Updates in the Unitarity Triangle fits with UTfit

Marcella Bona
QMUL

40th International Conference on High Energy Physics
Wednesday July 29th 2020
Virtually in Prague, Czech Republic

Unitarity Triangle analysis in the SM

- SM UT analysis:
  - All updated with Summer 2020 inputs
  - 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:
  - Also all updated with Summer 2020 inputs
  - model-independent analysis
  - provides limit on the allowed deviations from the SM
  - obtain the NP scale

www.utfit.org

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

Plots and numbers in this talk are
hot-off-the-press for this conference

Will appear in the next day(s) on the webpage

Usual method and inputs:

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

Bayes Theorem

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

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

$(b \to u)/(b \to c)$	$\bar\rho^2+\bar\eta^2$	$\bar\Lambda, \lambda_1, F(1), ...$
ϵ_K	$\bar\eta[(1-\bar\rho)+P]$	B_K }
Δm_d	$(1-\bar\rho)^2+\bar\eta^2$	$f_B^2 B_B$
$\Delta m_d/\Delta m_s$	$(1-\bar\rho)^2+\bar\eta^2$	ξ
$A_{CP}(J/\psi K_S)$	$\sin 2\beta$	

, $\mathbf{m_t}$

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

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

V_{cb} and V_{ub}

from FLAG

$|V_{cb}|$ *(excl)* = (39.44 ± 0.59) 10^{-3}

$|V_{cb}|$ *(incl)* = (42.19 ± 0.78) 10^{-3}

from HFLAV

~2.8σ discrepancy

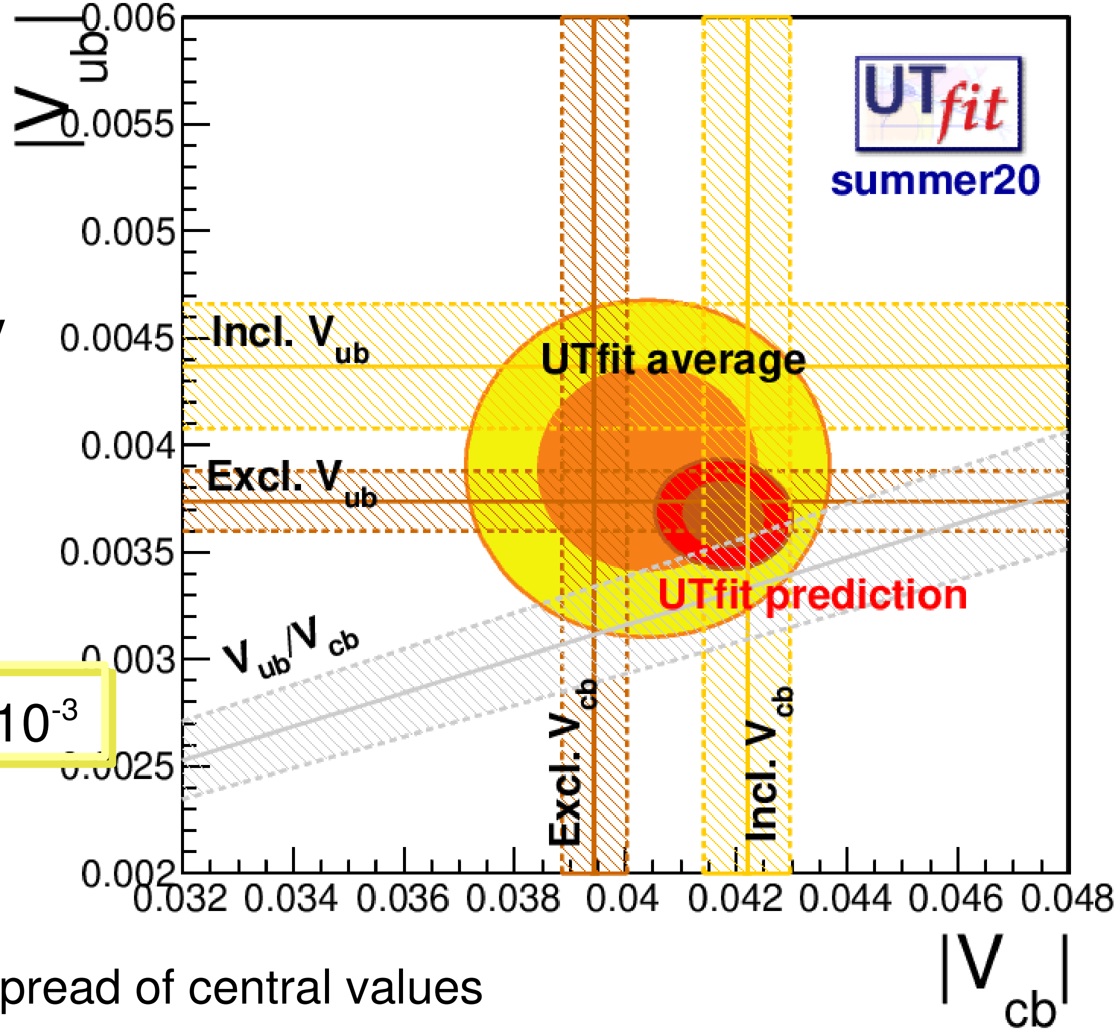
from FLAG

$|V_{ub}|$ *(excl)* = (3.74 ± 0.14) 10^{-3}

$|V_{ub}|$ *(incl)* = (4.37 ± 0.25 ± 0.26 *[flat]*) 10^{-3}

from HFLAV adding a flat uncertainty covering the spread of central values

~1.9σ discrepancy



$|V_{ub} / V_{cb}|$ *(LHCb)* = (7.9 ± 0.6) 10^{-2}

Excluded at the moment following the FLAG guidelines

V_{cb} and V_{ub}

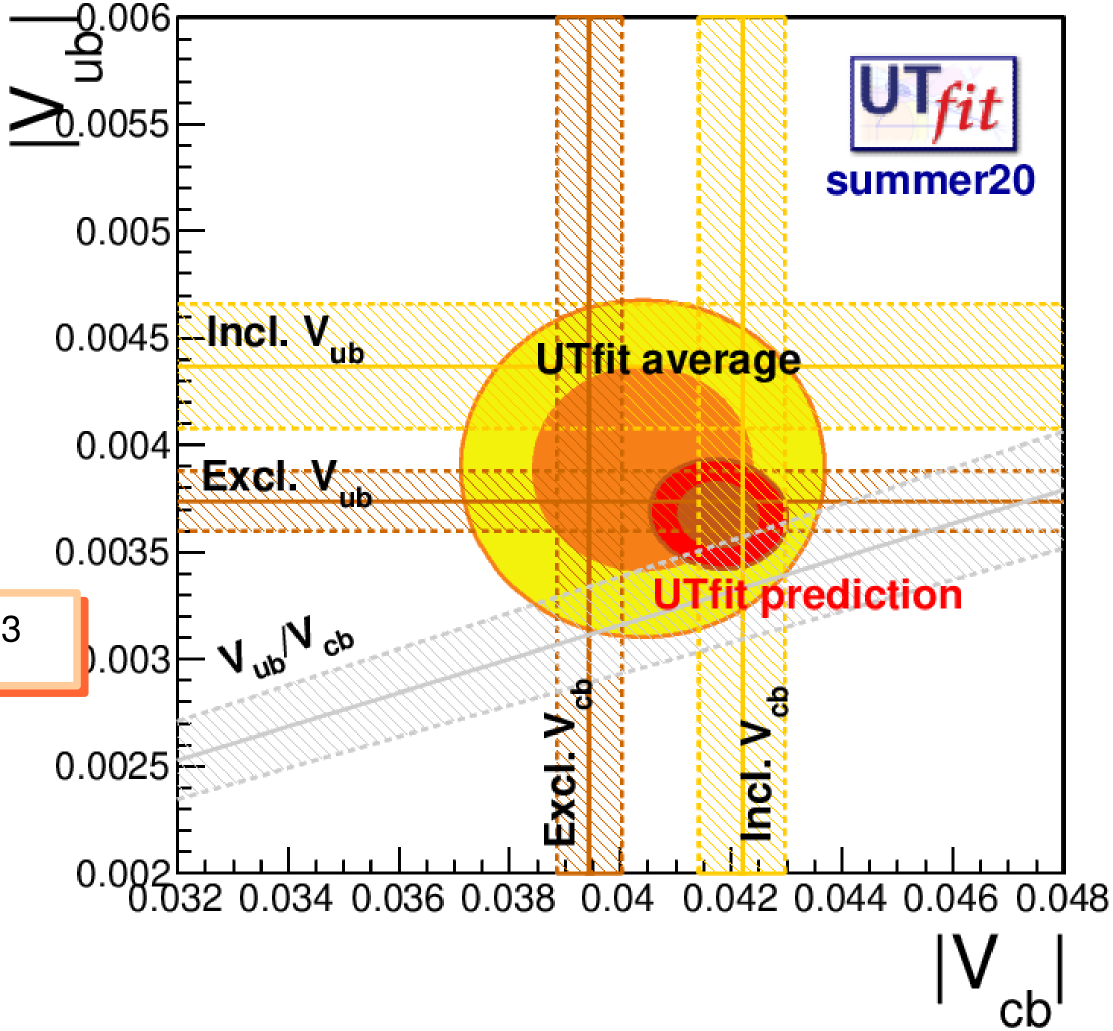
A-la-PDG procedure for both averages

$|V_{cb}| = (40.4 \pm 1.3)\ 10^{-3}$

uncertainty ~ 3.2%

$|V_{ub}| = (3.89 \pm 0.27 \pm 0.26)\ 10^{-3}$

uncertainty ~ 8.0%



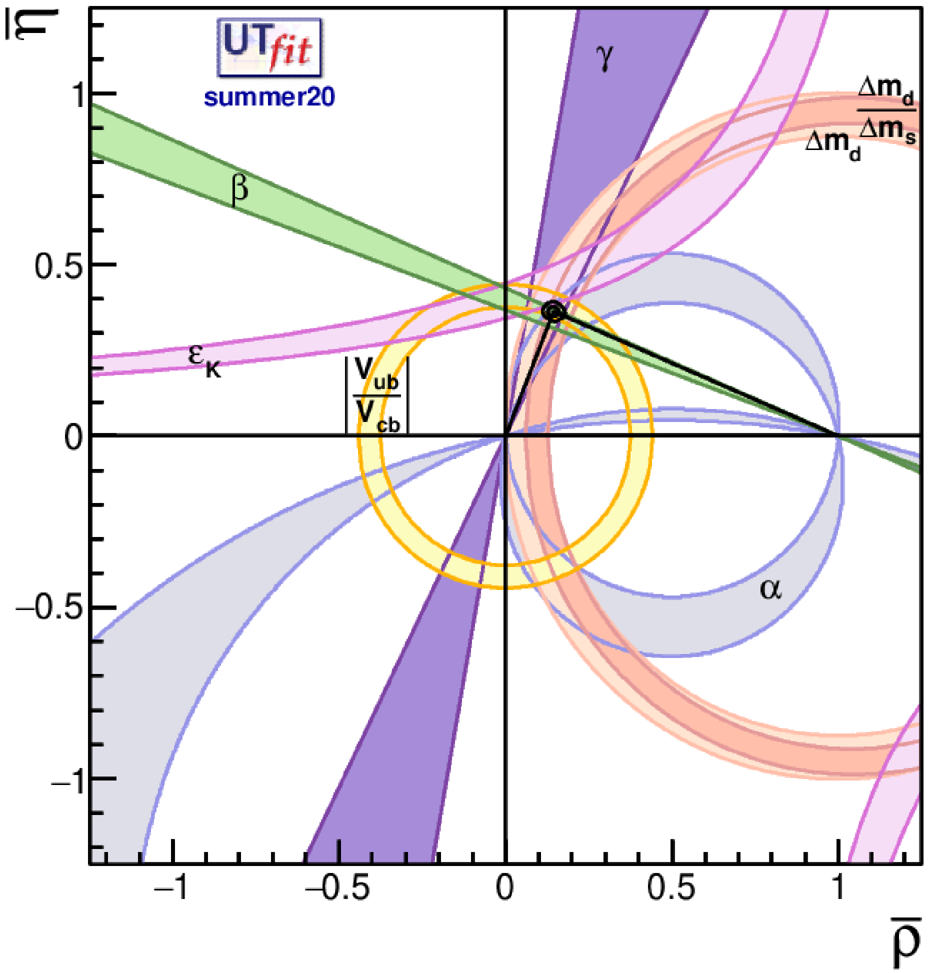
$|V_{cb}| = (42.0 \pm 0.5)\ 10^{-3}$

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

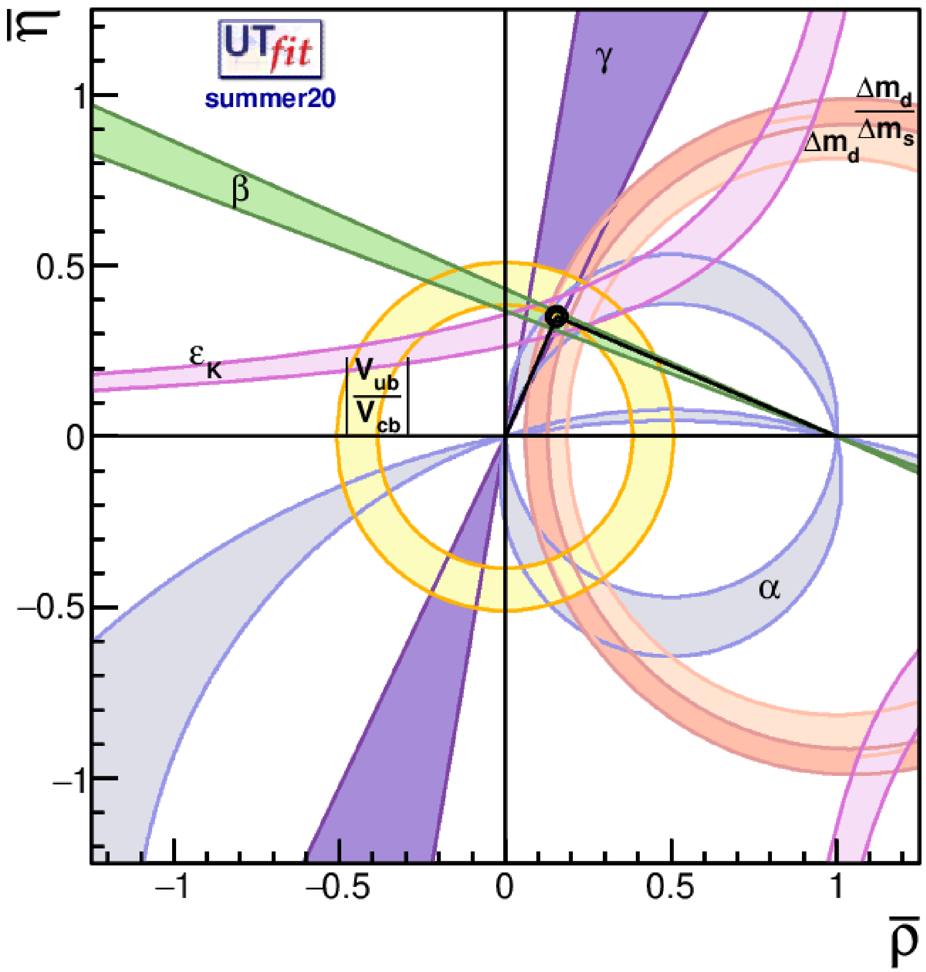
UTfit predictions

exclusives vs inclusives

only exclusive values



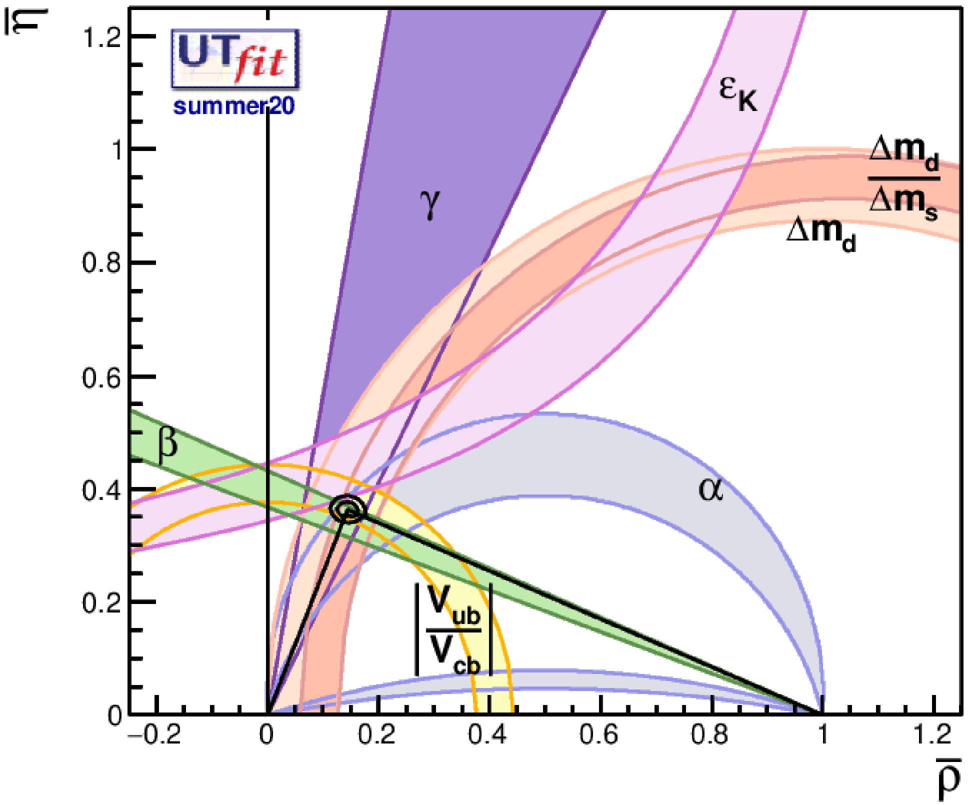
only inclusive values



exclusives vs inclusives

zoomed in..

only exclusive values

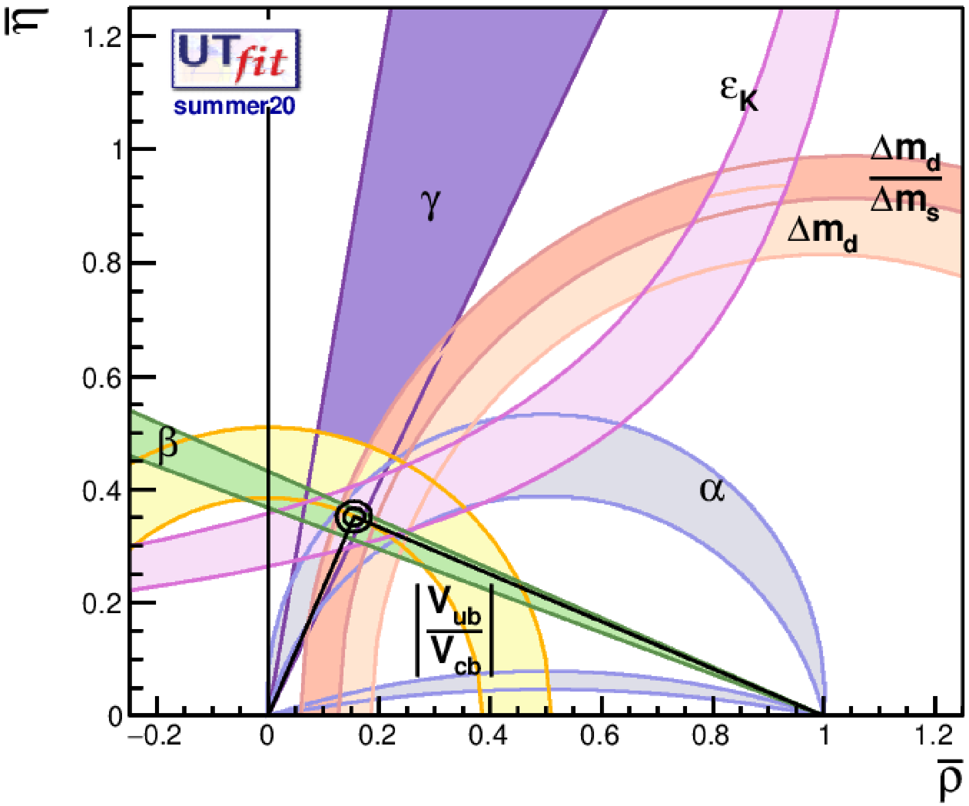


$\sin 2\beta_{exp} = 0.688 \pm 0.020$

$\sin 2\beta_{excl} = 0.755 \pm 0.020$

~2.3σ

only inclusive values



$\sin 2\beta_{incl} = 0.769 \pm 0.031$

~2.1σ

lattice QCD inputs

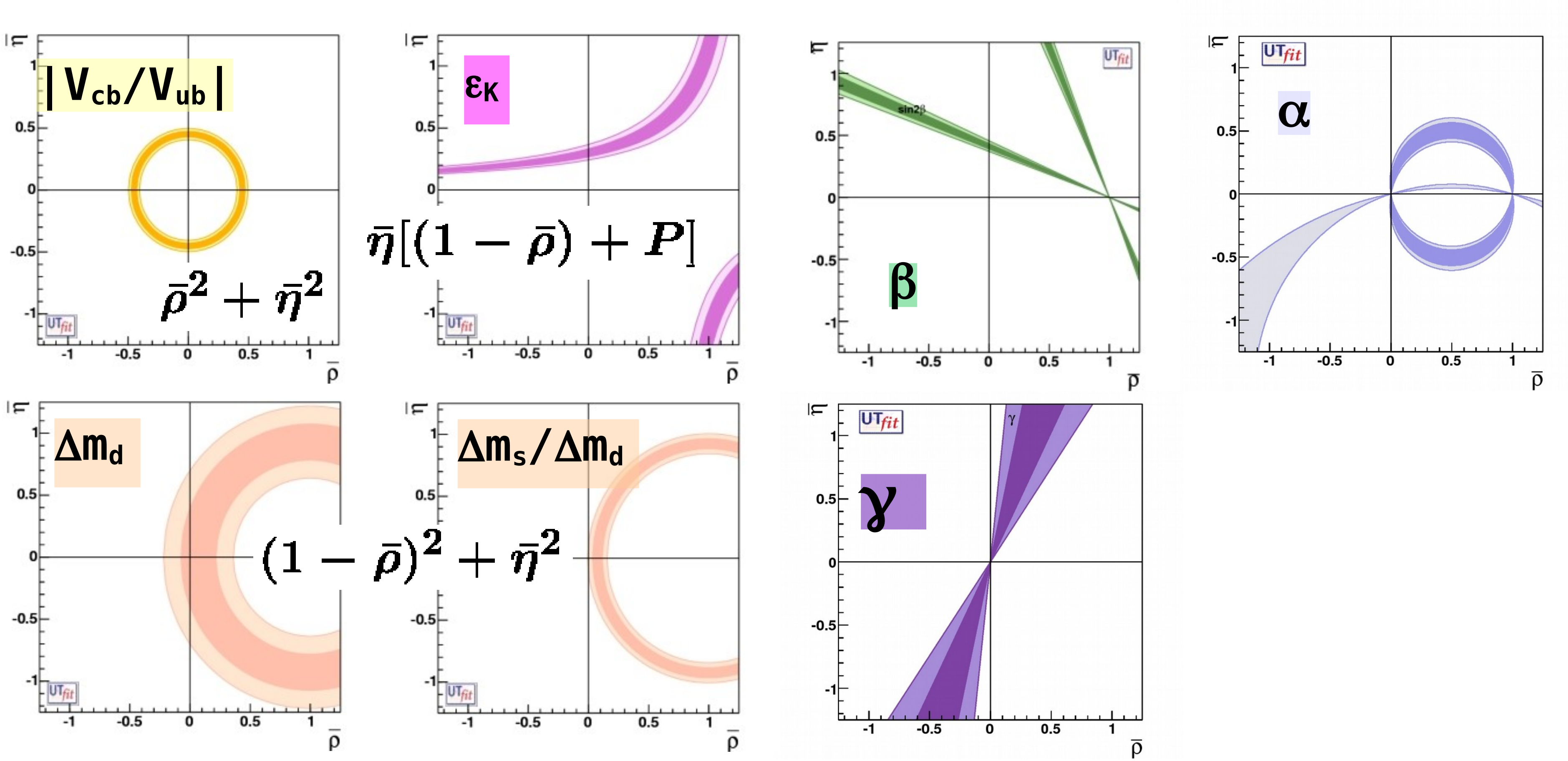
updated in early 2020

Observables	Measurement
B_K	**0.756 ± 0.016**
f_{Bs}	**0.2301 ± 0.0012**
f_{Bs}/f_{Bd}	**1.208 ± 0.005**
B_{Bs}/B_{Bd}	**1.032 ± 0.038**
B_{Bs}	**1.35 ± 0.06**

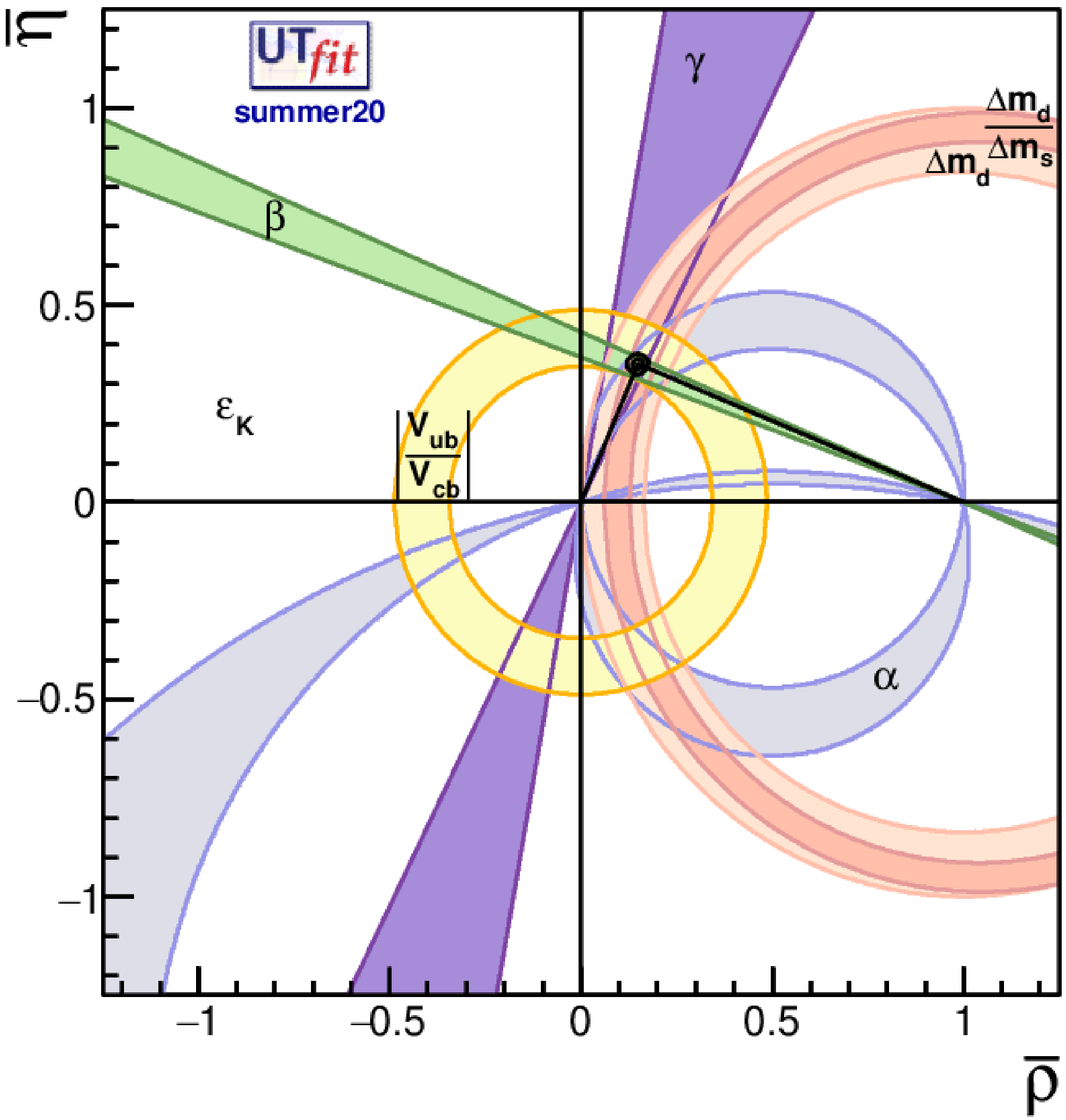
FLAG 2019 suggests to take the most precise between the Nf=2+1+1 and Nf=2+1 averages.

We quote, instead, the weighted average of the Nf=2+1+1 and Nf=2+1 results with the error rescaled when chi2/dof > 1, as done by FLAG for the Nf=2+1+1 and Nf=2+1 averages separately

Unitarity Triangle analysis in the SM:



Unitarity Triangle analysis in the SM:



levels @
95% Prob

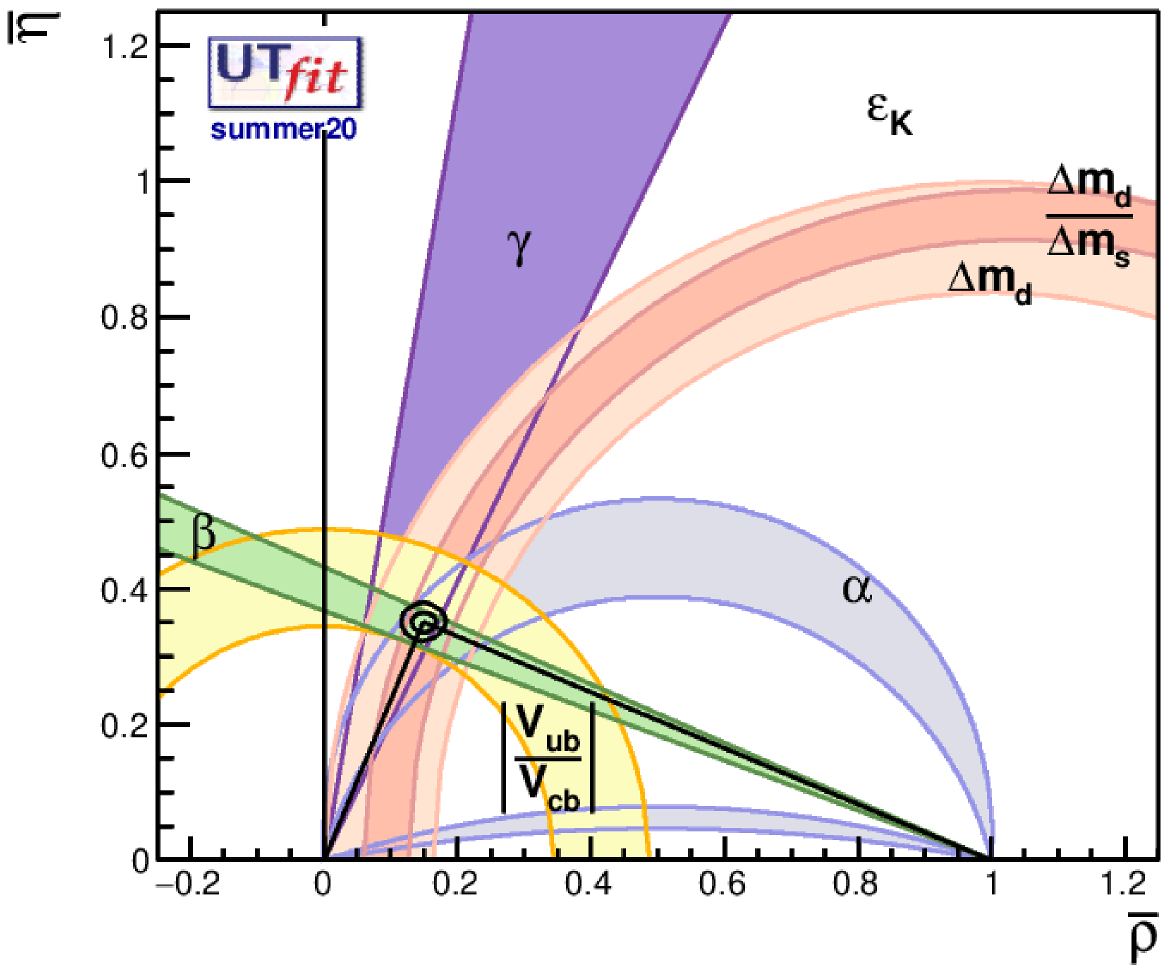
~9%

$\bar{\rho}$ = 0.149 ± 0.013
$\bar{\eta}$ = 0.350 ± 0.013

~4%

Unitarity Triangle analysis in the SM:

zoomed in..



levels @
95% Prob

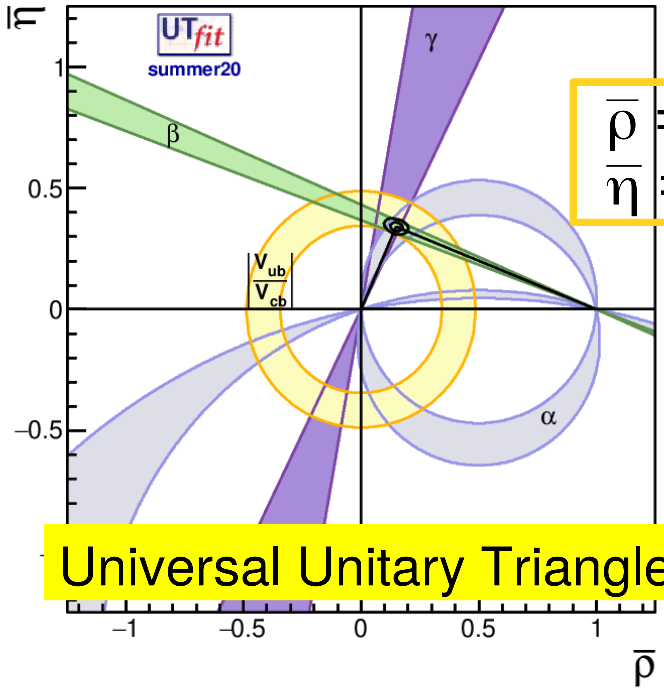
~9%

$\bar{\rho} = 0.149 \pm 0.013$

$\bar{\eta} = 0.350 \pm 0.013$

~4%

Pick-and-choose configurations

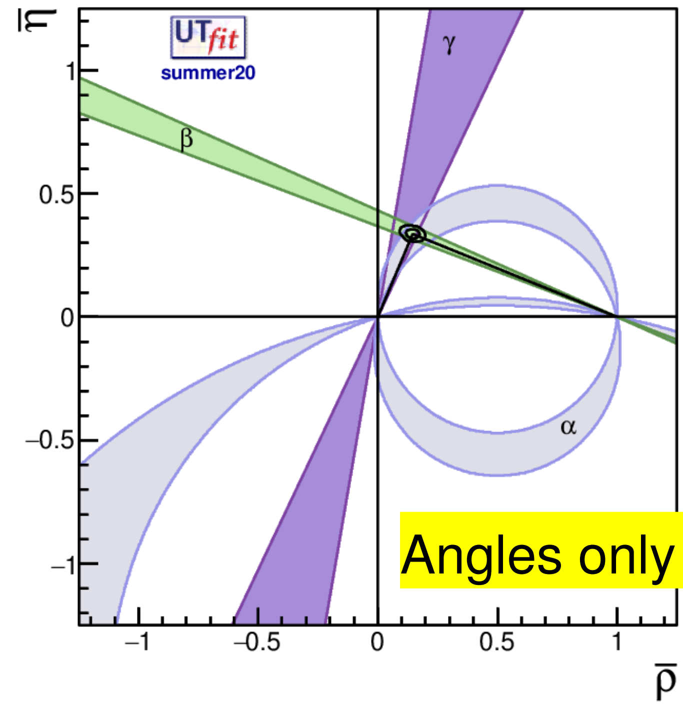


Universal Unitary Triangle

~14%

$\bar{\rho} = 0.150 \pm 0.021$
$\bar{\eta} = 0.342 \pm 0.014$

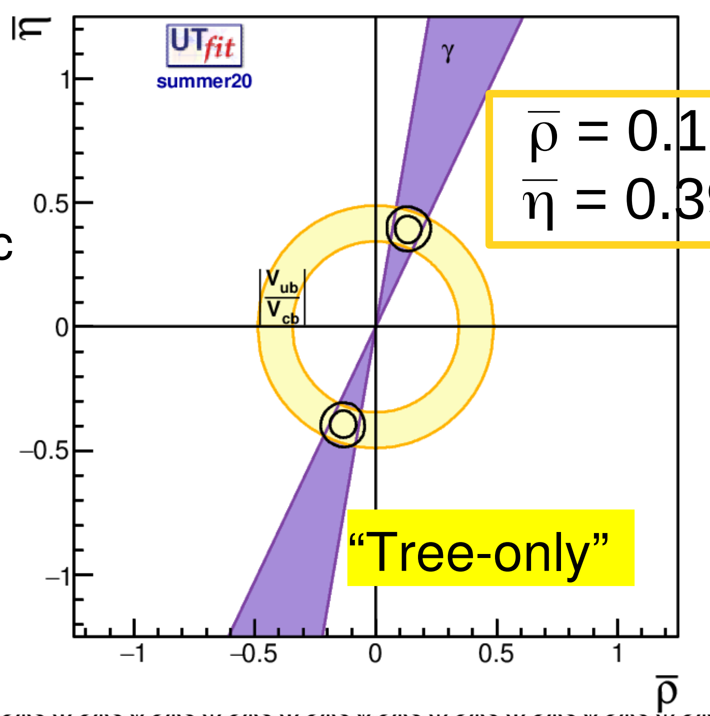
~4%



Angles only

Tree-level processes: Semileptonic and DK B decays

→ reference for model building

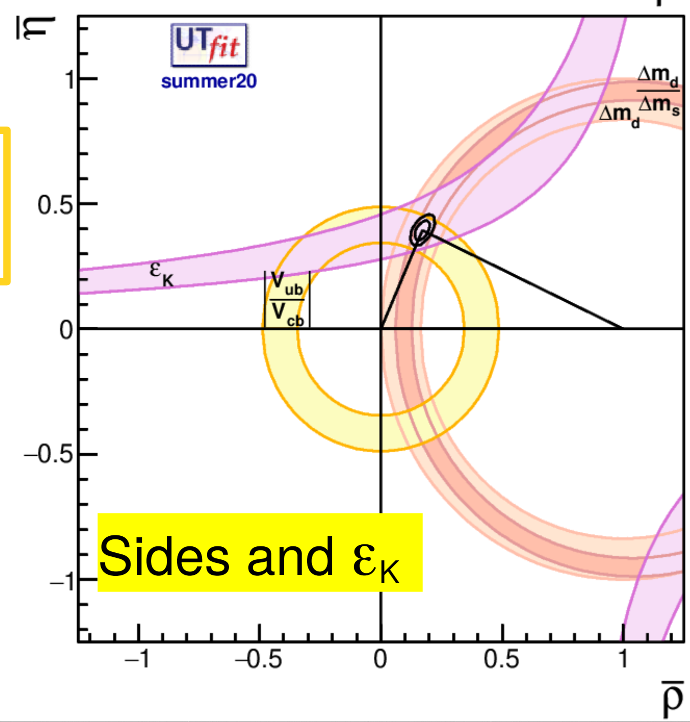


"Tree-only"

~27%

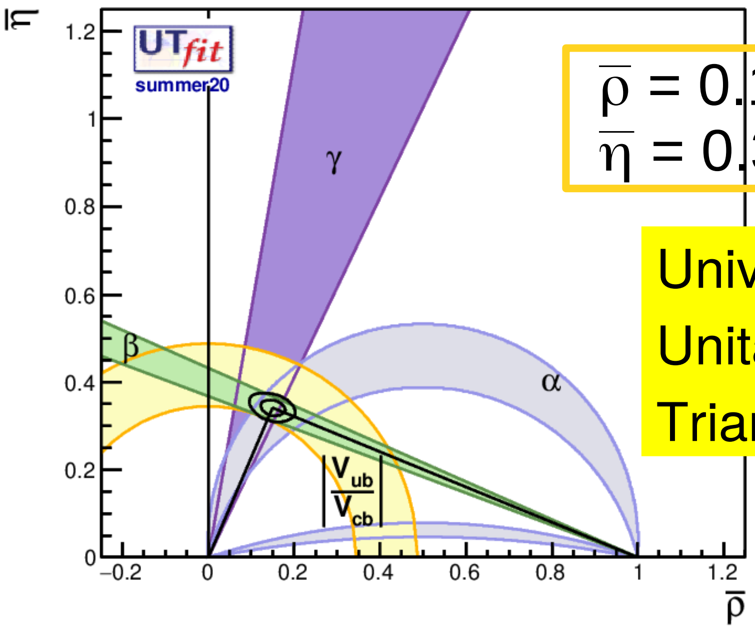
$\bar{\rho} = 0.135 \pm 0.037$
$\bar{\eta} = 0.394 \pm 0.036$

~9%



Sides and ε_K

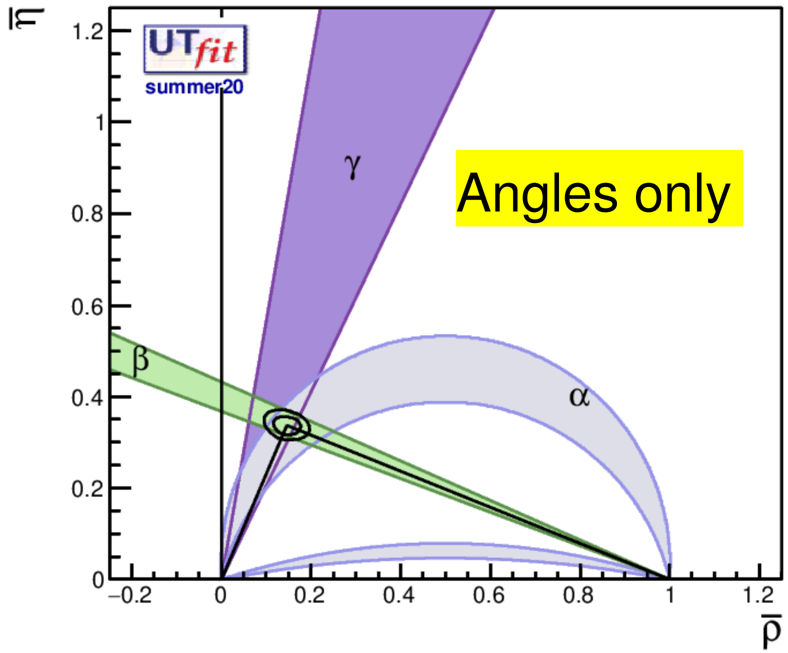
Pick-and-choose configurations



$\bar{\rho} = 0.150 \pm 0.021$ ~14%

$\bar{\eta} = 0.342 \pm 0.014$ ~4%

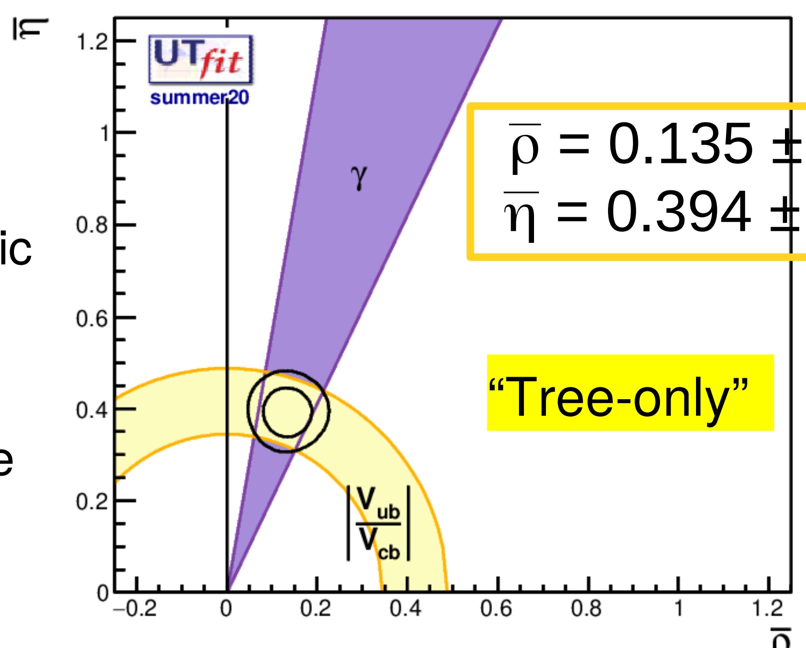
Universal Unitary Triangle



Angles only

Tree-level processes: Semileptonic and DK B decays

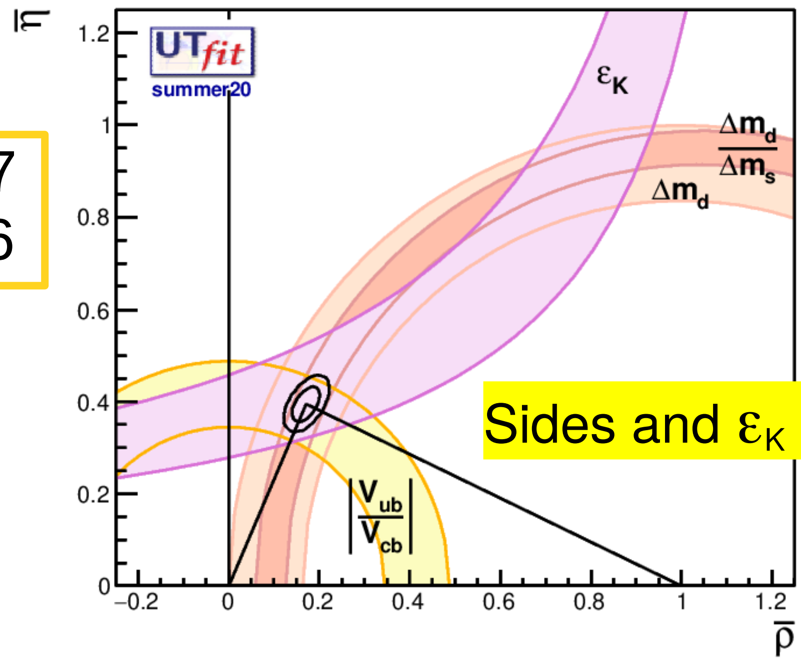
→ reference for model building



$\bar{\rho} = 0.135 \pm 0.037$ ~27%

$\bar{\eta} = 0.394 \pm 0.036$ ~9%

"Tree-only"



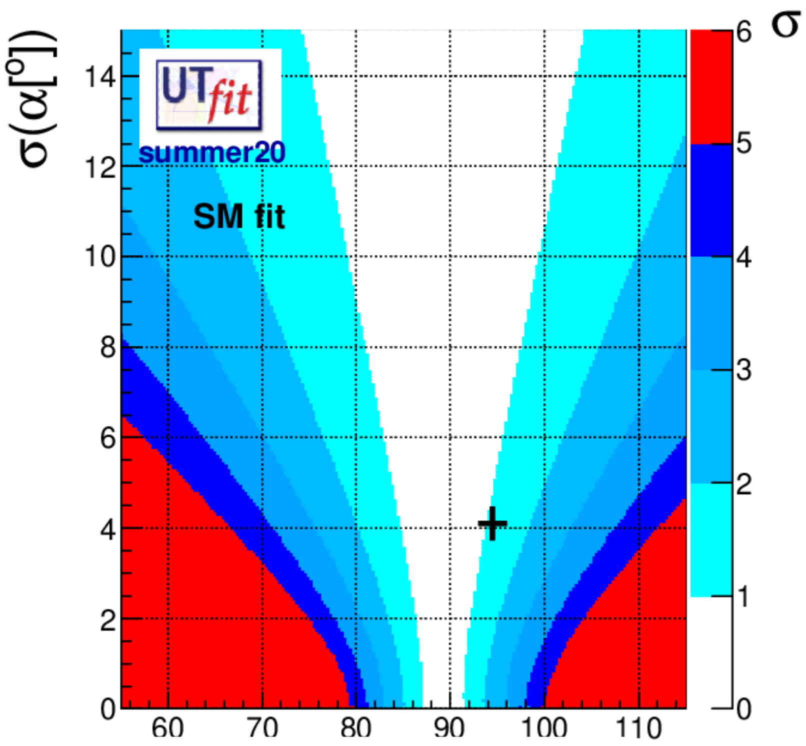
Sides and ε_K

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

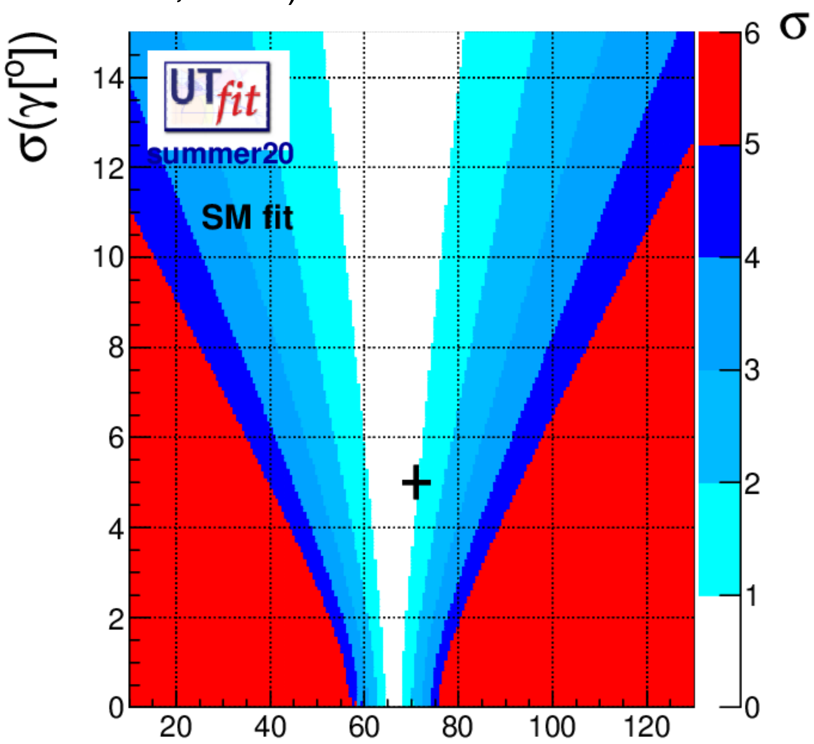
Color code: agreement between the predicted values and the measurements at better than 1, 2, ...nσ

The cross has the coordinates (x,y)=(central value, error) of the direct measurement



$\alpha_{exp} = (94.5 \pm 4.1)^\circ$

$\alpha_{UTfit} = (89.2 \pm 2.2)^\circ$



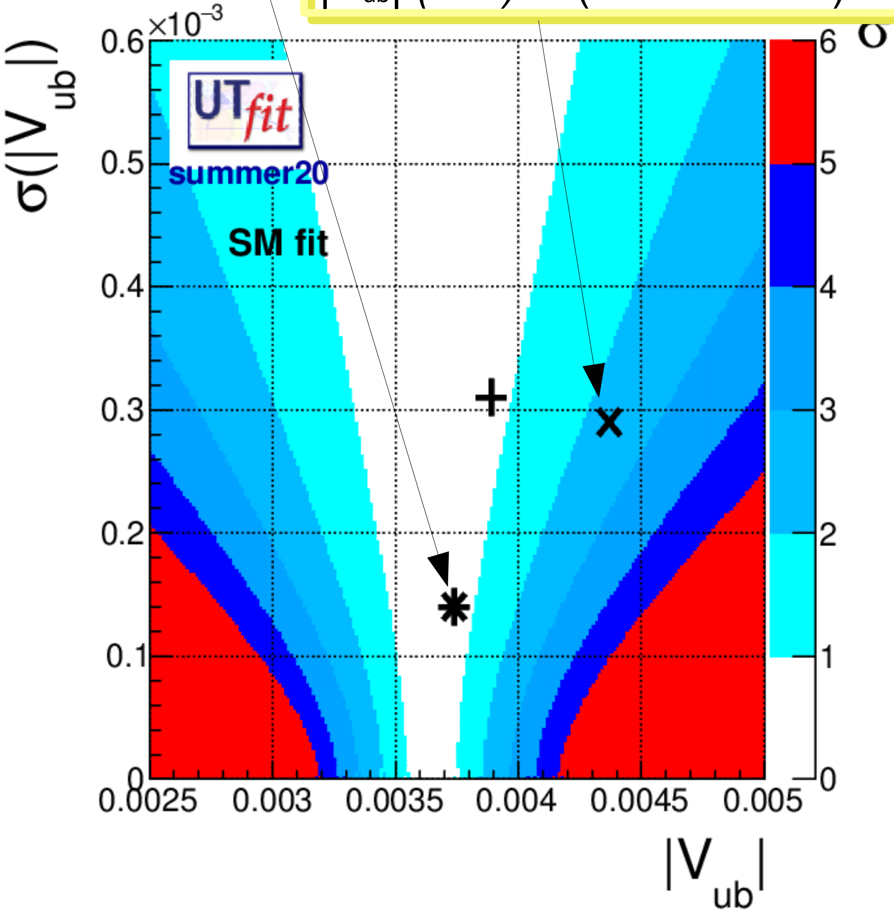
$\gamma_{exp} = (71.1 \pm 5.0)^\circ$

$\gamma_{UTfit} = (66.4 \pm 2.0)^\circ$

Checking the usual *tensions*..

$|V_{ub}|$ *(excl)* = (3.74 ± 0.14) 10^{-3}

$|V_{ub}|$ *(incl)* = (4.37 ± 0.29) 10^{-3}



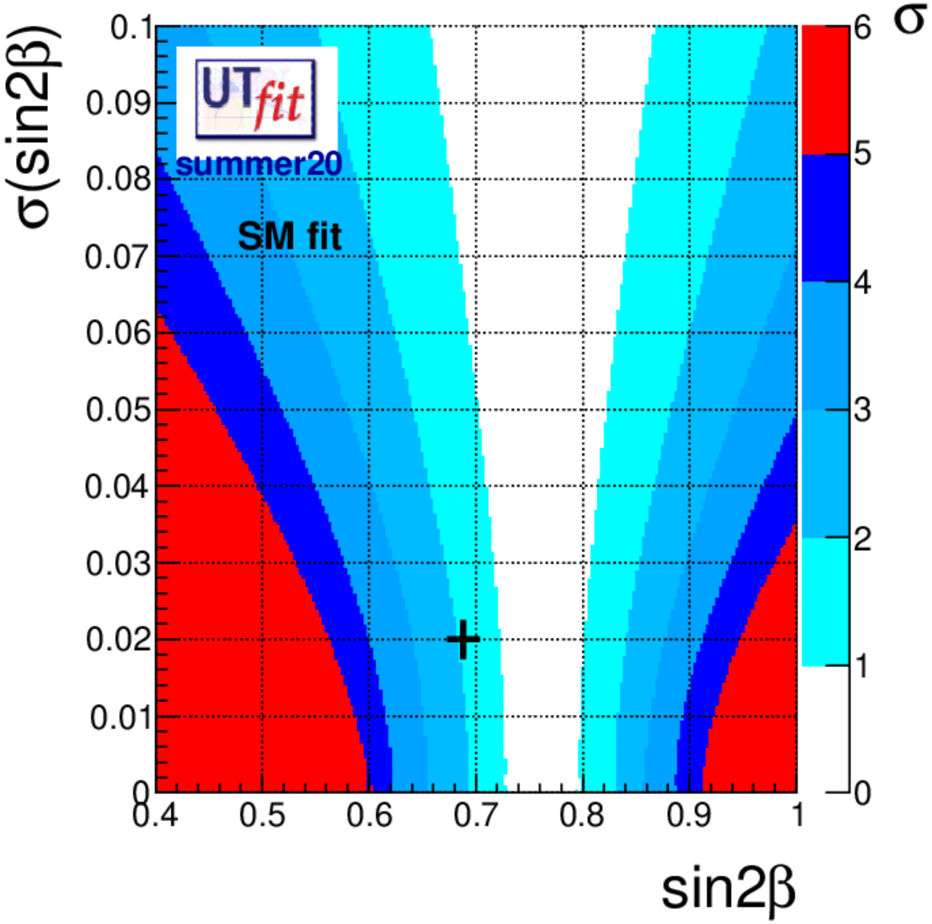
$Vub_{exp} = (3.89 \pm 0.31) \cdot 10^{-3}$

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

~1.8σ

$\sin 2\beta_{exp} = 0.688 \pm 0.020$

$\sin 2\beta_{UTfit} = 0.762 \pm 0.036$



Unitarity Triangle analysis in the SM:

obtained excluding the given constraint from the fit

Observables	Measurement	Prediction	Pull (#σ)
$\sin 2\beta$	0.688 ± 0.020	0.762 ± 0.036	~ 1.8
γ	71.1 ± 5.0	66.4 ± 2.0	<1
α	94.5 ± 4.1	89.2 ± 2.2	~ 1.1
$\lvert V_{cb}\rvert \cdot 10^3$	40.4 ± 1.3	42.0 ± 0.5	~1.1
$\lvert V_{ub}\rvert \cdot 10^3$	3.89 ± 0.31	3.66 ± 0.11	< 1
$\lvert V_{ub}\rvert \cdot 10^3$ (incl)	4.37 ± 0.29	-	~ 2.3
$\lvert V_{ub}\rvert \cdot 10^3$ (excl)	3.74 ± 0.14	-	< 1
$BR(B \to \tau\nu)[10^{-4}]$	1.09 ± 0.24	0.85 ± 0.05	< 1
$A_{SL}^{d} \cdot 10^3$	-2.1 ± 1.7	-0.32 ± 0.03	~ 1.1
$A_{SL}^{s} \cdot 10^3$	-0.6 ± 2.8	0.014 ± 0.001	< 1

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 ΔF=2 transitions

B_d and B_s mixing amplitudes

(2+2 real parameters):

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

$$\Delta m_{q/K} = C_{B_q/\Delta m_K} (\Delta m_{q/K})^{SM}$$
$$A_{CP}^{B_d \to J/\psi K_s} = \sin 2(\beta + \phi_{B_d})$$
$$A_{SL}^q = \text{Im}\left(\Gamma_{12}^q / A_q\right)$$

$$\varepsilon_K = C_\varepsilon \varepsilon_K^{SM}$$
$$A_{CP}^{B_s \to J/\psi\phi} \sim \sin 2(-\beta_s + \phi_{B_s})$$
$$\Delta\Gamma^q / \Delta m_q = \text{Re}\left(\Gamma_{12}^q / A_q\right)$$

new-physics-specific constraints

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

semileptonic asymmetries in B^0 and B_s: sensitive to NP effects in both size and phase. Taken from the latest HFLAV.

Cleo, BaBar, Belle, D0 and LHCb

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

D0 arXiv:1106.6308

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

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

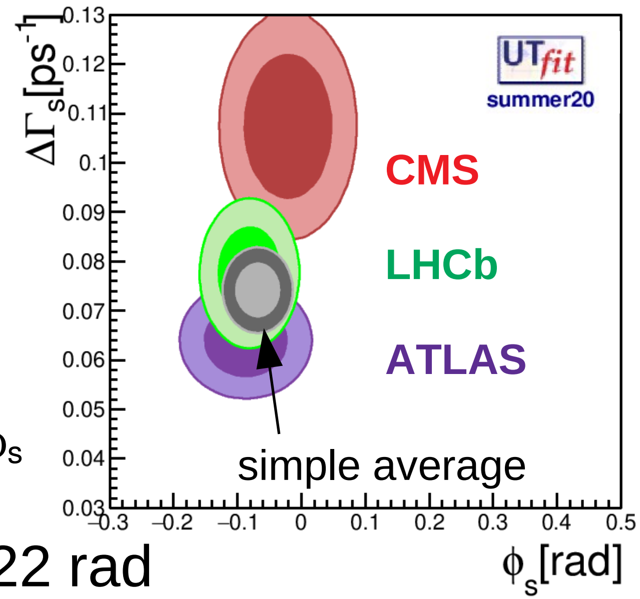
lifetime τ^{FS} in flavour-specific final states: average lifetime is a function to the width and the width difference

$$\tau^{FS}(B_s) = 1.527 \pm 0.011 \text{ ps}$$

HFLAV

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

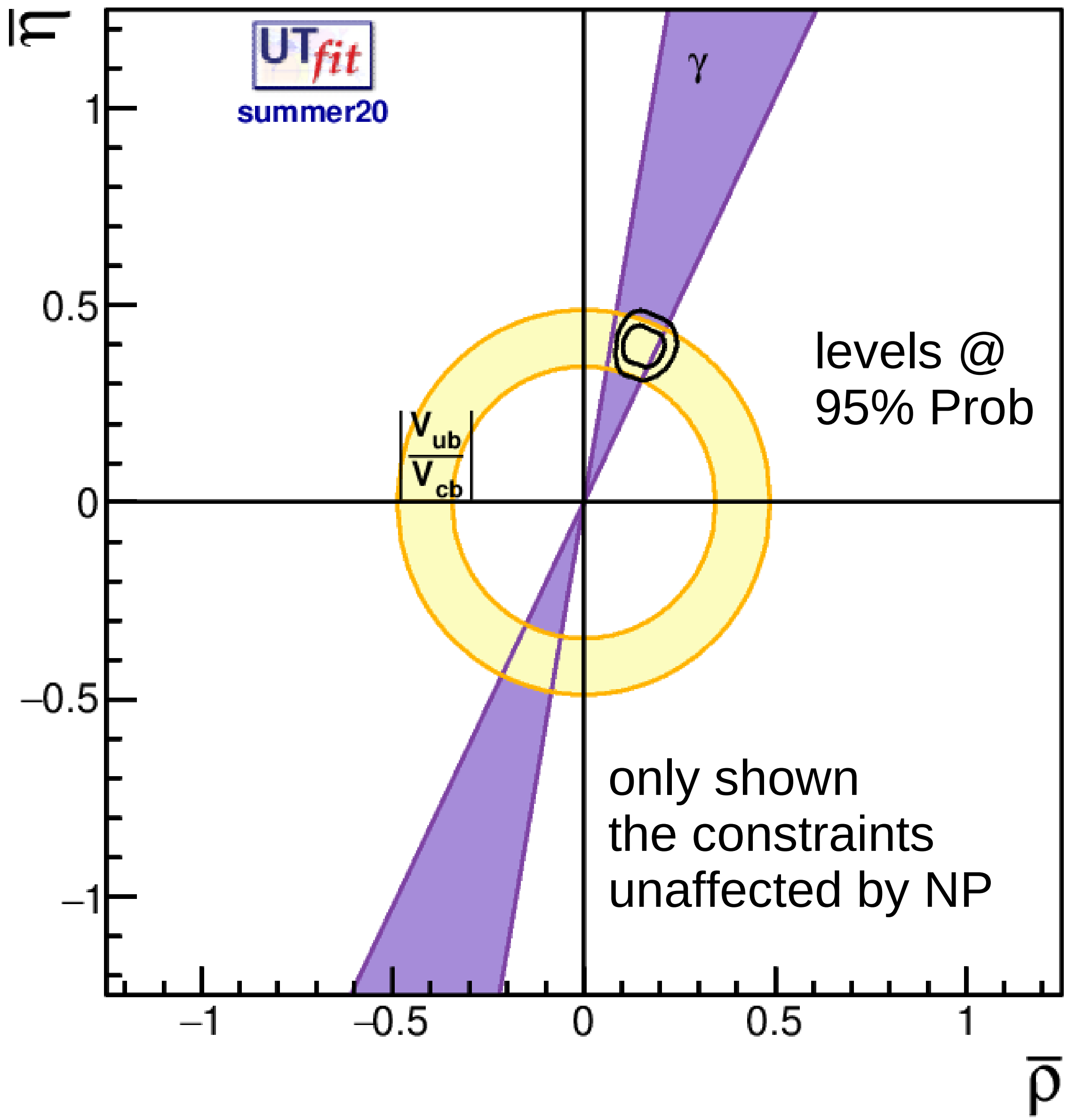
angular analysis as a function of proper time and b-tagging



As we use only ϕ_s simple average:

$$\phi_s = -0.068 \pm 0.022 \text{ rad}$$

NP analysis results



$\bar{\rho} = 0.158 \pm 0.037$

$\bar{\eta} = 0.397 \pm 0.037$

SM is

$\bar{\rho} = 0.149 \pm 0.013$

$\bar{\eta} = 0.350 \pm 0.013$

NP parameter results

K system

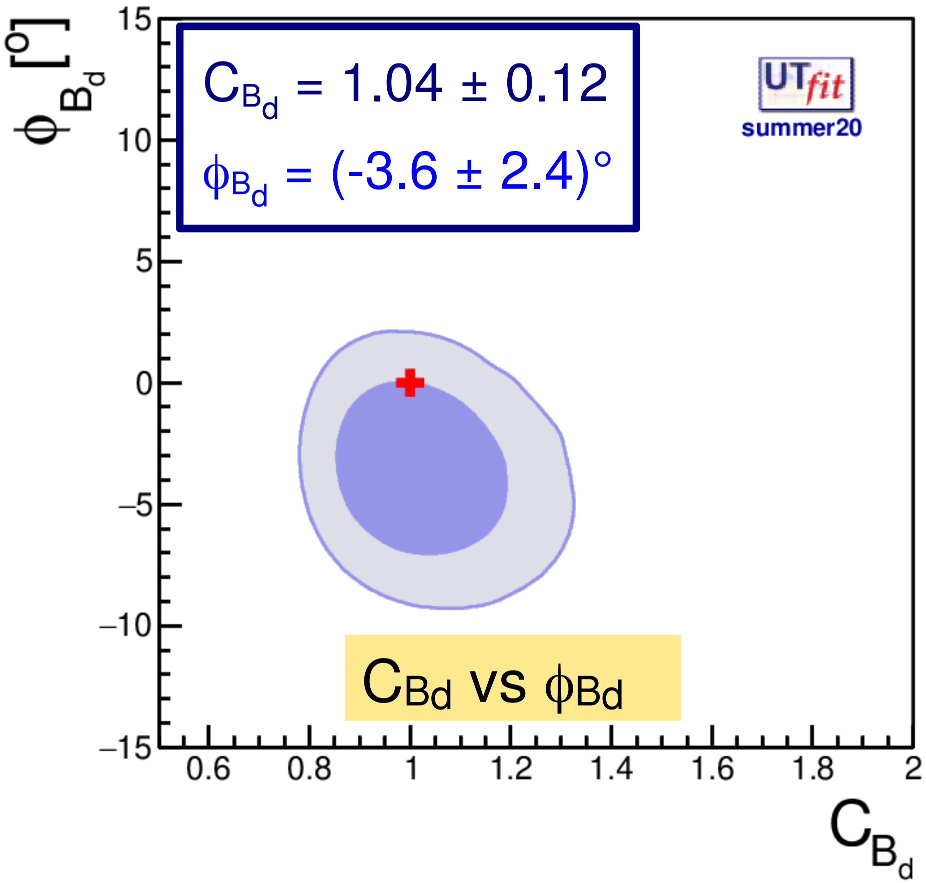
$C_{\varepsilon_K} = 1.09 \pm 0.13$

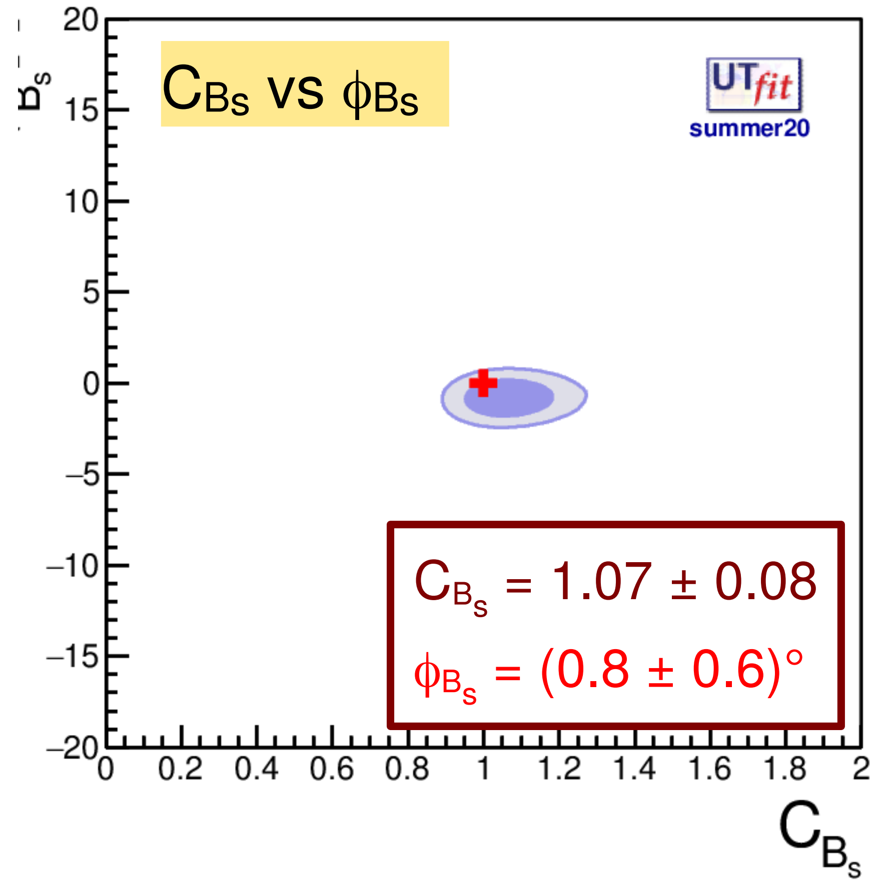
dark: 68%

light: 95%

SM: red cross

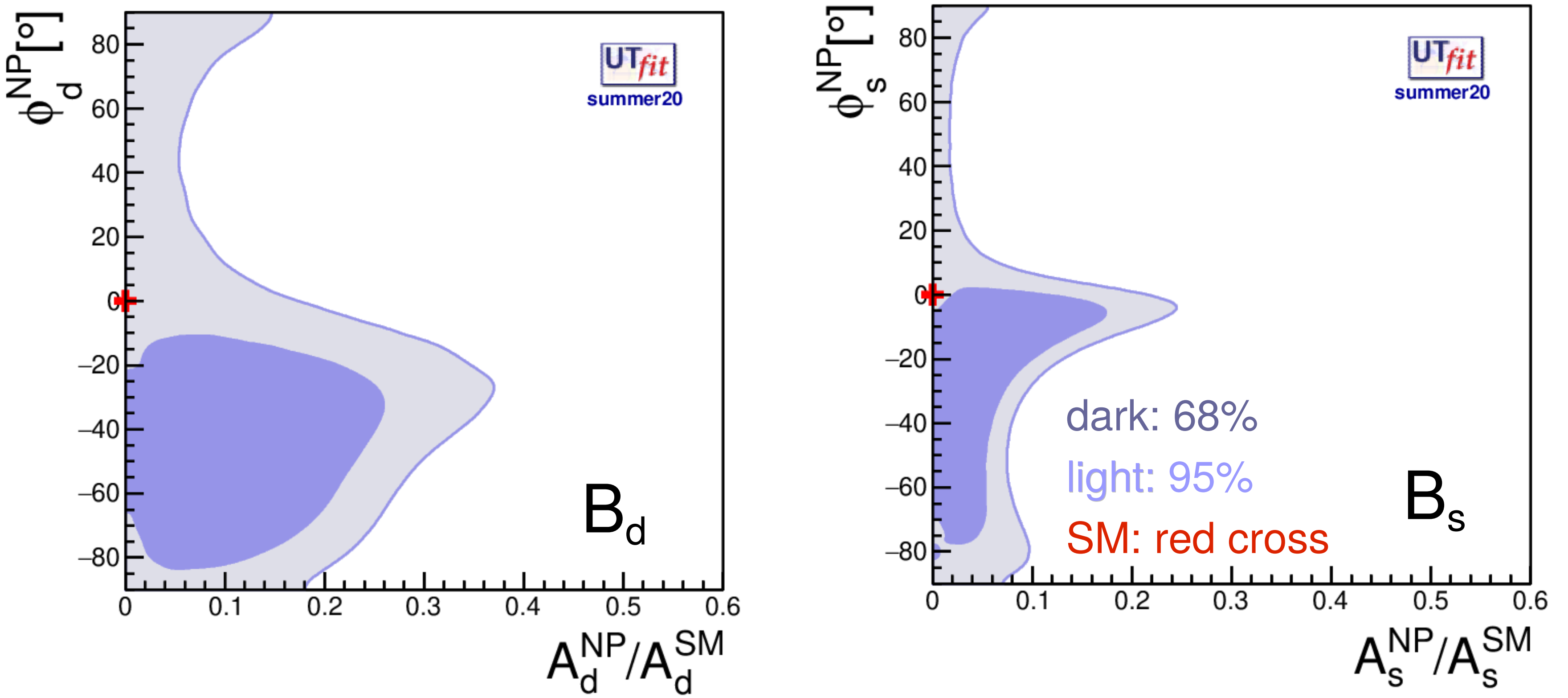
$$A_q = C_{B_q} e^{2i\phi_{B_q}} A_q^{SM} e^{2i\phi_q^{SM}}$$





NP parameter results

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



The ratio of NP/SM amplitudes is:

< 26% @68% prob. (37% @95%) in B_d mixing

< 18% @68% prob. (25% @95%) in B_s mixing

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

testing the new-physics scale

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

RGE

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

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

$$\begin{aligned}
Q_1^{q_i q_j} &= \bar{q}_{jL}^{\alpha}\gamma_\mu q_{iL}^{\alpha}\bar{q}_{jL}^{\beta}\gamma^\mu q_{iL}^{\beta}\,, \\
Q_2^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha}\bar{q}_{jR}^{\beta} q_{iL}^{\beta}\,, \\
Q_3^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\beta}\bar{q}_{jR}^{\beta} q_{iL}^{\alpha}\,, \\
Q_4^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha}\bar{q}_{jL}^{\beta} q_{iR}^{\beta}\,, \\
Q_5^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\beta}\bar{q}_{jL}^{\beta} q_{iR}^{\alpha}\,.
\end{aligned}$$

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

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 $\Delta F=2$ processes)

testing the TeV scale

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

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

α (L_i) is the coupling among NP and SM
- $\alpha \sim 1$ for strongly coupled NP
- $\alpha \sim \alpha_W$ (α_S) in case of loop coupling through weak (strong) interactions

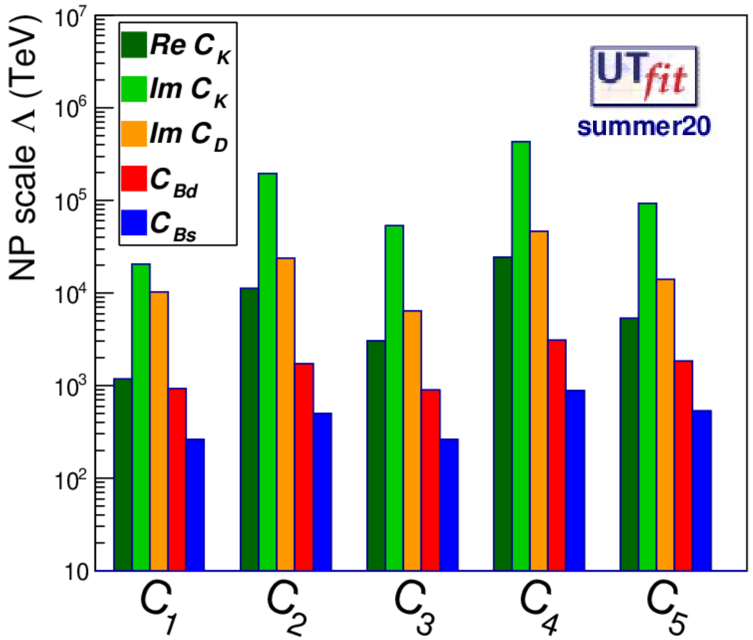
If no NP effect is seen lower bound on NP scale Λ

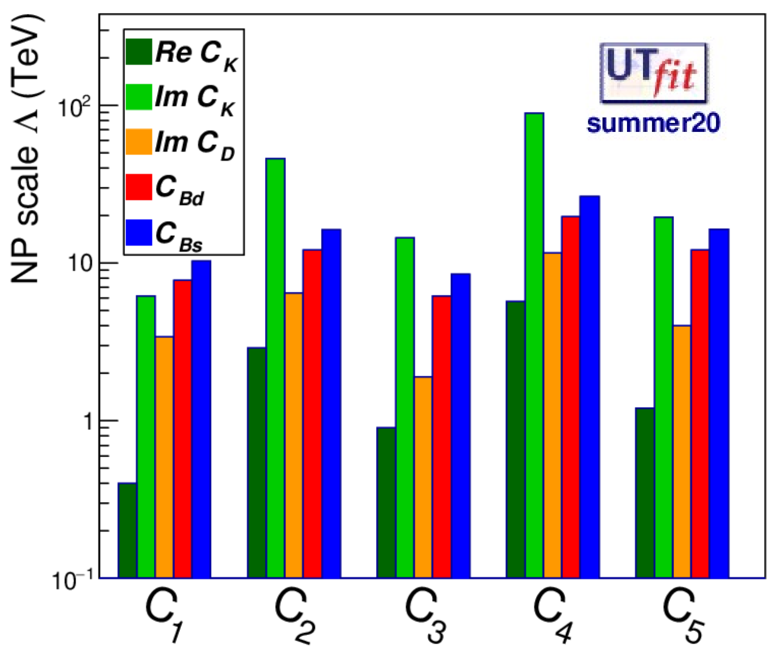
F is the flavour coupling and so
F_{SM} is the combination of CKM factors for the considered process

results from the Wilson coefficients

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

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





$\Lambda > 4.3\ 10^5$ TeV

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

$\Lambda > 89$ TeV

$\alpha \sim \alpha_W$ in case of loop coupling through weak interactions
$\Lambda > 1.3\ 10^4$ TeV

$\alpha \sim \alpha_W$ in case of loop coupling through weak interactions
$\Lambda > 2.7$ TeV

for lower bound for loop-mediated contributions, simply multiply by α_s (~ 0.1) or by α_W (~ 0.03).

conclusions

- SM analysis displays very good overall consistency
- Still open discussion on semileptonic inclusive vs exclusive: V_{ub} inclusive still the outlier...
- UTA provides determination of NP contributions to $\Delta F=2$ amplitudes. It currently leaves space for NP at the level of 25-35%
- 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 not only complementary to direct searches, but they might be the main way to glimpse at new physics.
- Need to keep an eye on the up-quark sector...

Back up slides

V_{cb} and V_{ub}

$|V_{cb}|$ *(excl)* = $(38.9 \pm 0.6)\ 10^{-3}$

$|V_{cb}|$ *(incl)* = $(42.19 \pm 0.78)\ 10^{-3}$

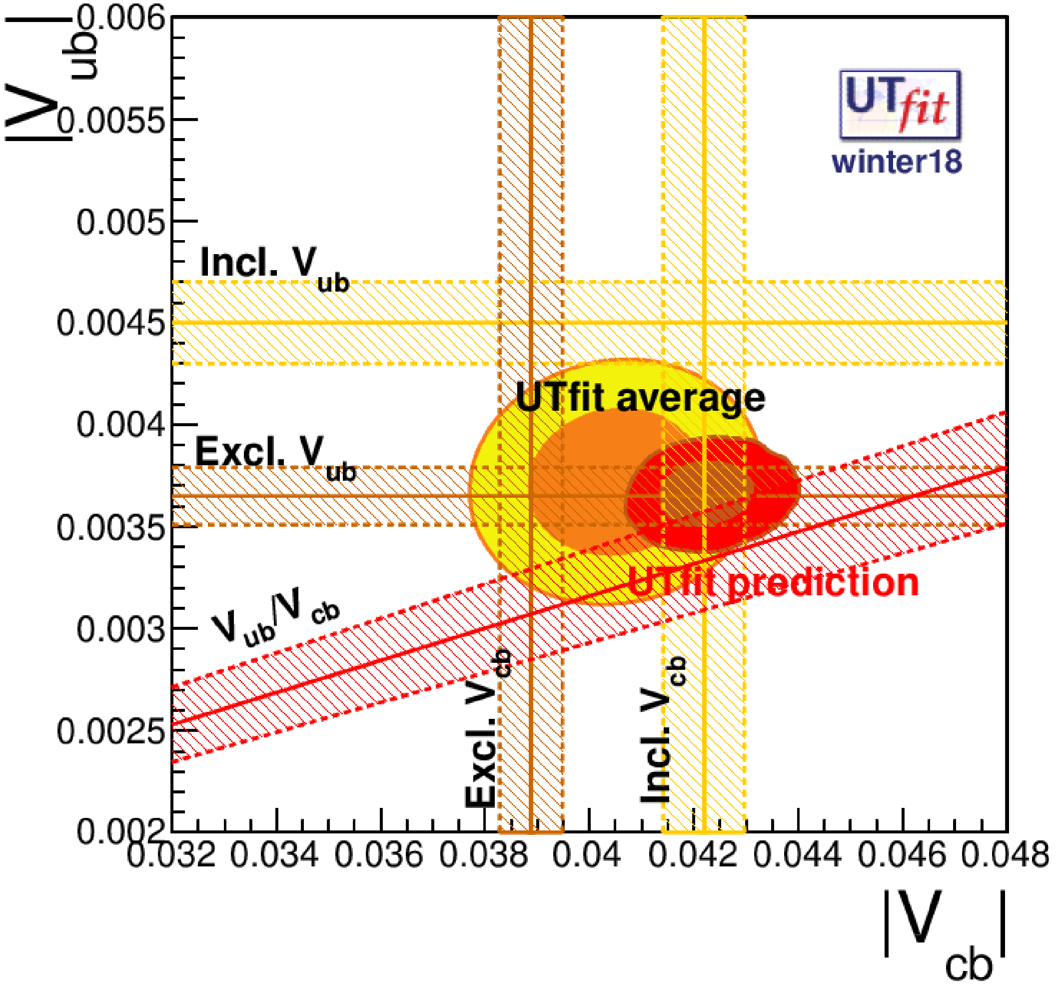
~3.3σ discrepancy

$|V_{ub}|$ *(excl)* = $(3.65 \pm 0.14)\ 10^{-3}$

$|V_{ub}|$ *(incl)* = $(4.50 \pm 0.20)\ 10^{-3}$

~3.4σ discrepancy

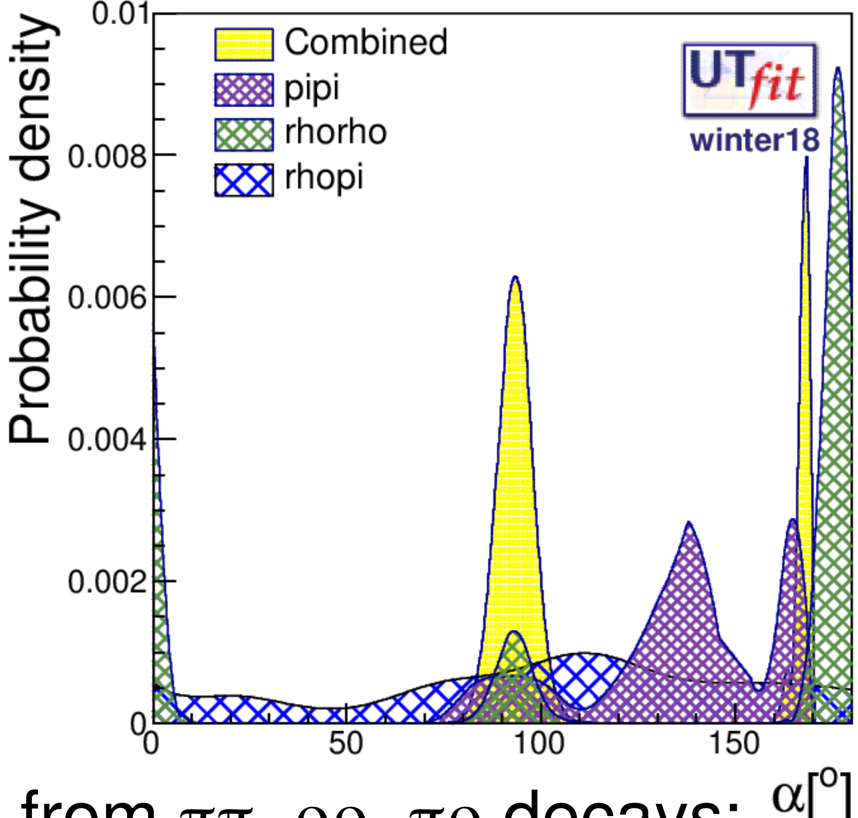
$|V_{ub} / V_{cb}|$ *(LHCb)* = $(7.9 \pm 0.6)\ 10^{-2}$



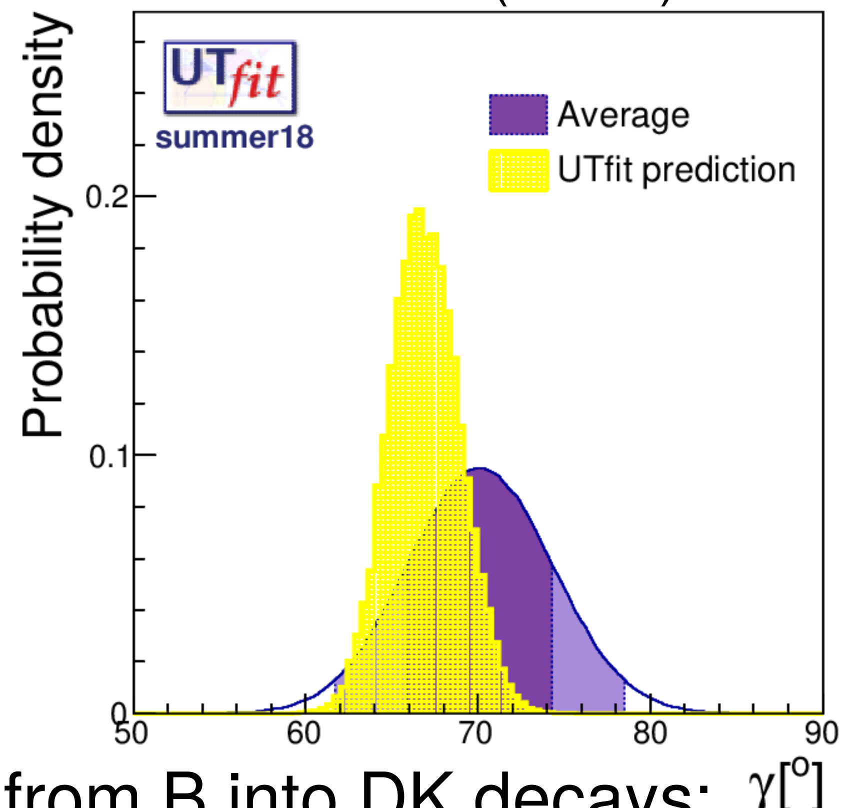
numbers mainly from HFLAV 2016

$\sin 2\alpha$ (ϕ_2) and γ (ϕ_3)

α updated with latest $\pi\pi/\rho\rho$ BR and C/S results



γ updated with all the latest results (LHCb)



α from $\pi\pi$, $\rho\rho$, $\pi\rho$ decays:

combined SM: $(93.3 \pm 5.6)^\circ$

UTfit prediction: $(90.1 \pm 2.2)^\circ$

γ from B into DK decays:

combined: $(70.0 \pm 4.2)^\circ$

UTfit prediction: $(65.8 \pm 2.2)^\circ$

α from HFLAV: 84.9 ± 5.1

γ from HFLAV: 73.5 ± 5.1

lattice QCD inputs

obtained excluding the given constraint from the fit

updated in winter 2018

Observables	Measurement	Prediction	Pull (#σ)
B_K	0.740 ± 0.029	0.848 ± 0.072	~ 1.3
f_{Bs}	0.226 ± 0.005	0.222 ± 0.006	< 1
f_{Bs}/f_{Bd}	1.203 ± 0.013	1.225 ± 0.035	< 1
B_{Bs}/B_{Bd}	1.032 ± 0.038	1.10 ± 0.05	< 1
B_{Bs}	1.35 ± 0.06	1.33 ± 0.07	< 1

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

for Bk, fBs, fBs/fBd:

FLAG Nf=2+1+1 (single result) and Nf=2+1 average

for B_{Bs}, B_{bs}/B_{bd}:

web update of FLAG Nf=2+1 average (no Nf=2+1+1 results yet)

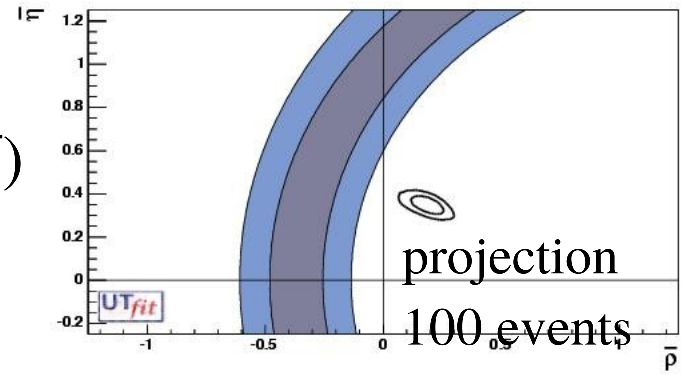
updating the FNAL/MILC result to FNAL/MILC 2016 (1602.03560)

some old plots coming back to fashion:

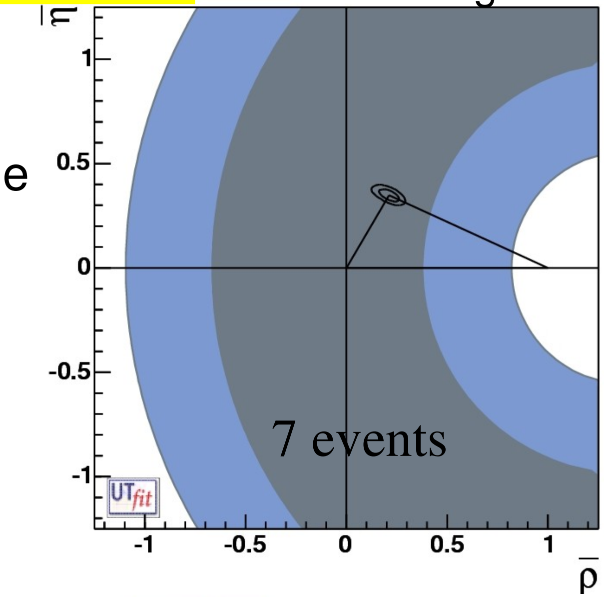
As NA62 and KOTO are analysing data:

$BR(K^+ \to \pi^+ \nu \bar{\nu})$

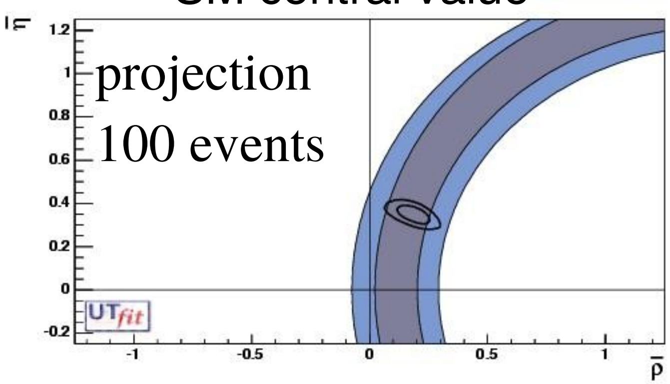
E949 central value

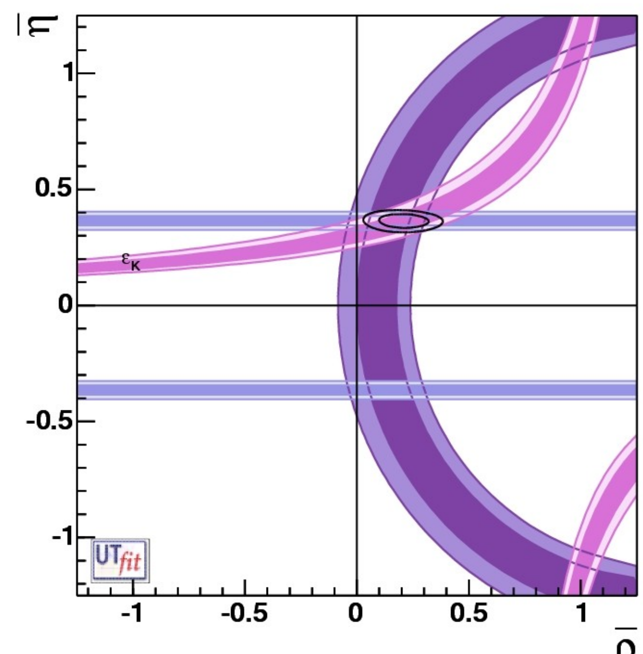


2007 global fit area



SM central value





including
$BR(K^0 \to \pi^0 \nu \bar{\nu})$
SM central value

new-physics-specific constraints

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

semileptonic asymmetries in B^0 and B_s: sensitive to NP effects in both size and phase. Currently using HFLAV.

BaBar, Belle, D0 + LHCb

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

D0 arXiv:1106.6308

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

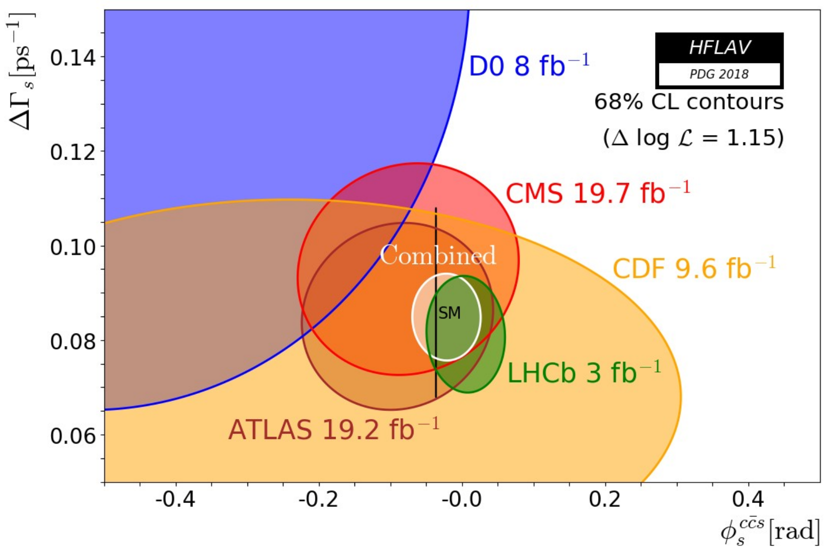
$$A_{SL}^{\mu\mu} = \frac{f_d \chi_{d0} A_{SL}^{d} + f_s \chi_{s0} A_{SL}^{s}}{f_d \chi_{d0} + f_s \chi_{s0}}$$

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

$\tau^{FS}(B_s) = 1.509 \pm 0.004$ ps **HFLAV**

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

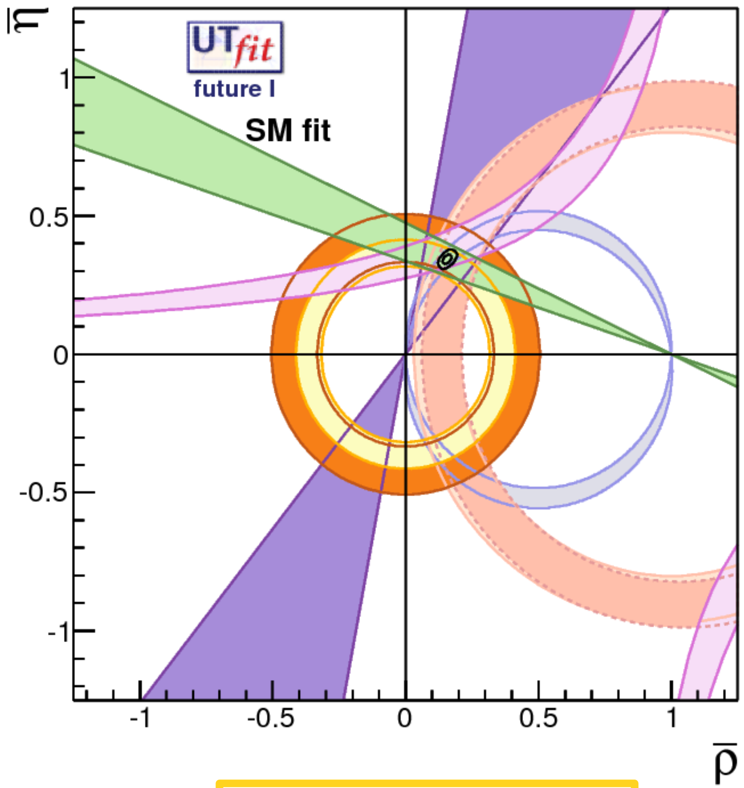
angular analysis as a function of proper time and b-tagging

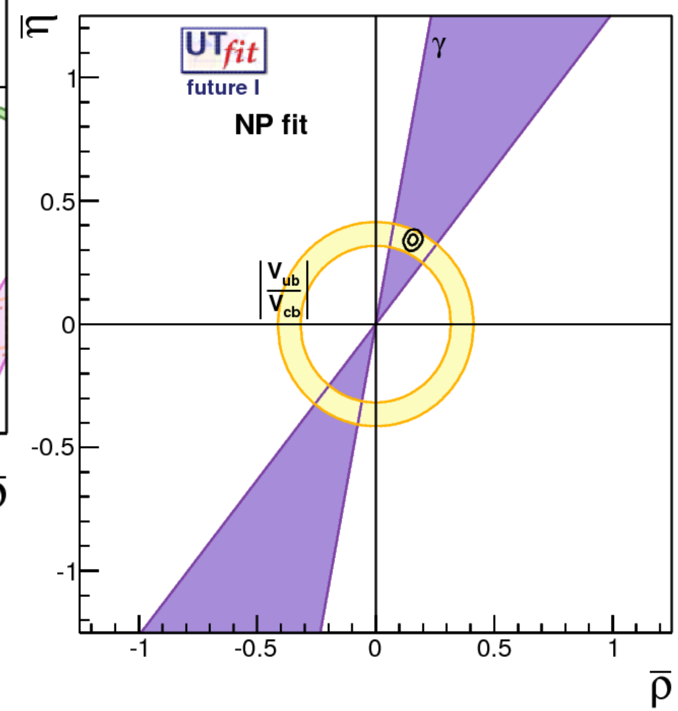


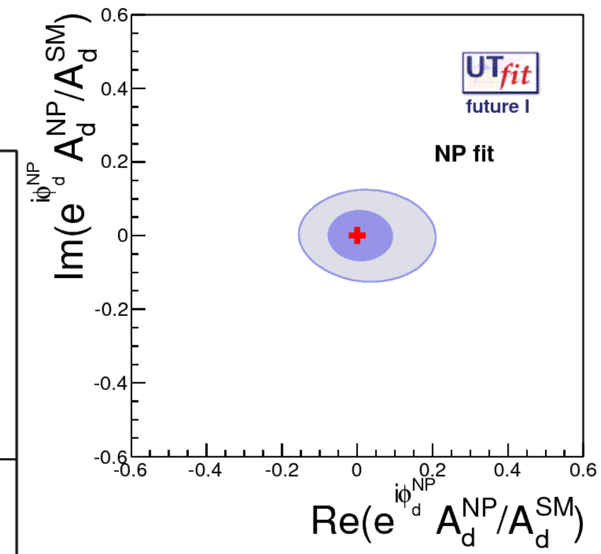
Look at the near future

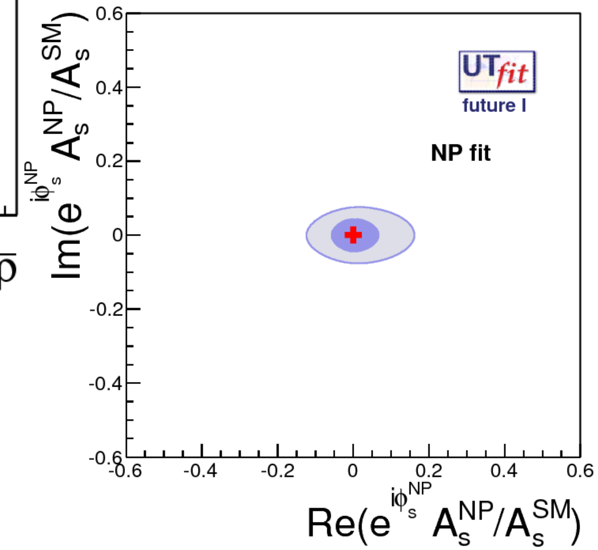
future I scenario:
errors from
Belle II at 5/ab
+ LHCb at 10/fb

preliminary









$\rho = \pm\ 0.015$
$\eta = \pm\ 0.015$

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

current sensitivity

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

$\rho = \pm\ 0.016$
$\eta = \pm\ 0.019$