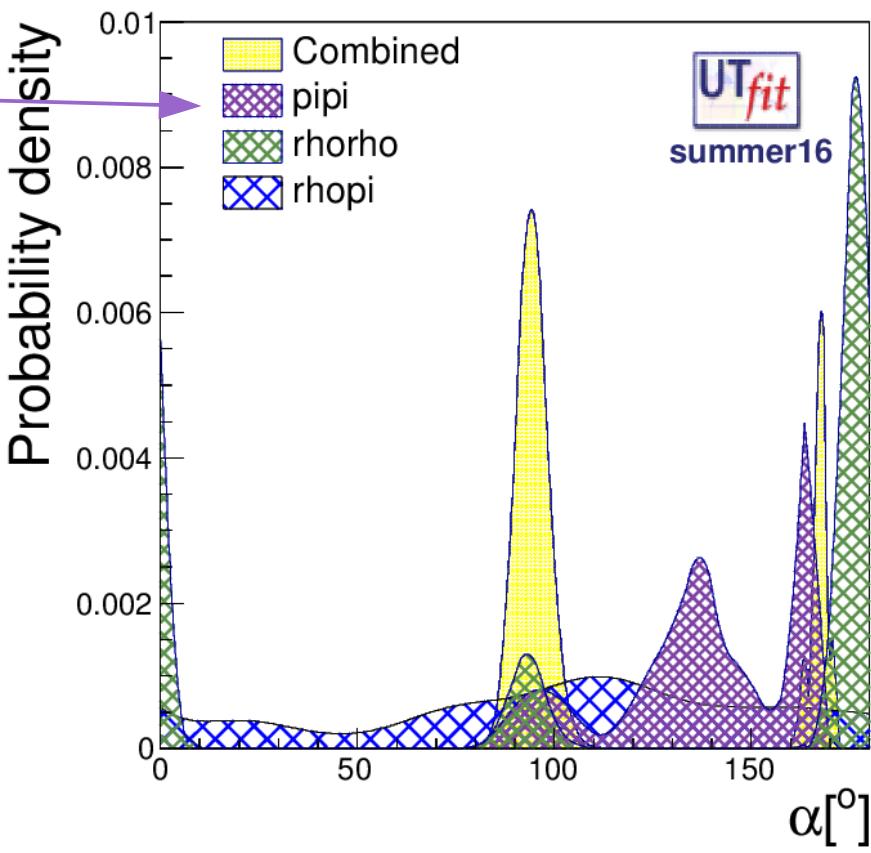
$\sin 2\alpha (\phi_2)$ from charmless B decays: pp, ($\rho\rho$, $\pi\rho$)



$\pi^0\pi^0$ from Belle at CKM14
to be updated soon (?)

$$\text{BR}(\pi^0\pi^0) = (1.17 \pm 0.13) 10^{-6}$$

compared with a à la PDG average
giving an inflated uncertainty of 0.41



α from $\pi\pi$, $\rho\rho$, $\pi\rho$ decays:
combined: $(94.2 \pm 4.5) {}^\circ$

V_{cb} and V_{ub}

Average of the two FLAG Nf=2+1 averages

$$|V_{cb}| \text{ (excl)} = (40.1 \pm 1.2) 10^{-3}$$

$$|V_{cb}| \text{ (incl)} = (42.00 \pm 0.64) 10^{-3}$$

Gambino 1606.06174

$\sim 1.3\sigma$ discrepancy

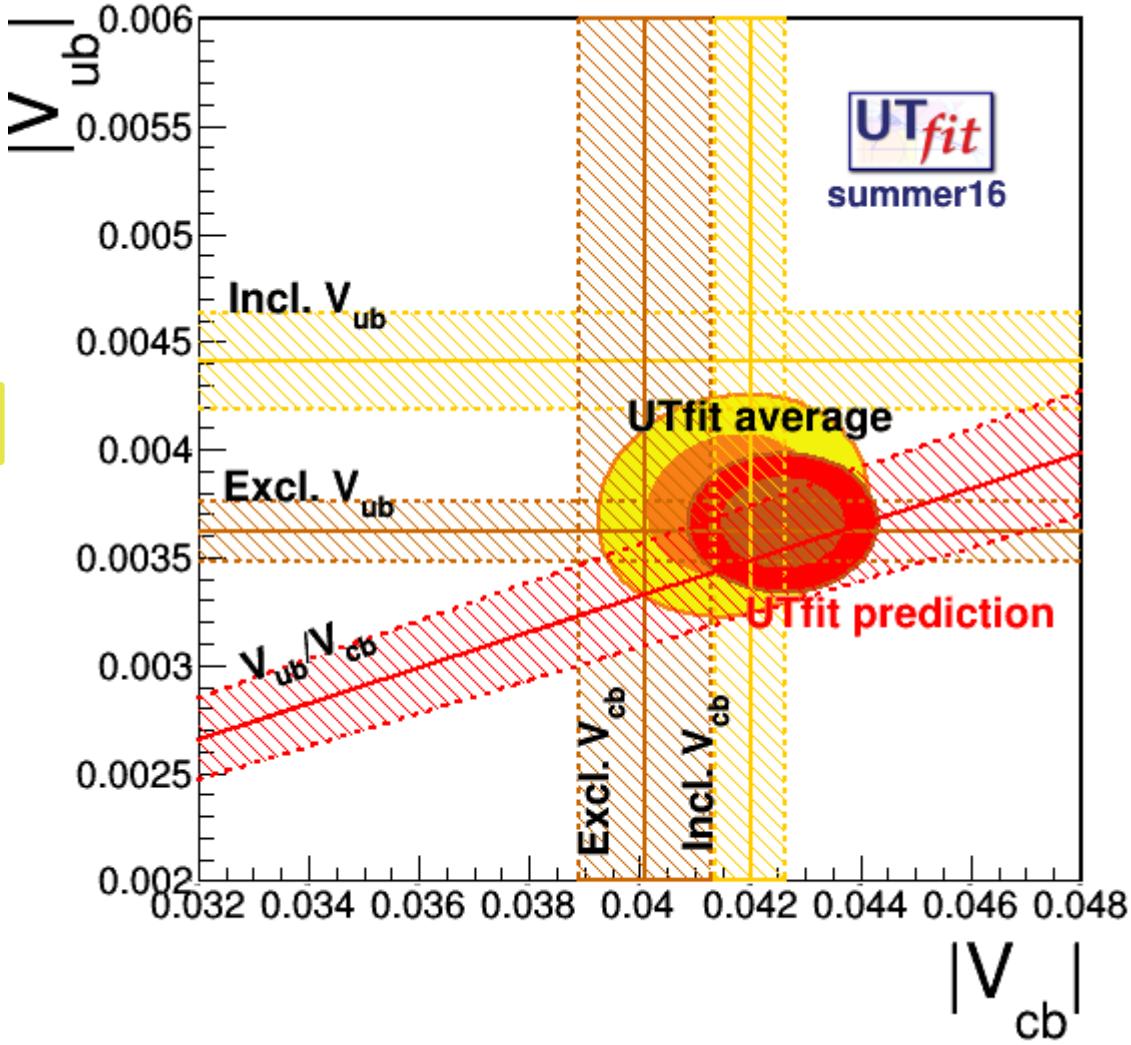
Nf=2+1 FLAG average

$$|V_{ub}| \text{ (excl)} = (3.62 \pm 0.14) 10^{-3}$$

$$|V_{ub}| \text{ (incl)} = (4.41 \pm 0.22) 10^{-3}$$

$\sim 3\sigma$ discrepancy

$$|V_{ub} / V_{cb}| \text{ (LHCb)} = (8.3 \pm 0.6) 10^{-2}$$



Unitarity Triangle analysis in the SM:

obtained excluding
the given constraint
from the fit

Observables	Measurement	Prediction	Pull (# σ)
B_K	0.740 ± 0.029	0.81 ± 0.07	< 1
f_{Bs}	0.226 ± 0.005	0.220 ± 0.007	< 1
f_{Bs}/f_{Bd}	1.203 ± 0.013	1.210 ± 0.030	< 1
B_{Bs}/B_{Bd}	1.032 ± 0.036	1.07 ± 0.05	< 1
B_{Bs}	1.35 ± 0.08	1.30 ± 0.07	< 1

in general: average the $N_f=2+1+1$ and $N_f=2+1$ FLAG averages,
through eq.(28) in arXiv:1403.4504

for B_K , f_{Bs} , f_{Bs}/f_{Bd} :

FLAG $N_f=2+1+1$ (single result) and $N_f=2+1$ average

for B_{Bs} , B_{Bs}/B_{Bd} :

update w.r.t. the $N_f=2+1$ FLAG average (no $N_f=2+1+1$
results yet) updating including FNAL/MILC 2016 (1602.13560)

Parameter	Error				
	Now	50/fb	300/fb	1000/fb	3000/fb
$\bar{\rho}$ (SM fit)	0.002	0.0039	0.0023	0.0013	0.00064
$\bar{\eta}$ (SM fit)	0.021	0.0037	0.0019	0.0013	0.00068
$\gamma [^\circ]$ (SM fit)	6.5	0.6	0.35	0.2	0.09
$\alpha [^\circ]$ (SM fit)	5.5	0.6	0.37	0.2	0.1
$\beta [^\circ]$ (SM fit)	4	0.2	0.10	0.07	0.04
$\beta_s [^\circ]$ (SM fit)	4	0.011	0.057	0.004	0.0023
$\bar{\rho}$ (NP fit)	0.002	0.006	0.0034	0.0028	0.0022
$\bar{\eta}$ (NP fit)	0.021	0.006	0.0053	0.0061	0.0052
$\gamma [^\circ]$ (NP fit)	6.5	0.9	0.4	0.2	0.09
$\alpha [^\circ]$ (NP fit)	5.5	1	0.5	0.45	0.36
$\beta [^\circ]$ (NP fit)	4	0.8	0.7	0.7	0.7
$\beta_s [^\circ]$ (NP fit)	4	0.017	0.016	0.016	0.016
C_{ε_K}	0.14	0.065	0.065	0.065	0.064
C_{B_d}	0.15	0.024	0.024	0.024	0.022
Φ_{B_d}	2.8	0.48	0.36	0.36	0.35
C_{B_s}	0.087	0.02	0.02	0.02	0.02
Φ_{B_s}	0.96	0.26	0.11	0.063	0.038
$\Phi_{M_{12}} [^\circ]$	2.5	0.4	0.1	0.08	0.04
$\Phi_{\Gamma_{12}} [^\circ]$	—	1.2	0.4	0.24	0.12

Very preliminary!!!



Crucial to improve
SM predictions
of rare decays!



Need
progress in

$|V_{ub}|$ and

$|V_{cb}|$

Steady
improvement

[Silvestrini@Pisa]

new-physics-specific constraints

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

Laplace et al.
Phys.Rev.D 65:
094040,2002

semileptonic asymmetries:

sensitive to NP effects in both size and phase

2D constraints a la HFAG for A_{sl}^s and A_{sl}^d

CDF + D0 + LHCb

same-side dilepton charge asymmetry:

admixture of B_s and B_d so sensitive to NP effects in both systems

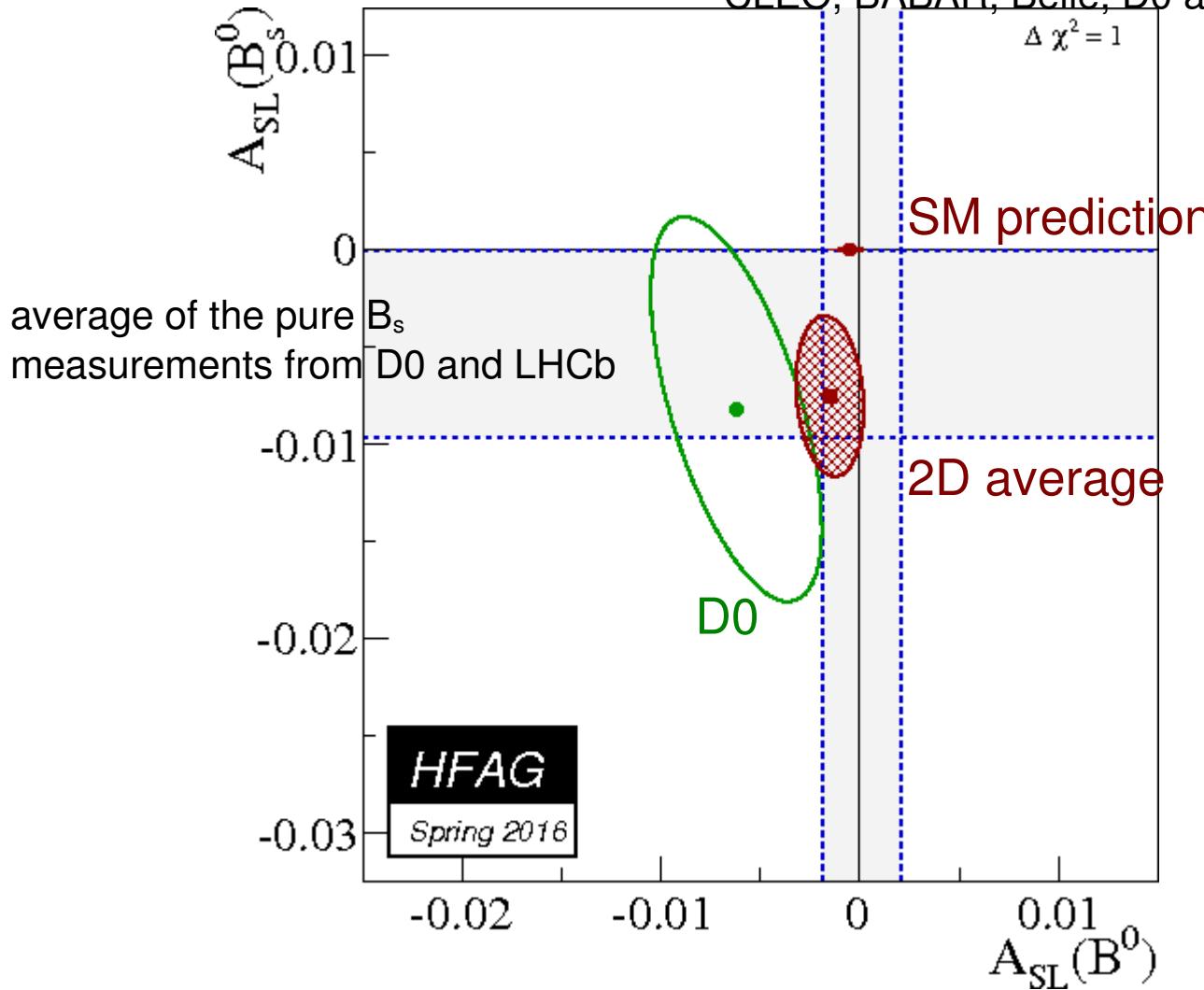
$$A_{\text{SL}}^{\mu\mu} \times 10^3 = -7.9 \pm 2.0$$

D0 arXiv:1106.6308

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

new-physics-specific constraints

semileptonic asymmetries



Artuso, et al,
arXiv:1511.09466

1.5 σ
tension

new-physics-specific constraints

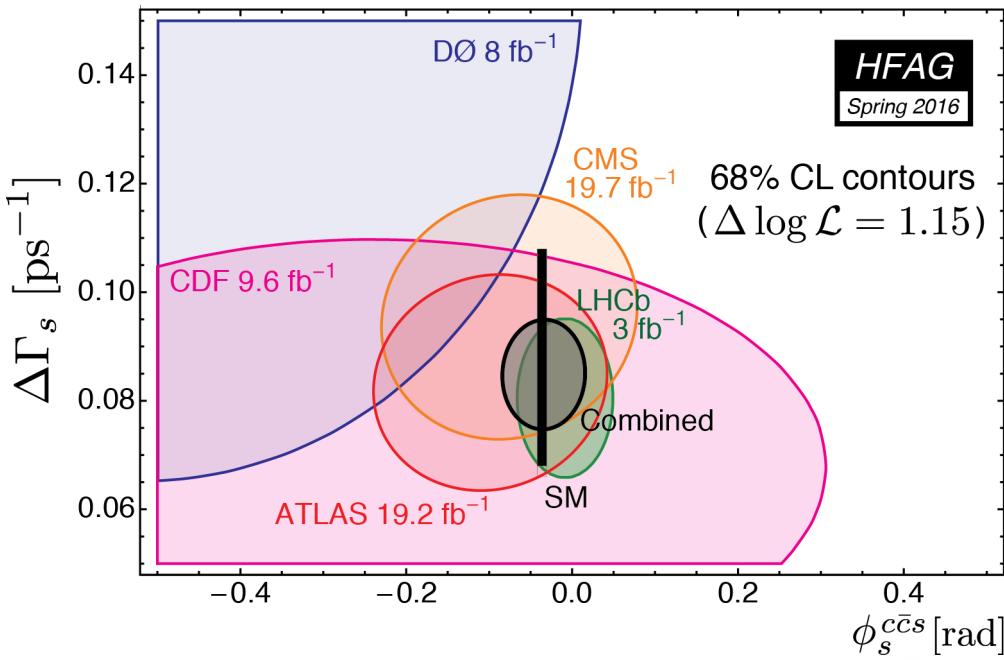
lifetime τ^{FS} in flavour-specific final states:
 average lifetime is a function to the width and
 the width difference (independent data sample)

$$\tau_{B_s}^{\text{FS}} \text{ [ps]} = 1.511 \pm 0.014$$

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

Dunietz et al.,
 hep-ph 0012219

$\phi_s = 2\beta_s$ vs $\Delta\Gamma_s$ from $B_s \rightarrow J/\psi \phi$
 angular analysis as a function
 of proper time and b-tagging
 additional sensitivity
 from the $\Delta\Gamma_s$ terms



new-physics-specific constraints

B meson mixing matrix element NLO calculation
 Ciuchini et al. JHEP 0308:031,2003.

C_{pen} and ϕ_{pen} are
 parameterize possible
 NP contributions from
 $b \rightarrow s$ penguins

$$\frac{\Gamma_{12}^q}{A_q^{\text{full}}} = -2 \frac{\kappa}{C_{B_q}} \left\{ e^{2\phi_{B_q}} \left(n_1 + \frac{n_6 B_2 + n_{11}}{B_1} \right) - \frac{e^{(\phi_q^{\text{SM}} + 2\phi_{B_q})}}{R_t^q} \left(n_2 + \frac{n_7 B_2 + n_{12}}{B_1} \right) \right. \\ \left. + \frac{e^{2(\phi_q^{\text{SM}} + \phi_{B_q})}}{R_t^{q^2}} \left(n_3 + \frac{n_8 B_2 + n_{13}}{B_1} \right) + e^{(\phi_q^{\text{Pen}} + 2\phi_{B_q})} C_q^{\text{Pen}} \left(n_4 + n_9 \frac{B_2}{B_1} \right) \right. \\ \left. - e^{(\phi_q^{\text{SM}} + \phi_q^{\text{Pen}} + 2\phi_{B_q})} \frac{C_q^{\text{Pen}}}{R_t^q} \left(n_5 + n_{10} \frac{B_2}{B_1} \right) \right\}$$

$\phi_s = 2\beta_s$ vs $\Delta\Gamma_s$ from $B_s \rightarrow J/\psi \phi$
 angular analysis as a function
 of proper time and b-tagging
 additional sensitivity
 from the $\Delta\Gamma_s$ terms

contribution to the mixing amplitudes

analytic expression for the contribution to the mixing amplitudes

$$\langle \bar{B}_q | \mathcal{H}_{\text{eff}}^{\Delta B=2} | B_q \rangle_i = \sum_{j=1}^5 \sum_{r=1}^5 (b_j^{(r,i)} + \eta c_j^{(r,i)}) \eta^{a_j} C_i(\Lambda) \langle \bar{B}_q | Q_r^{bq} | B_q \rangle$$

Lattice QCD

arXiv:0707.0636: *for "magic numbers" a, b and c ,* $\eta = \alpha_s(\Lambda)/\alpha_s(m_t)$
 (numerical values updated last in summer'16)

analogously for the K system

$$\langle \bar{K}^0 | \mathcal{H}_{\text{eff}}^{\Delta S=2} | K^0 \rangle_i = \sum_{j=1}^5 \sum_{r=1}^5 (b_j^{(r,i)} + \eta c_j^{(r,i)}) \eta^{a_j} C_i(\Lambda) R_r \langle \bar{K}^0 | Q_1^{sd} | K^0 \rangle$$

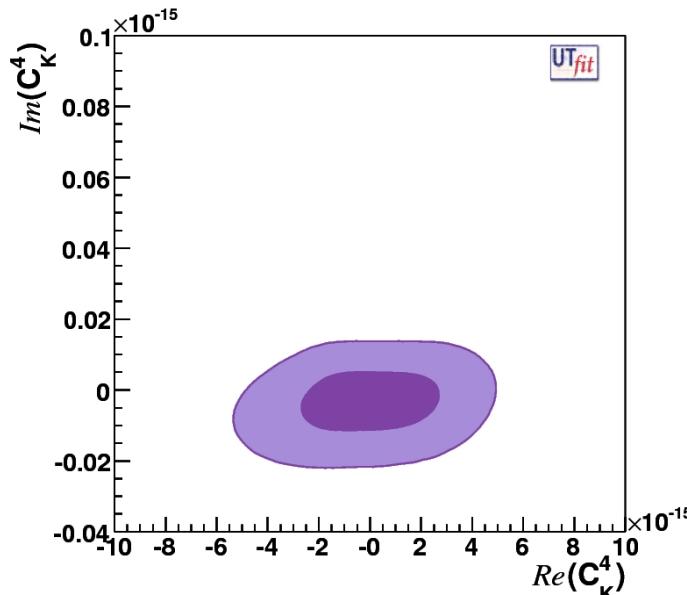
To obtain the p.d.f. for the Wilson coefficients $C_i(\Lambda)$ at the new-physics scale, we switch on **one coefficient at a time** in each sector and calculate its value from the result of the NP analysis.

Results from the Wilson coefficients

the results obtained for the flavour scenarios:

In deriving the lower bounds on the NP scale, we assume $L_i = 1$, corresponding to strongly-interacting and/or tree-level NP.

Parameter	95% allowed range (GeV $^{-2}$)	Lower limit on Λ (TeV)	
		for arbitrary NP	for NMHV
ReC_K^1	$[-9.6, 9.6] \cdot 10^{-13}$	$1.0 \cdot 10^3$	0.35
ReC_K^2	$[-1.8, 1.9] \cdot 10^{-14}$	$7.3 \cdot 10^3$	2.0
ReC_K^3	$[-6.0, 5.6] \cdot 10^{-14}$	$4.1 \cdot 10^3$	1.1
ReC_K^4	$[-3.6, 3.6] \cdot 10^{-15}$	$17 \cdot 10^3$	4.0
ReC_K^5	$[-1.0, 1.0] \cdot 10^{-14}$	$10 \cdot 10^3$	2.4
ImC_K^1	$[-4.4, 2.8] \cdot 10^{-15}$	$1.5 \cdot 10^4$	5.6
ImC_K^2	$[-5.1, 9.3] \cdot 10^{-17}$	$10 \cdot 10^4$	28
ImC_K^3	$[-3.1, 1.7] \cdot 10^{-16}$	$5.7 \cdot 10^4$	19
ImC_K^4	$[-1.8, 0.9] \cdot 10^{-17}$	$24 \cdot 10^4$	62
ImC_K^5	$[-5.2, 2.8] \cdot 10^{-17}$	$14 \cdot 10^4$	37



To obtain the lower bound for loop-mediated contributions, one simply multiplies the bounds by $\alpha_s \sim 0.1$ or by $\alpha_w \sim 0.03$.