Status of global CKM fits

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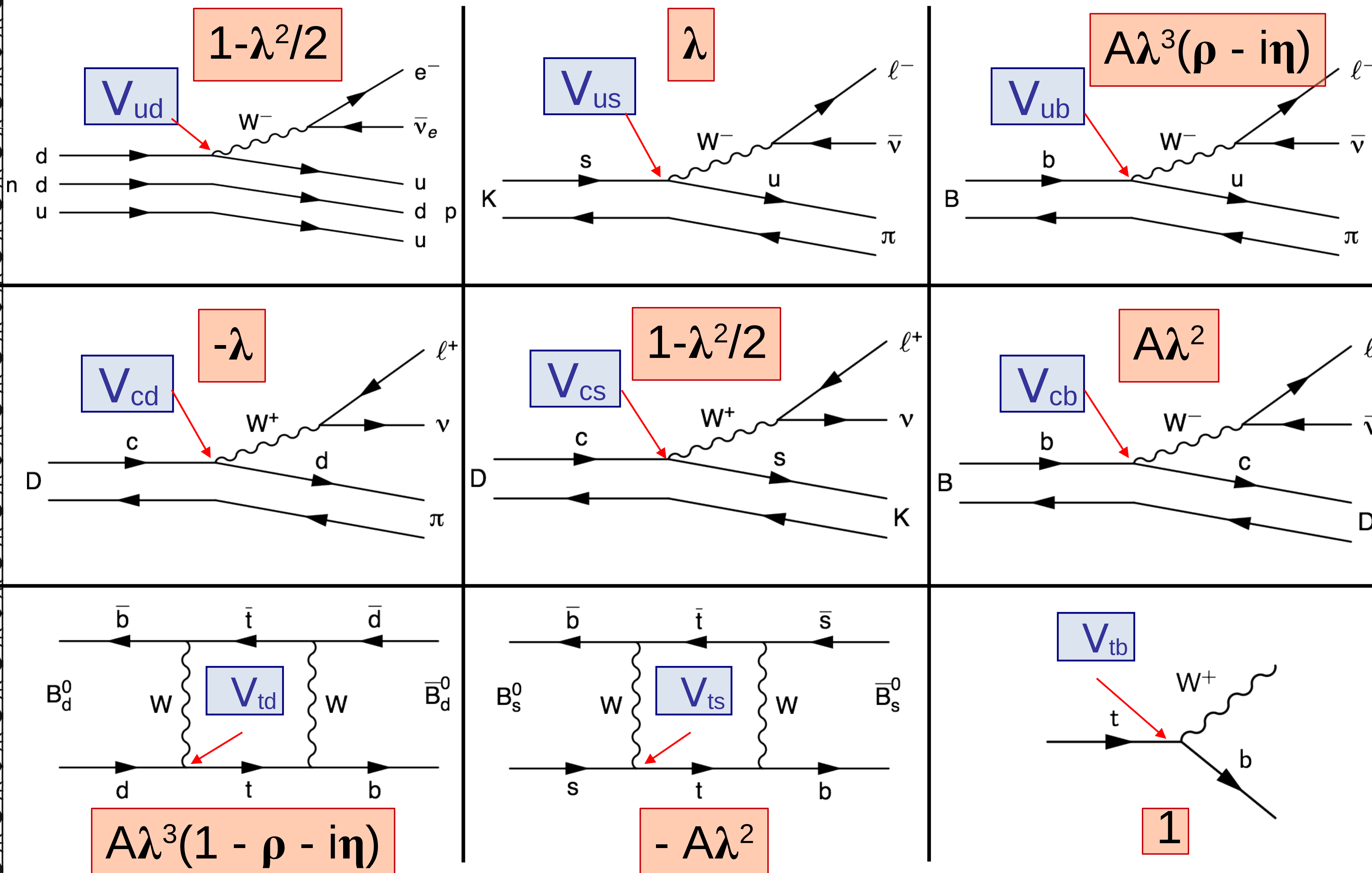
CK @CKM2006
in Nagoya

10th International Workshop on the CKM Unitarity Triangle
Friday September 21st 2018
Heidelberg, Germany

CKM matrix and the Wolfenstein parameterisation



CKM matrix and Unitarity Triangle

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

many observables functions of ρ and η: overconstraining

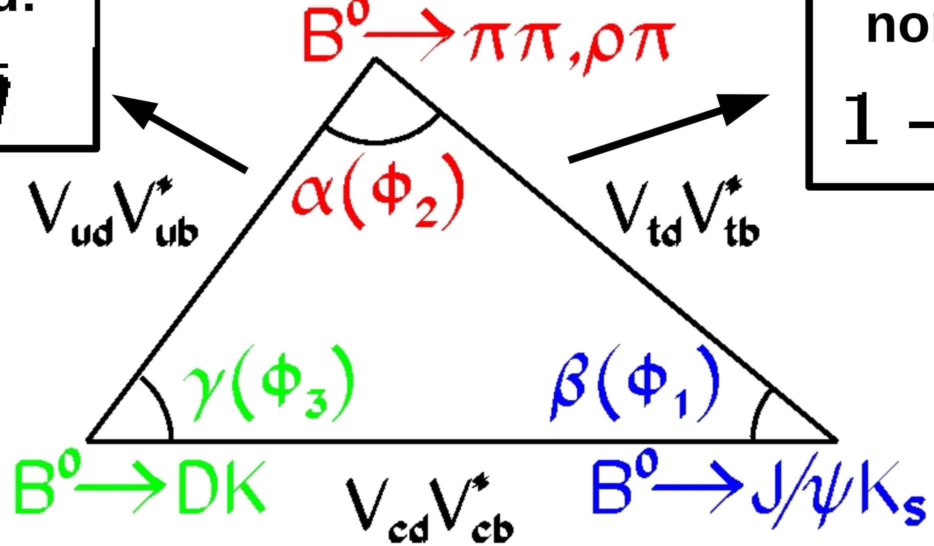
$$\alpha = \pi - \beta - \gamma$$

normalized:

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

normalized:

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



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

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

CKM parameter extraction

example of observables

$(b \to u)/(b \to c)$	$\bar{\rho}^2 + \bar{\eta}^2$	$\bar{\Lambda}, \lambda_1, F(1), \ldots$
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

Joined WG4+WG5, Thursday

CKM fitter

report from Vale Silva

Charles et al. (CKMfitter Group)
Phys. Rev. D 91, 073007 (2015)
arXiv:1501.05013 [hep-ph]

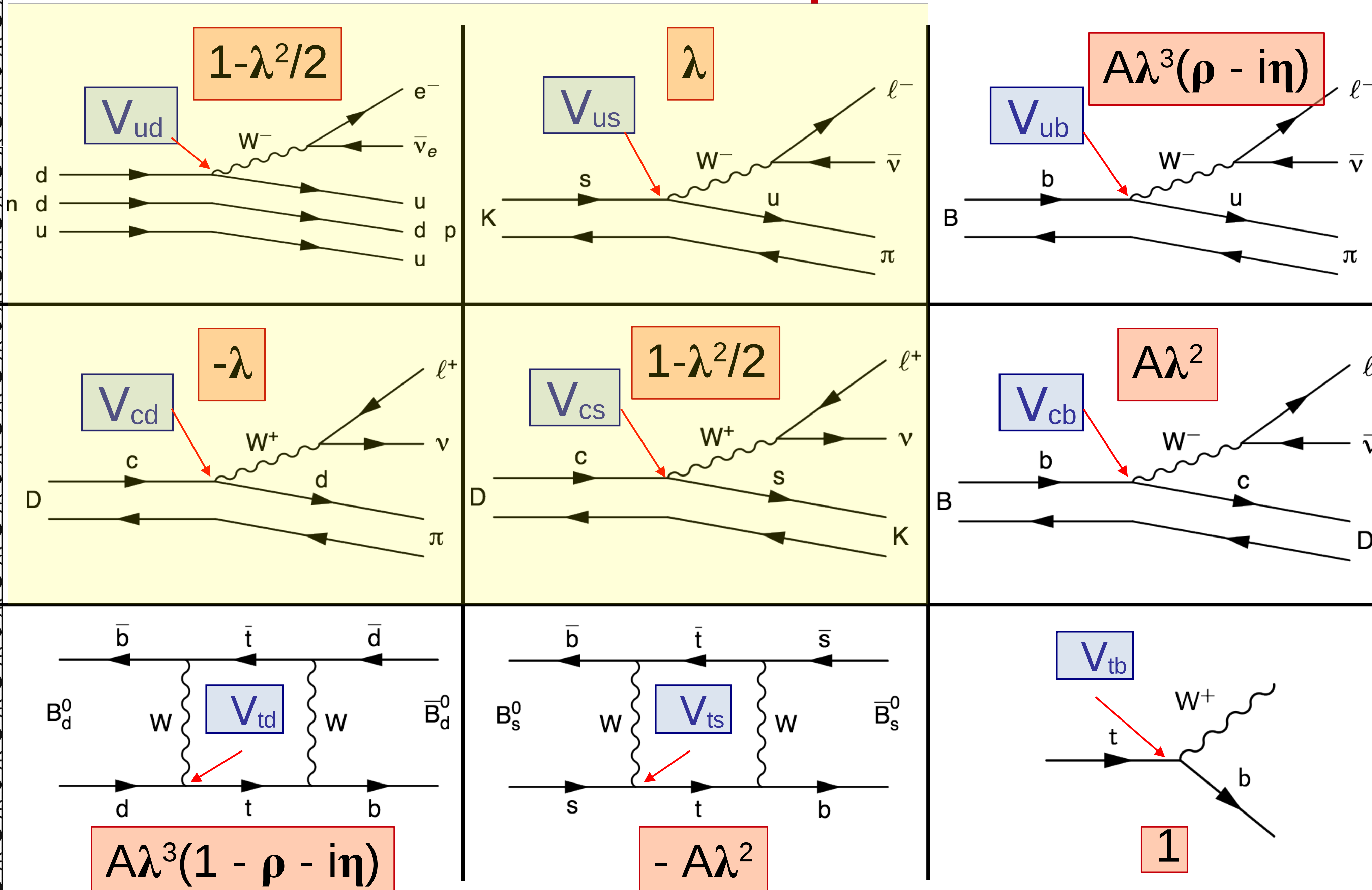
UTfit

report from MB

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

Other UT analyses exist, by:
Laiho&Lunghi&Van de Water @http://latticeaverages.org/,
Lunghi&Soni (1010.6069),
etc..

CKM matrix and the Wolfenstein parameterisation



first two generations:

mainly decoupled from the third:
the global fits include the relevant inputs

V_{ud} from
nuclear beta decays:

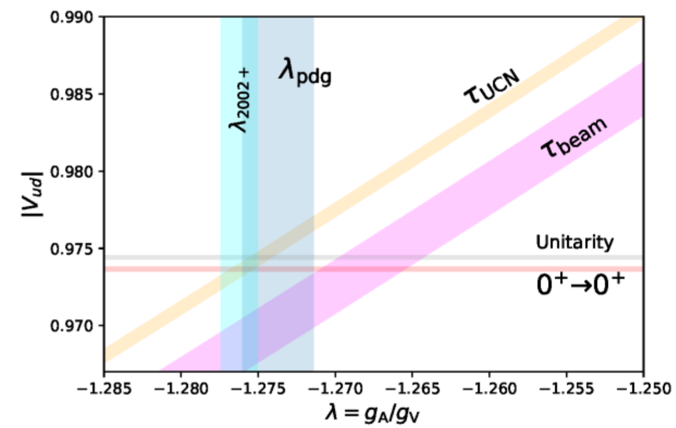
$$V_{ud} = 0.97420 \pm 0.00021$$

arXiv:1411.5987 [nucl-ex]
updated in CKM2016,
and PDG

Recent (two weeks) shift in radiative corrections:
4 σ tension between nuclear beta decay and V_{us}

Neutron lifetime and g_A/g_V
Saunders

- This is the situation today
- Next generation of λ experiments, plus resolution of lifetime puzzle, needed to distinguish between nuclear beta decay value and unitarity value of V_{ud}



20 September 2018
CKM Workshop

Seng, Gorchtein, Patel, and Ramsey-Musolf, 9/2018 (arXiv:1807.10197).

WG1, Thursday
Neutron lifetime and g_A/g_V, Saunders
|Vus|/|Vud| from K_μ2/π_μ2, Tantalo

first two generations:

mainly decoupled from the third:
the global fits include the relevant inputs

$|V_{us}|$ from K semileptonic decays modulo the form factor at $q^2=0$

$|V_{us}|$ = 0.2248 ± 0.0007 from FLAV average

PDG2018 value:
0.2243 ± 0.0005

CKMfitter report from Vale Silva,
Joint WG4+WG5, Thursday

CKM	Process	Observables			Theoretical inputs		
$\|V_{ud}\|$	$0^+ \to 0^+ \beta$	$\|V_{ud}\|_{\rm nucl}$	$=$	$0.97420 \pm 0 \pm 0.00021$	Nuclear matrix elements		
$\|V_{us}\|$	$K \to \pi\ell\nu$	$\|V_{us}\|_{\rm SL} f_+^{K\to\pi}(0)$	$=$	0.2165 ± 0.0004	$f_+^{K\to\pi}(0)$	$=$	$0.9681 \pm 0.0014 \pm 0.0022$
	$K \to e\nu$	$\mathcal{B}(K \to e\nu)$	$=$	$(1.582 \pm 0.007) \cdot 10^{-5}$	f_K	$=$	$155.6 \pm 0.2 \pm 0.6$ MeV
	$K \to \mu\nu$	$\mathcal{B}(K \to \mu\nu)$	$=$	0.6356 ± 0.0011			
	$\tau \to K\nu$	$\mathcal{B}(\tau \to K\nu)$	$=$	$(0.6960 \pm 0.0096) \cdot 10^{-2}$			
$\frac{\|V_{us}\|}{\|V_{ud}\|}$	$K \to \mu\nu/\pi \to \mu\nu$	$\frac{\mathcal{B}(K \to \mu\nu)}{\mathcal{B}(\pi \to \mu\nu)}$	$=$	1.3367 ± 0.0029	f_K/f_π	$=$	$1.1959 \pm 0.0007 \pm 0.0029$
	$\tau \to K\nu/\tau \to \pi\nu$	$\frac{\mathcal{B}(\tau \to K\nu)}{\mathcal{B}(\tau \to \pi\nu)}$	$=$	$(6.438 \pm 0.094) \cdot 10^{-2}$			
$\|V_{cd}\|$	νN	$\|V_{cd}\|_{\rm not\ lattice}$	$=$	0.230 ± 0.011			
	$D \to \mu\nu$	$\mathcal{B}(D \to \mu\nu)$	$=$	$(3.74 \pm 0.17) \cdot 10^{-4}$	f_{D_s}/f_D	$=$	$1.175 \pm 0.001 \pm 0.004$
	$D \to \pi\ell\nu$	$\|V_{cd}\| f_+^{D\to\pi}(0)$	$=$	0.1426 ± 0.0019	$f_+^{D\to\pi}(0)$	$=$	$0.621 \pm 0.016 \pm 0.012$
$\|V_{cs}\|$	$W \to c\bar{s}$	$\|V_{cs}\|_{\rm not\ lattice}$	$=$	$0.94^{+0.32}_{-0.26} \pm 0.13$			
	$D_s \to \tau\nu$	$\mathcal{B}(D_s \to \tau\nu)$	$=$	$(5.55 \pm 0.24) \cdot 10^{-2}$	f_{D_s}	$=$	$247.8 \pm 0.3 \pm 2.0$ MeV
	$D_s \to \mu\nu$	$\mathcal{B}(D_s \to \mu\nu)$	$=$	$(5.39 \pm 0.16) \cdot 10^{-3}$			
	$D \to K\ell\nu$	$\|V_{cs}\| f_+^{D\to K}(0)$	$=$	0.7226 ± 0.0034	$f_+^{D\to K}(0)$	$=$	$0.741 \pm 0.010 \pm 0.012$

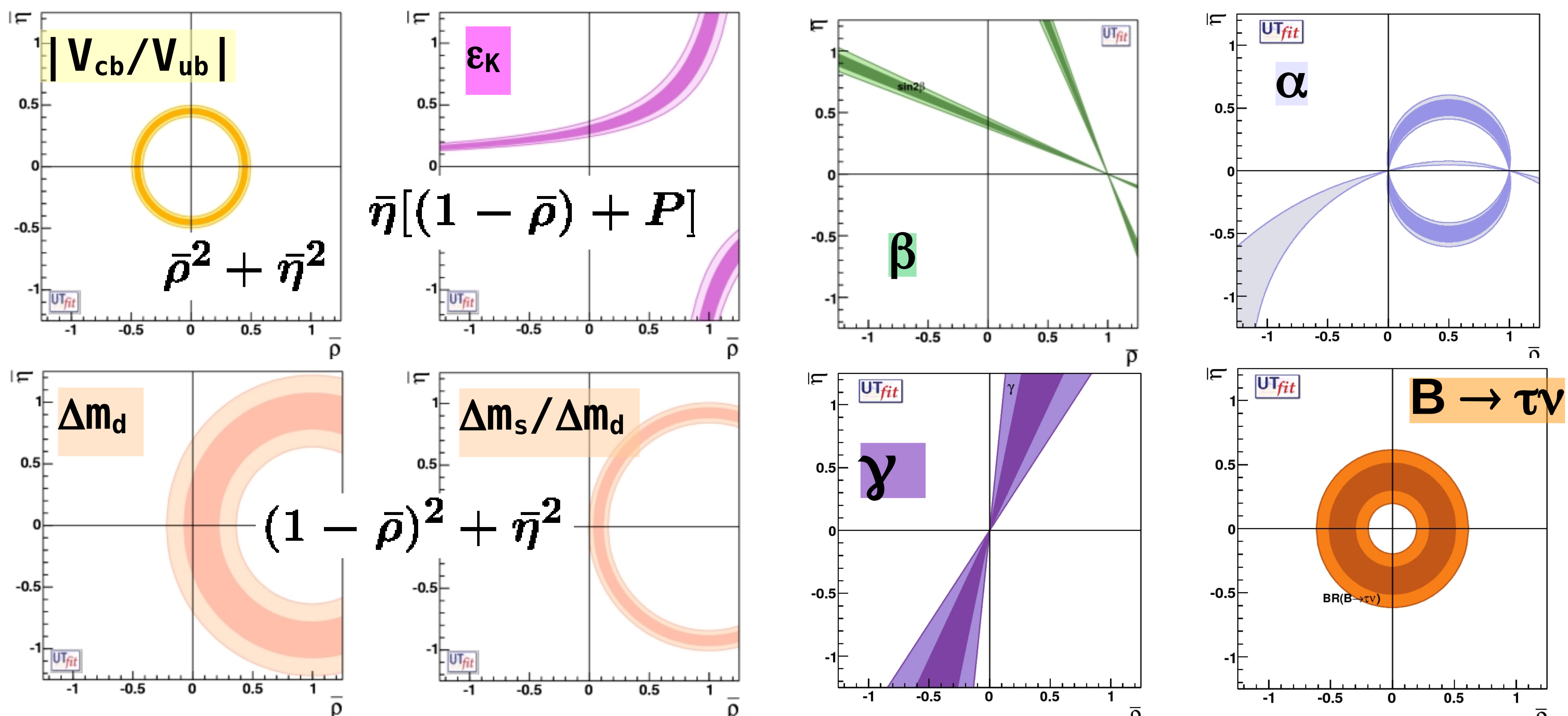
third generation: the observables

Tree-level diagrams: $|V_{ub}|$, $|V_{cb}|$, γ

Loop diagrams: Δm_d, Δm_s, ε_K

CP-conserving: $|V_{xb}|$, Δm_d, Δm_s

CP-violating: $\sin(2\beta)$, α, γ, ε_K

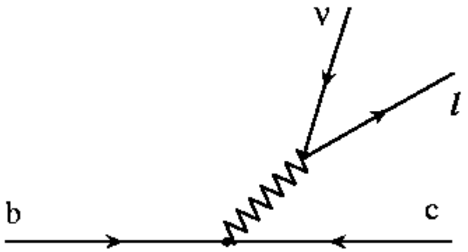


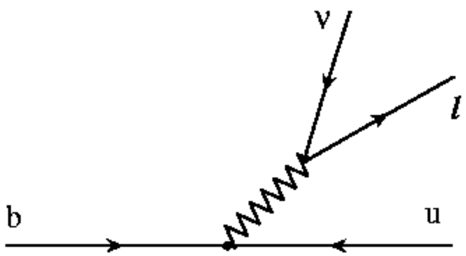
V_{cb} and V_{ub} from semileptonic B decays

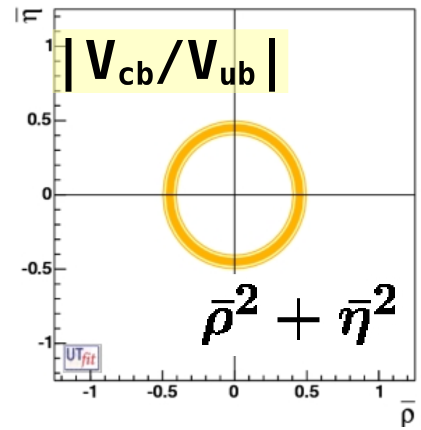
From tree level processes:
semileptonic B decays
$B \to X_{u,c}\, l\nu$

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

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







V_{cb} and V_{ub} from semileptonic B decays

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

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

~3.3σ discrepancy

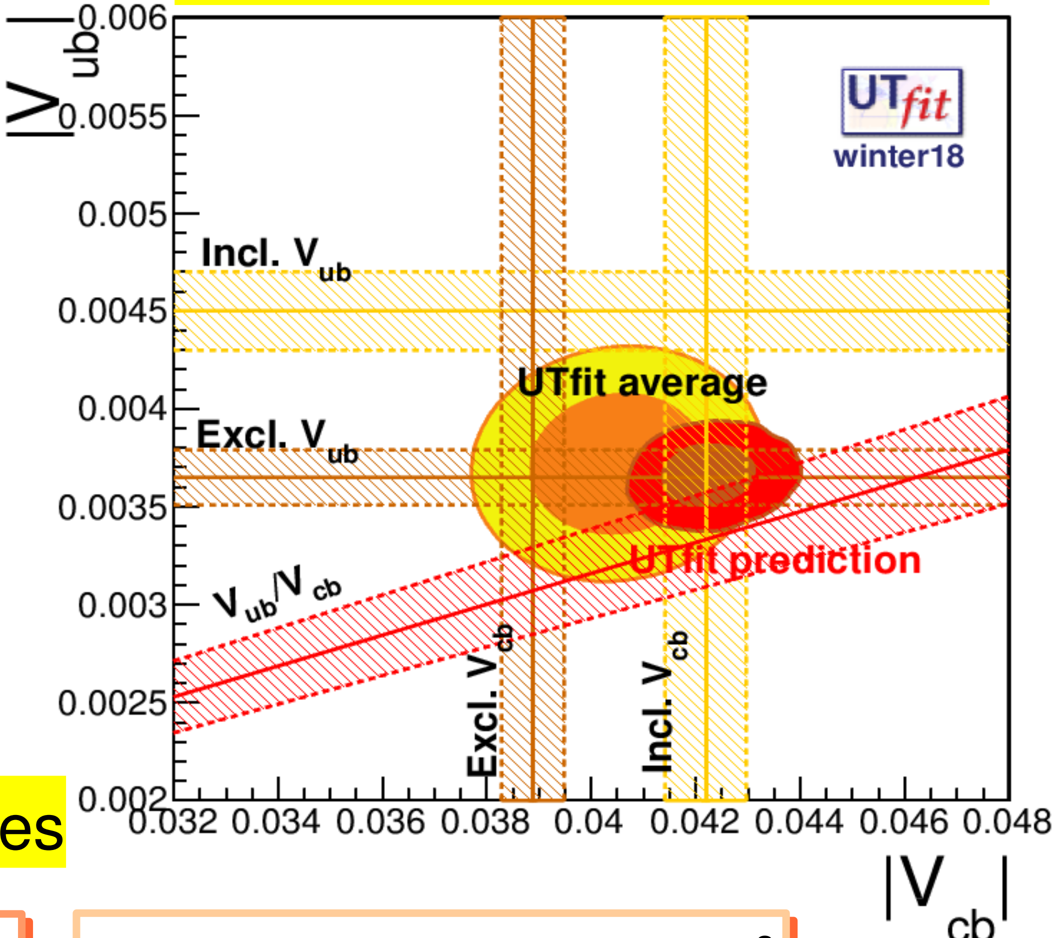
$|V_{ub}|$ *(excl)* = $(3.65 \pm 0.14)\ 10^{-3}$

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

~3.4σ discrepancy

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

numbers from HFLAV 2016



2D D'Agostini skeptical averages

$|V_{cb}| = (42.14 \pm 0.97)\ 10^{-3}$

uncertainty ~ 2.4%

$|V_{ub}| = (3.76 \pm 0.24)\ 10^{-3}$

uncertainty ~ 6.4%

V_{cb} and V_{ub}

talk by Lieret, BGL D*lnu
arXiv:1809.03290
talk by Gambino, Dlnu
arXiv:1411.6560

$|V_{cb}|$ *(excl)* = $(41.73 \pm 0.74)\ 10^{-3}$

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

~3.3σ discrepancy

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

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

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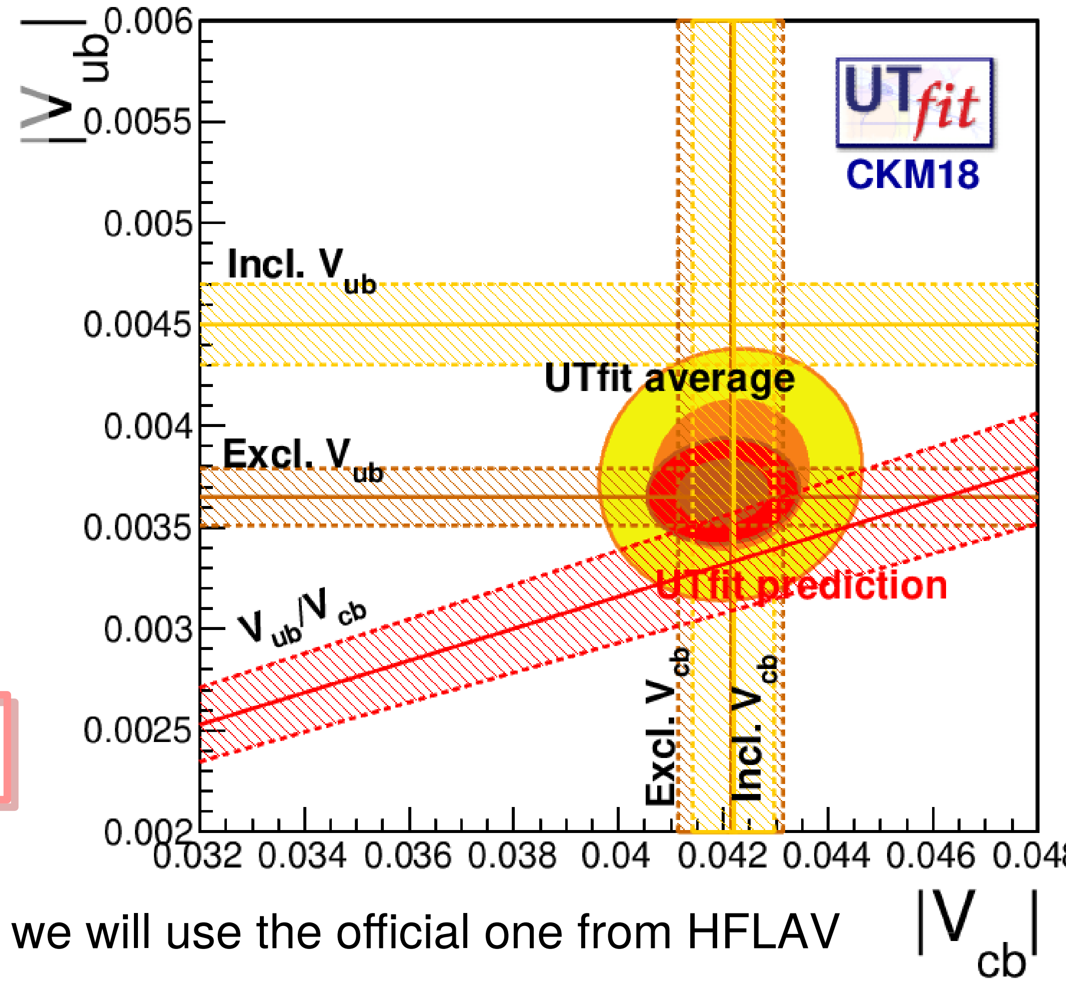
$|V_{ub} / V_{cb}|$ *(LHCb)* = $(7.9 \pm 0.6)\ 10^{-2}$



preliminary for CKM 2018

we will use the official one from HFLAV

$|V_{cb}| = (42.14 \pm 0.97)\ 10^{-3}$

uncertainty ~ 2.4%

$|V_{ub}| = (3.76 \pm 0.24)\ 10^{-3}$

uncertainty ~ 6.4%

V_{cb} and V_{ub}

new average

Belle B → D* lν combined (tagged and untagged), BGL
Belle and Babar B → Dlν combined, BGL:

$|V_{cb}|$ *(excl)* = (41.2 ± 0.6(exp) ± 0.9(LQCD) ± 0.2(EM)) 10^{-3}

$|V_{cb}|$ *(incl)* = (42.2 ± 0.4 ± 0.6) 10^{-3}

no discrepancy!

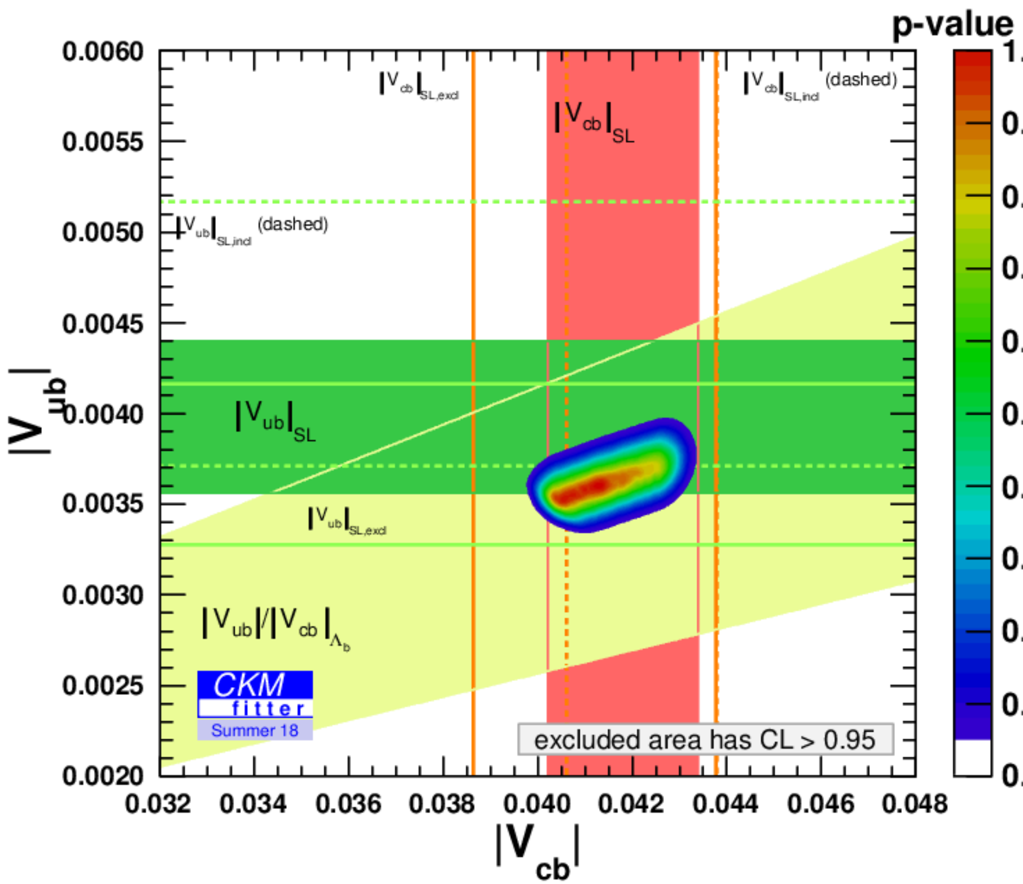
$|V_{ub}|$ *(excl)* = (3.72 ± 0.09 ± 0.22) 10^{-3}

$|V_{ub}|$ *(incl)* = (4.44 ± 0.17 ± 0.31) 10^{-3}

update for Summer 2018

$|V_{cb}|$ = (41.8 ± 0.4 ± 0.6) 10^{-3}

$|V_{ub}|$ = (3.98 ± 0.08 ± 0.22) 10^{-3}



CKM fitter

V_{cb} and V_{ub}

new average

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$|V_{ub}|$ *(incl)* = (4.44 ± 0.17 ± 0.31) 10^{-3}

- Theo. inputs: published Lattice papers, **with error budgets**, different sources of syst. uncertainty are **combined linearly**, using FLAG reports as a guide to sort results

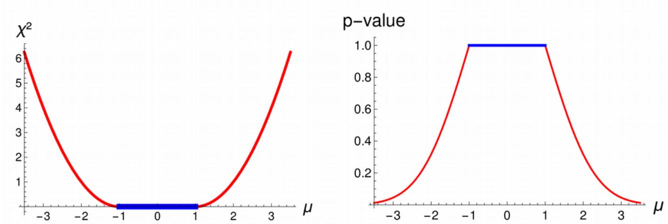
$$\mathcal{L} \overset{Rfit}{=} \mathcal{L}_{stat} \times \mathcal{L}_{theo},$$
$$\chi^2 = -2 \ln \mathcal{L}$$

$\mathcal{L}_{stat}$: exp. data

$\mathcal{L}_{theo}$: had. inputs

[cf. Charles, Descotes-G., Niess, LVS '17]

Example in 1D, $0 \pm 1_{stat} \pm 1_{theo}$ ($N_{dof} = 1$)



χ^2: flat bottom, quadratic walls

update for Summer 2018

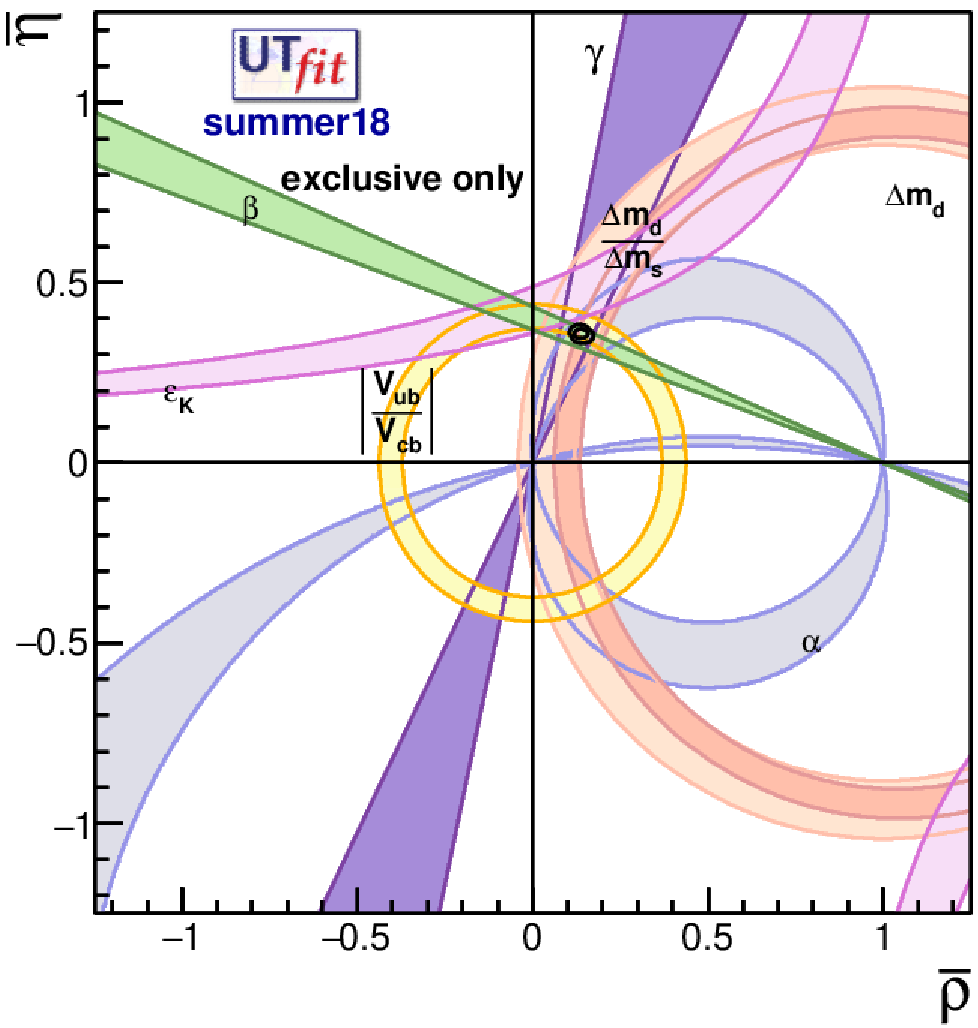
$|V_{cb}|$ = (41.8 ± 0.4 ± 0.6) 10^{-3}

$|V_{ub}|$ = (3.98 ± 0.08 ± 0.22) 10^{-3}

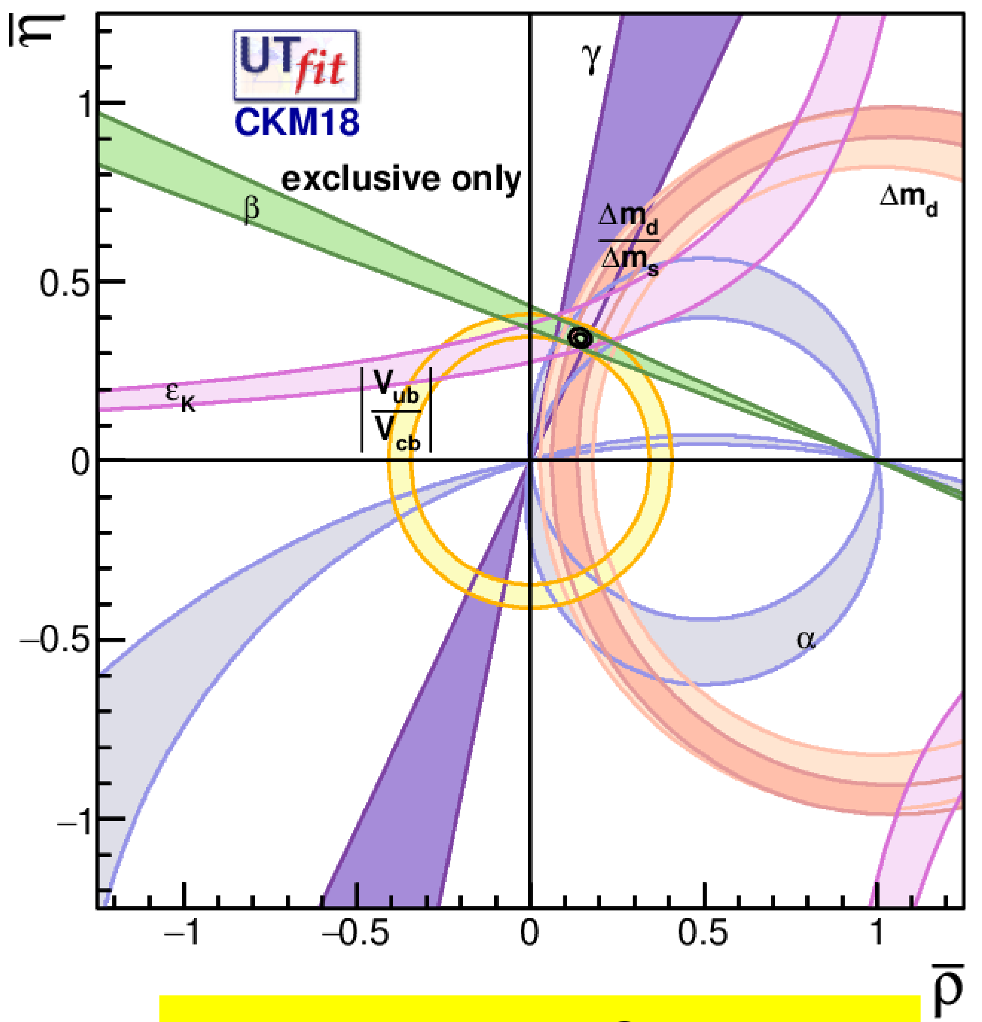
CKMfitter report from Vale Silva,
Joint WG4+WG5, Thursday

only inclusives: before and now

only exclusive values



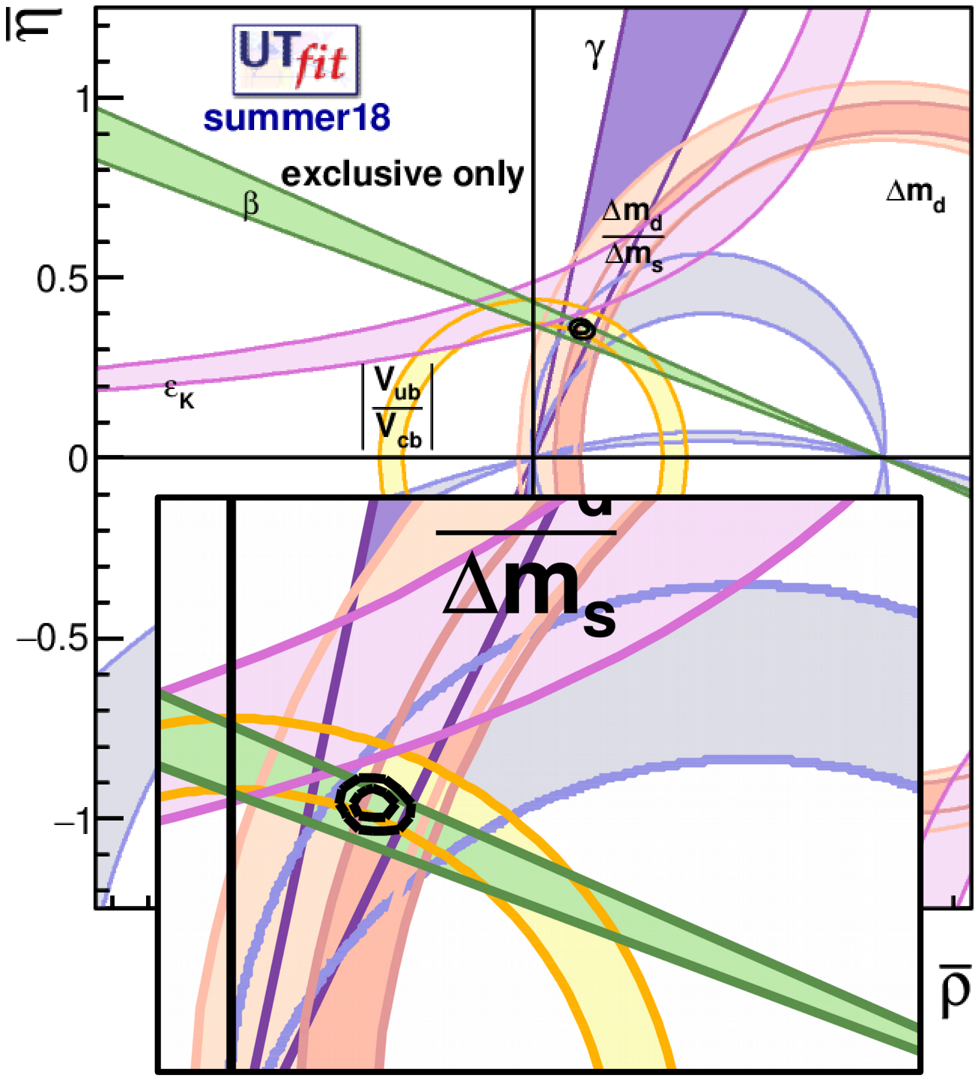
only exclusive values



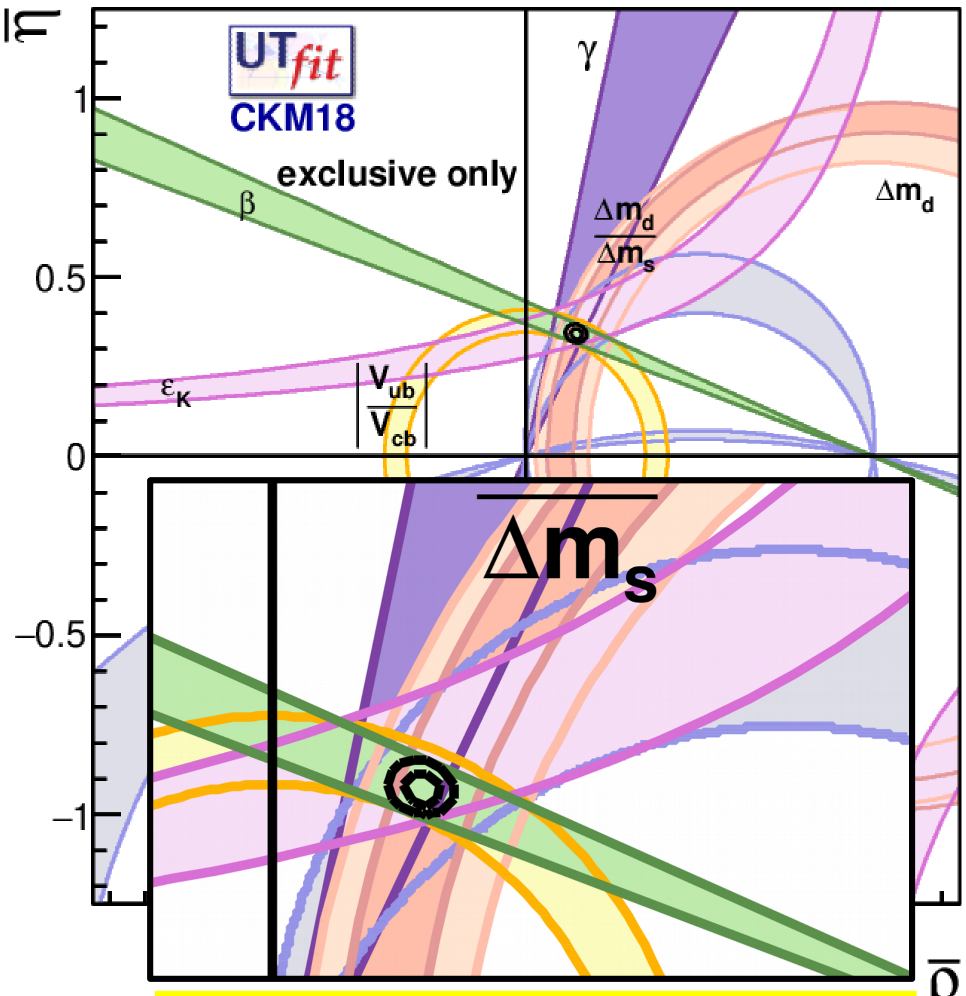
preliminary for CKM 2018

only inclusives: before and now

only exclusive values



only exclusive values



preliminary for CKM 2018

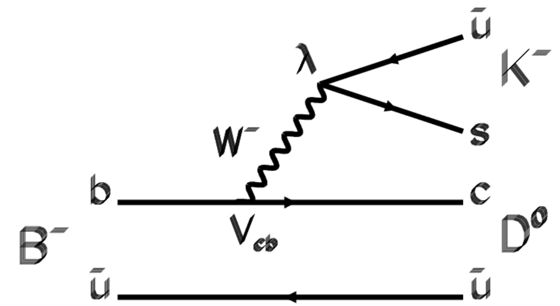
γ (ϕ_3) from B decays in DK

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 → c and b → u transitions: two amplitudes leading to the same final states

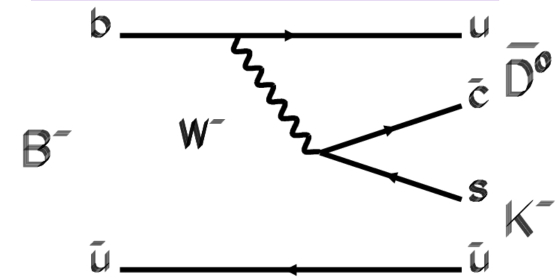
some rates can be really small: ~ 10^{-7}

need to combine all the possible modes and analysis methods.



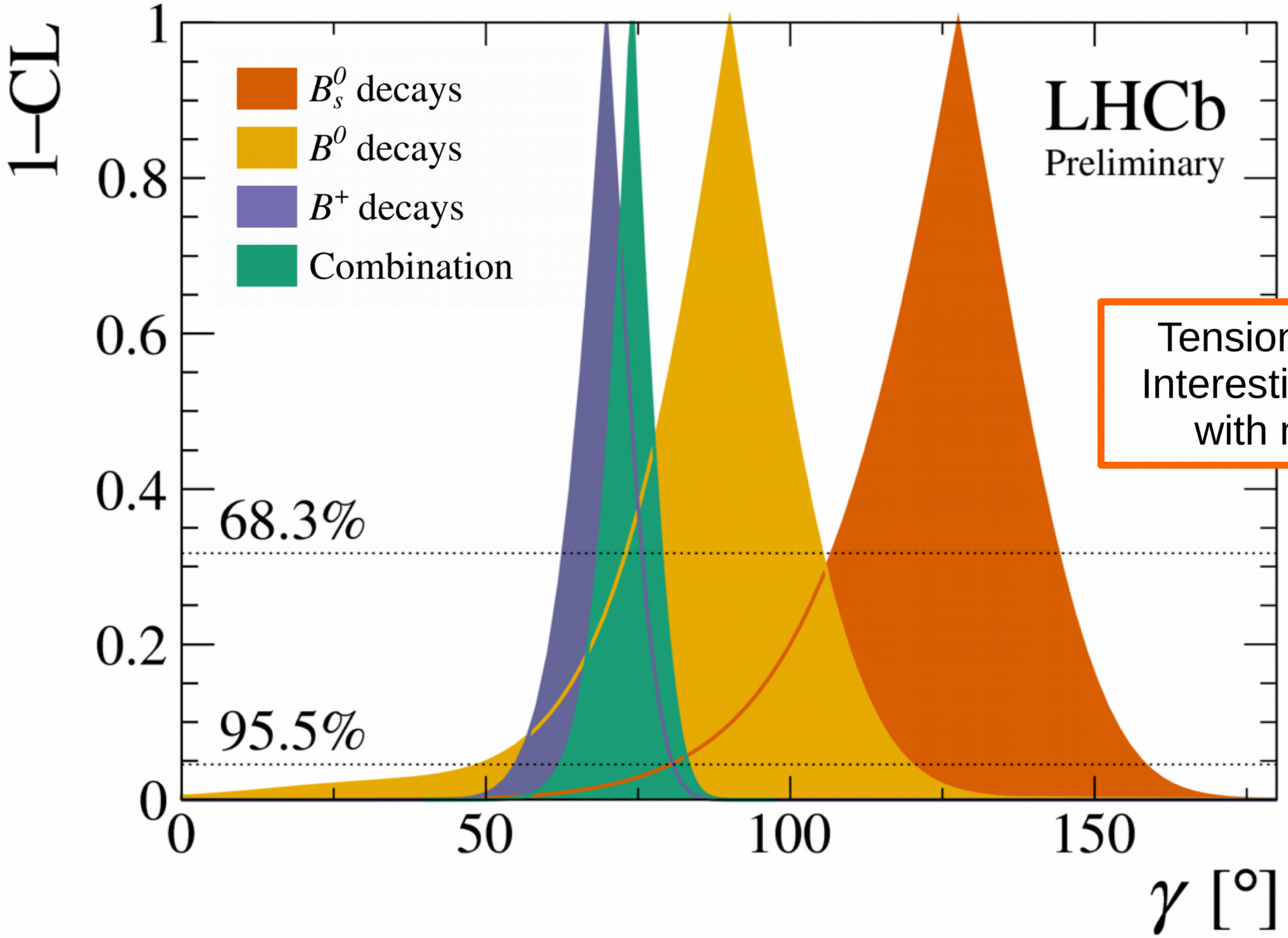
V_{cb} $(\sim\lambda^2)$

$V_{ub}=|V_{ub}|e^{-i\gamma}$ $(\sim\lambda^3)$



γ (ϕ_3) from B decays in DK

LHCb-CONF-2018-002

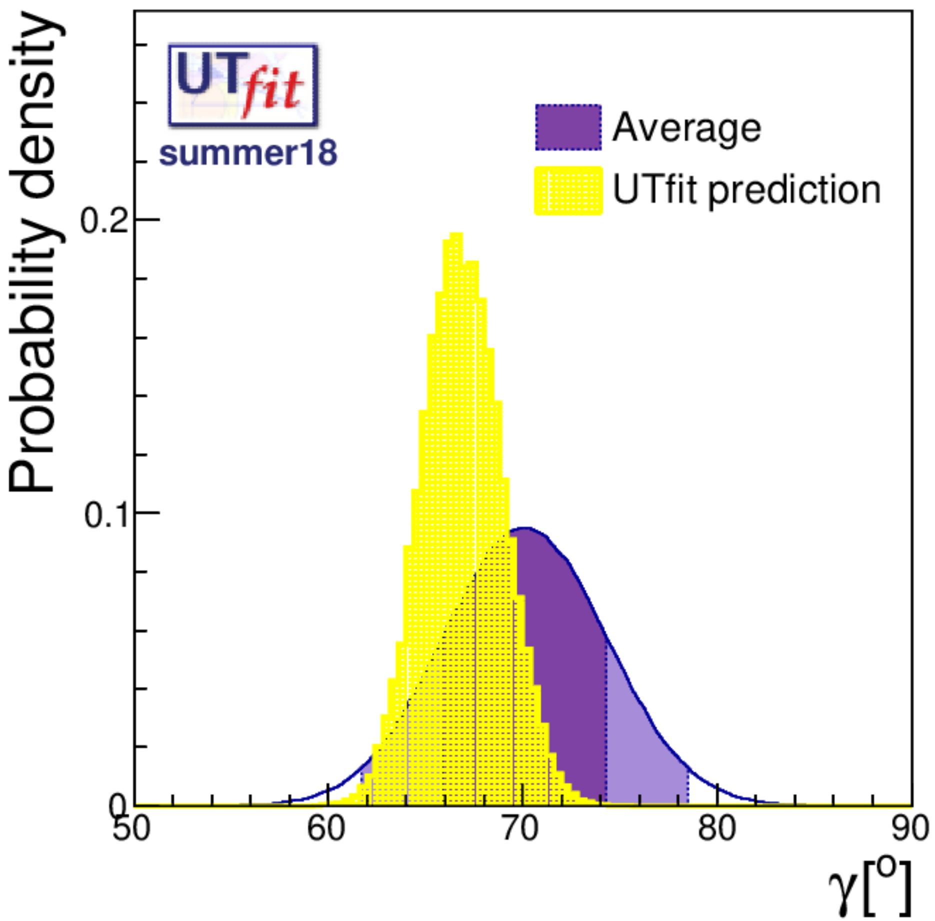


Gershon
Joint WG4+WG5
Thursday

Tension at 2σ level
Interesting to update
with more data

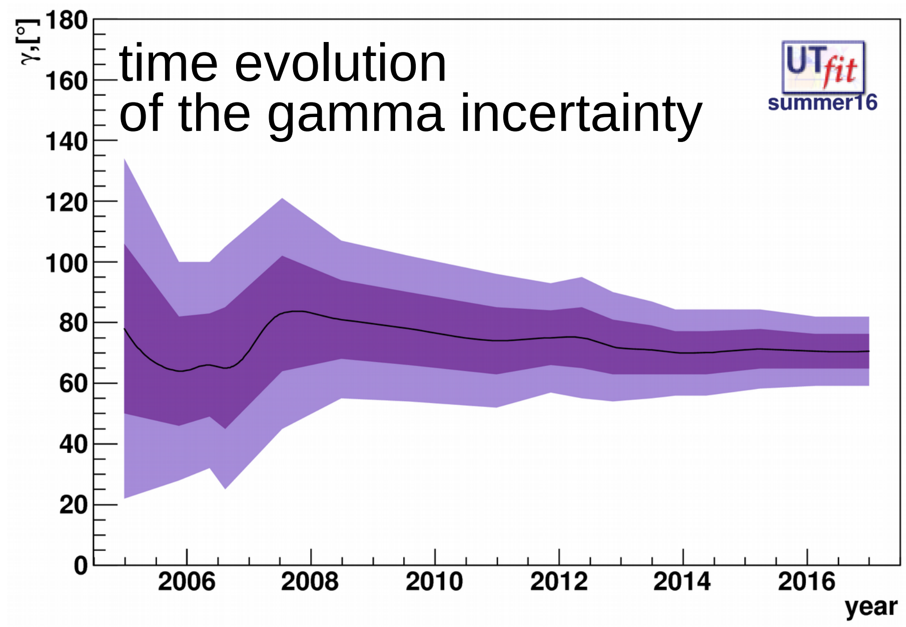
$\gamma - 2\beta_s$ converted to γ using
$-2\beta_s$ from $B_s \to J/\psi\varphi$

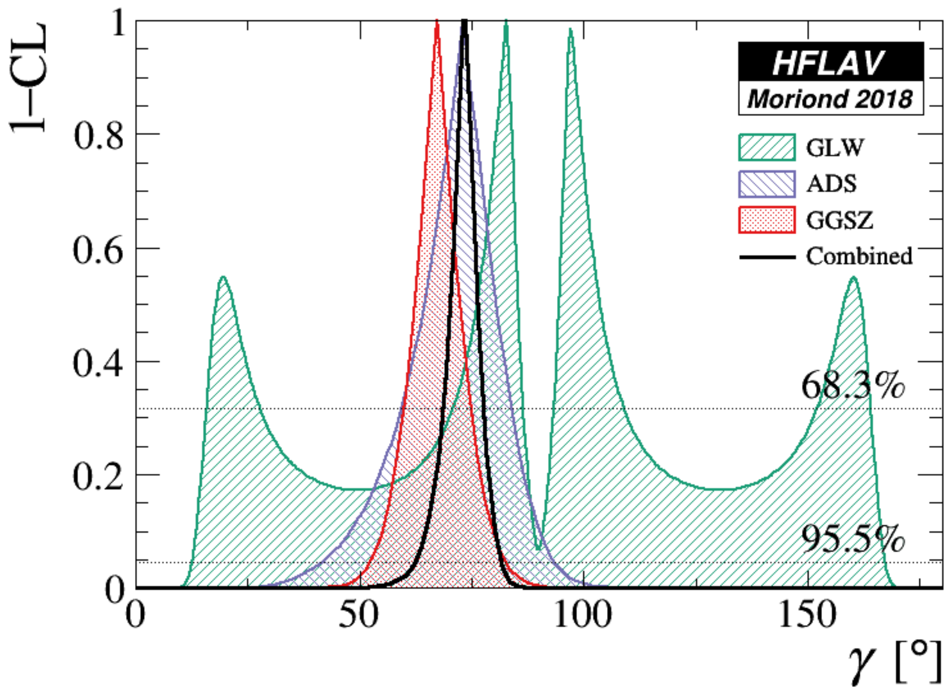
γ (ϕ$_3$) from B decays in DK



combined: (70.0 ± 4.2)°

UTfit prediction: (65.8 ± 2.2)°

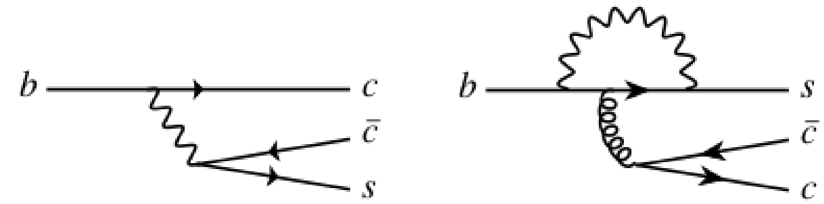




γ from HFLAV: 73.5 ± 5.1

β (ϕ_1) from b to ccs transitions

sin2β from time-dependent CP asymmetry: interference between tree and mixing box



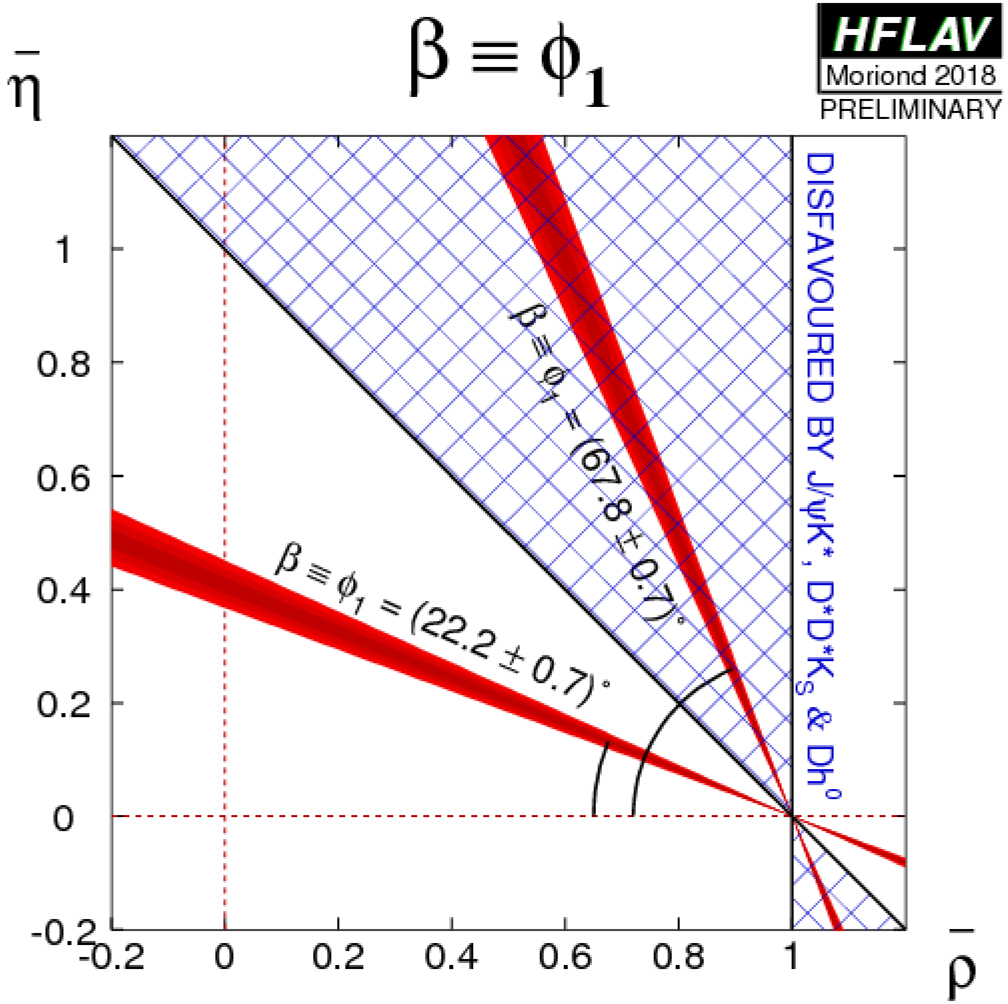
UTfit

$\sin(2\beta)$ [$J/\psi K^0$] = 0.690 ± 0.018

adding -0.01 ± 0.01

as data-driven theory uncertainty

M.Ciuchini, M.Pierini, L.Silvestrini
Phys. Rev. Lett. 95, 221804 (2005)



CKM fitter

$\sin(2\beta)$ [$c\bar{c}$] = 0.699 ± 0.017

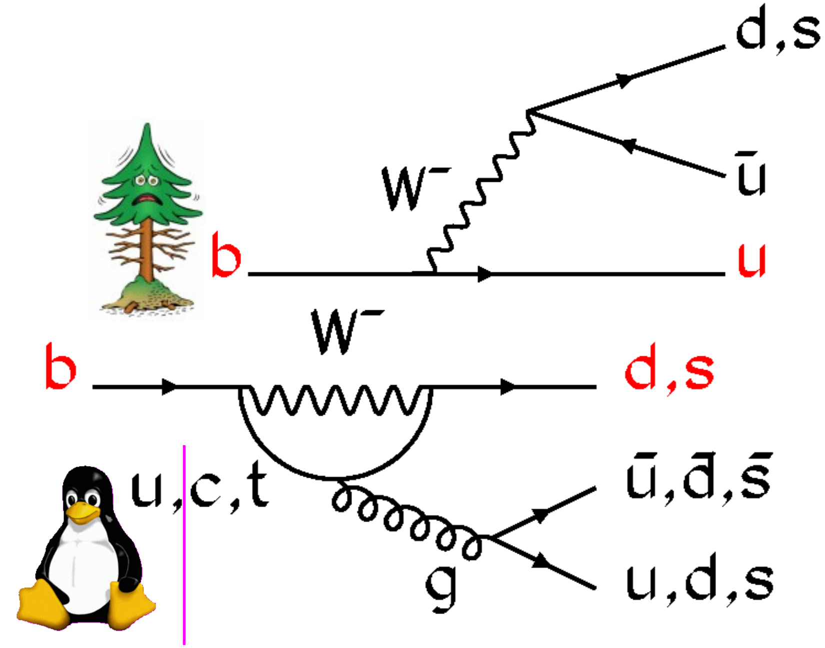
HFLAV

α (ϕ_2) from $\pi\pi$, $\rho\rho$, $\pi\rho$ decays with Isospin analysis

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

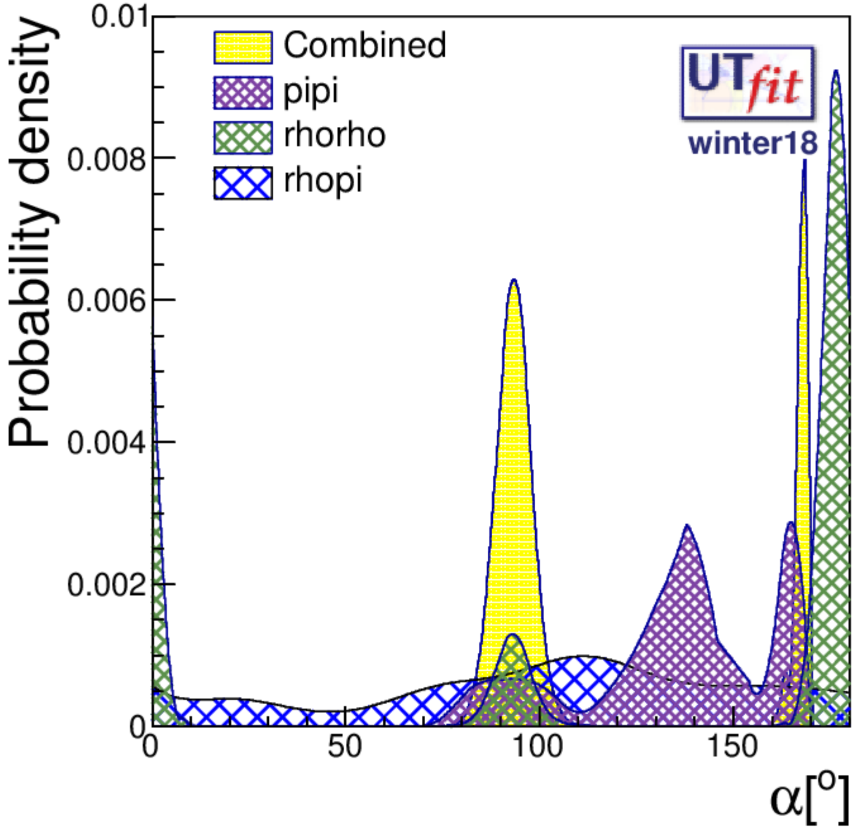
Unlike for β, loop (penguin diagrams) corrections are not negligible for α

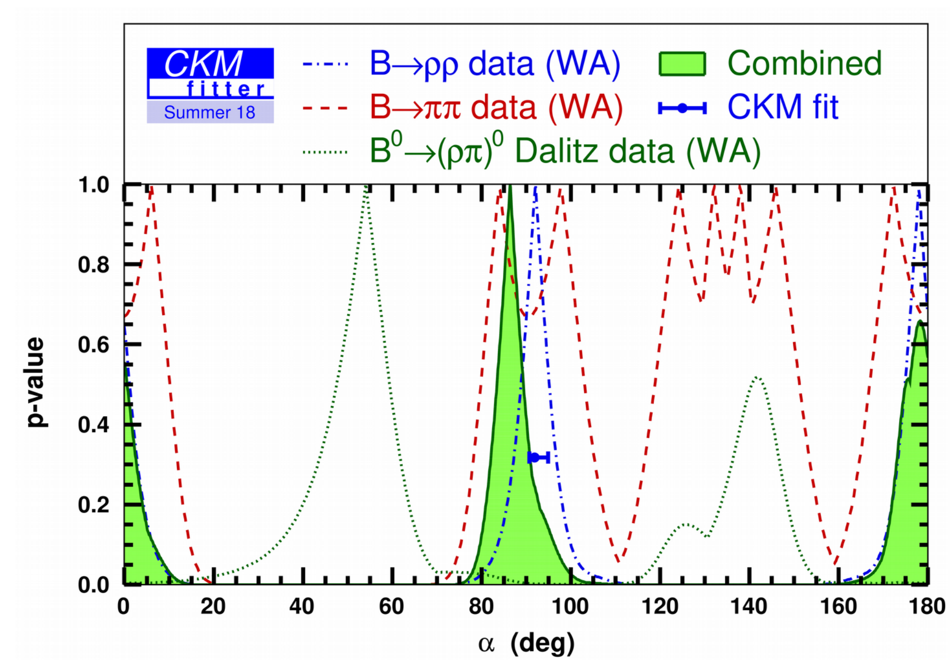
Need Isospin analysis including all modes (B of all charges and flavours) to obtain the α estimate



α (ϕ_2) from $\pi\pi$, $\rho\rho$, $\pi\rho$ decays with Isospin analysis

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





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

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

[dir.] $(86.4 +4.5)^\circ \cup (-1.8 +4.3)^\circ$

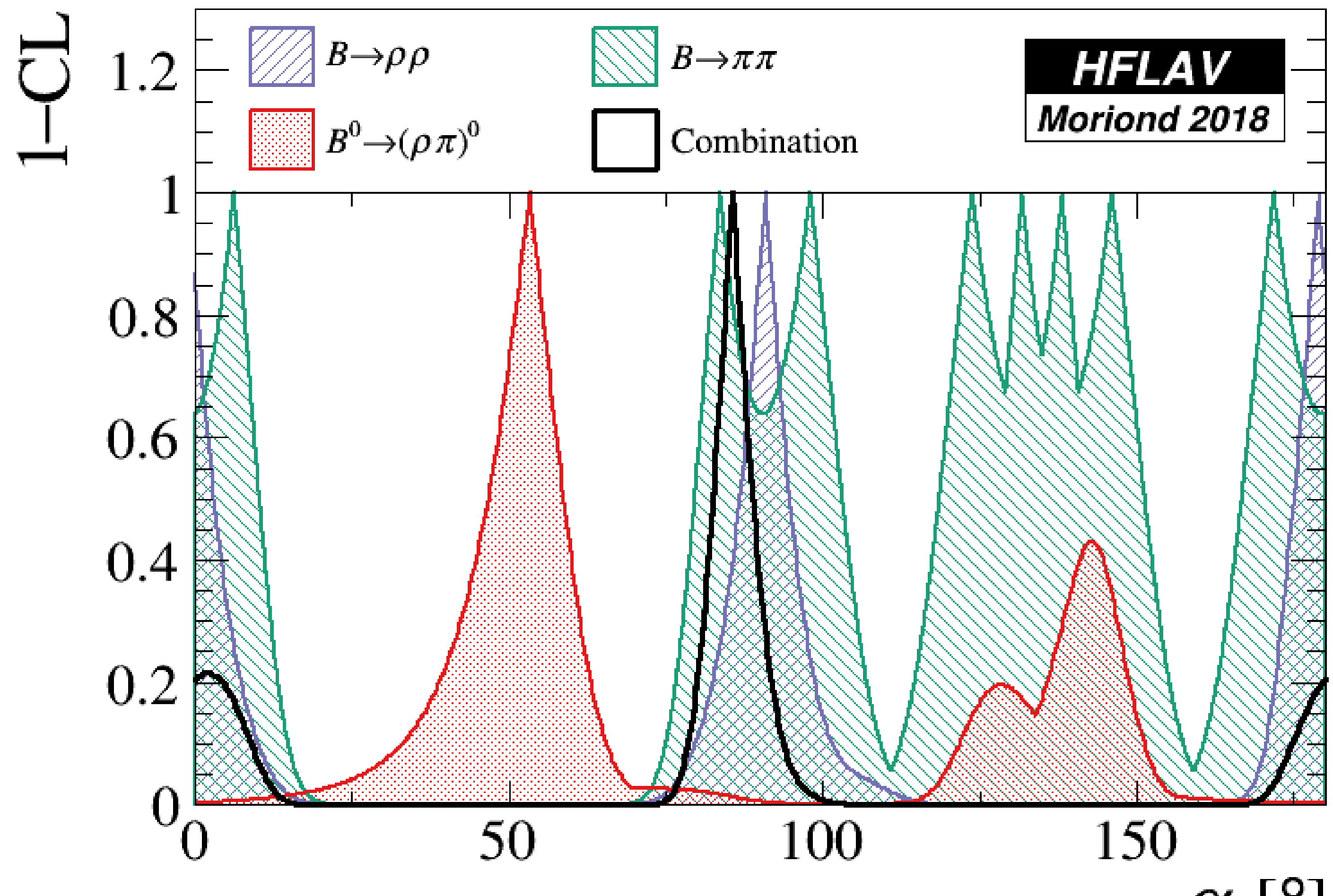
[indir.] $(91.9 +3.0)^\circ$

[comb.] $(91.6 +1.7)^\circ$

α (ϕ_2) from $\pi\pi$, $\rho\rho$, $\pi\rho$ decays

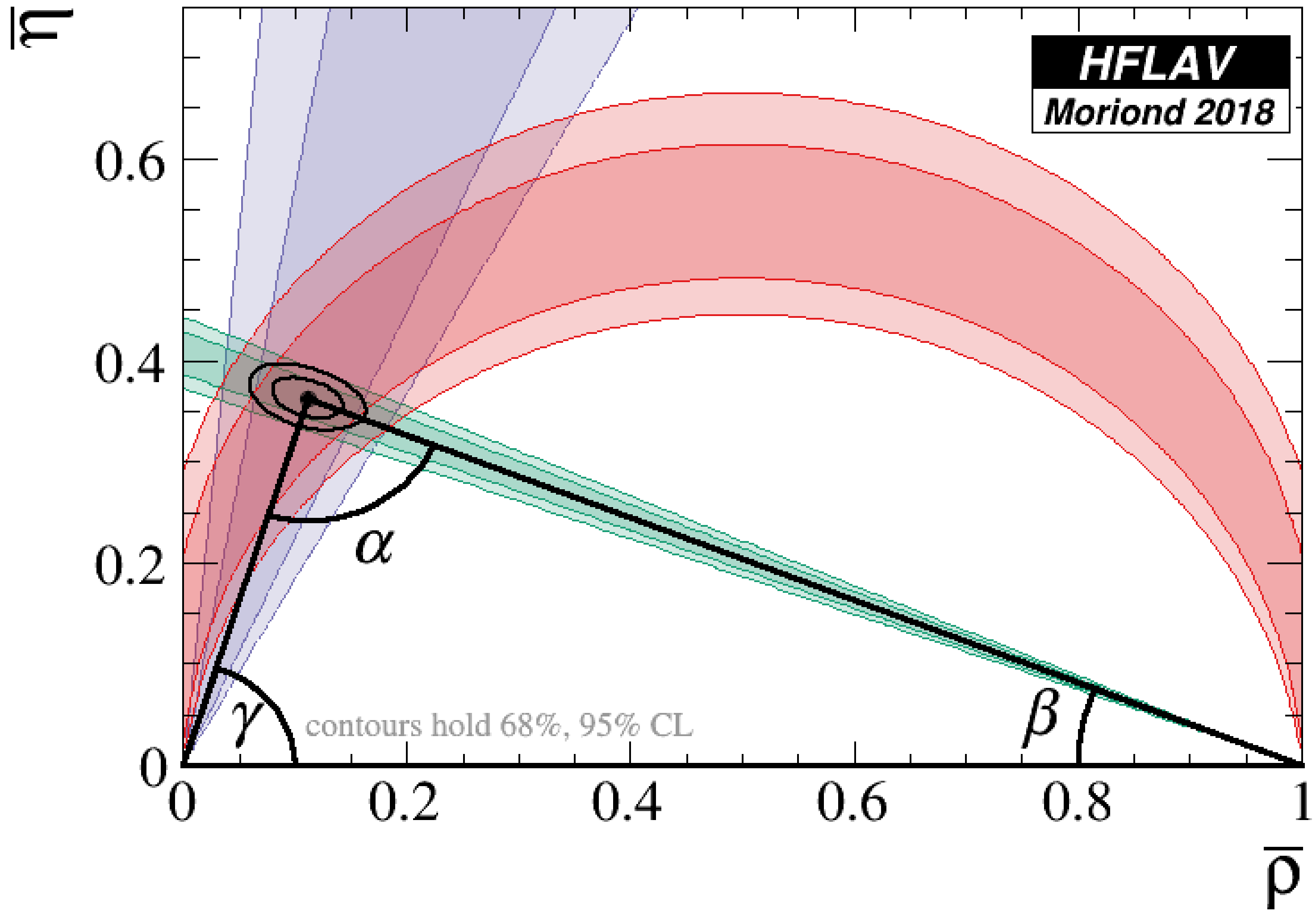
combined SM: $(93.3 \pm 5.6)^\circ$

[dir.] $(86.4 + 4.5)^\circ \cup (-1.8 + 4.3)^\circ$



from HFLAV: 84.9 ± 5.1

angle fit from HFLAV



lattice QCD inputs for mixing

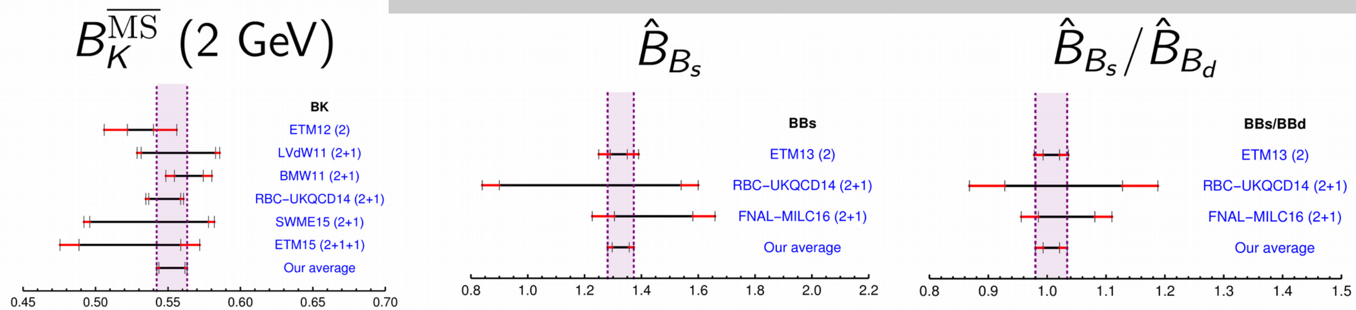
updated in winter 2018

in general: average the Nf=2+1+1 and Nf=2+1 FLAG averages

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

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



CKMfitter report from Vale Silva, Joint WG4+WG5, Thursday

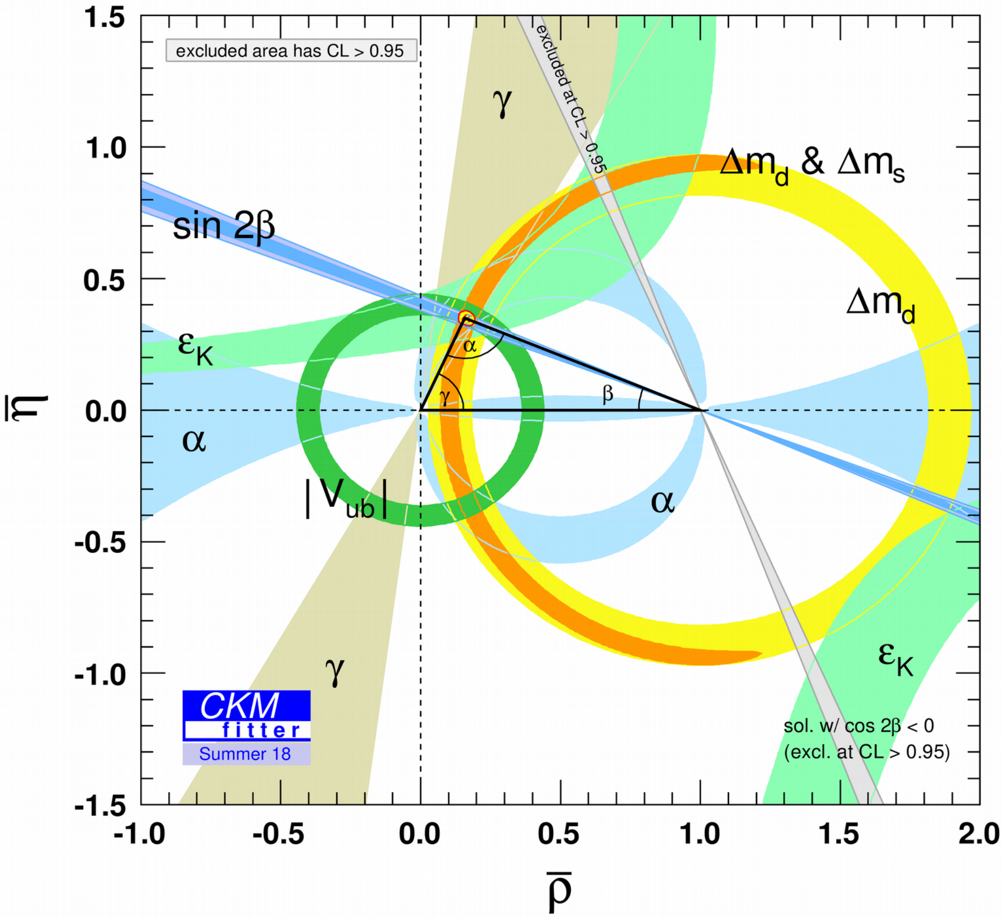
Educated *R*fit average; **black**: theoretical uncs., **red**: statistical uncs.
rescaling of uncertainties and averages follow our *R*fit scheme

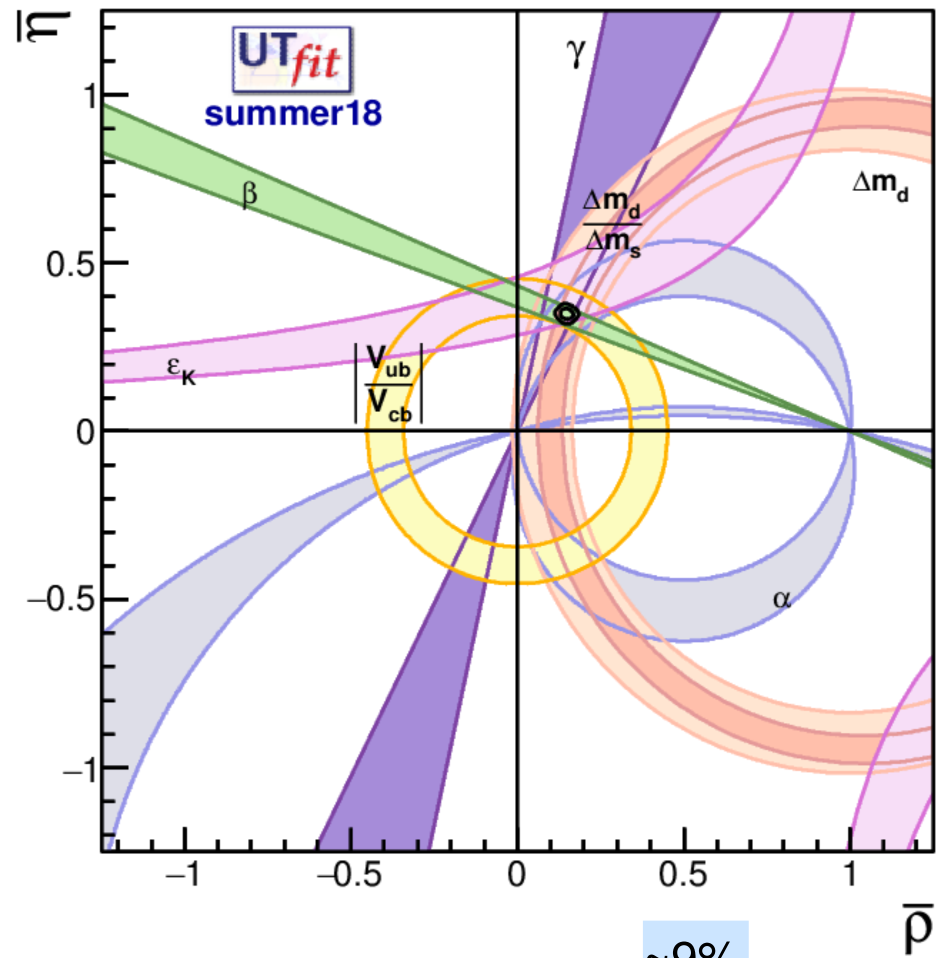
Indirect extractions:

$$\hat{B}_K = 0.83^{+0.13}_{-0.19}(19\%),\ \frac{B_{B_s}}{B_{B_d}} = 1.143^{+0.056}_{-0.069}(5\%),\ B_{B_s} = 1.287^{+0.077}_{-0.072}(6\%)$$

→ Fit results consistent, but mostly not competitive w/ LQCD

Unitarity Triangle analysis in the SM:





~9%

$$\bar{\rho} = 0.1577\,^{+0.0096}_{-0.0074}\ \text{(5\% unc.)}$$

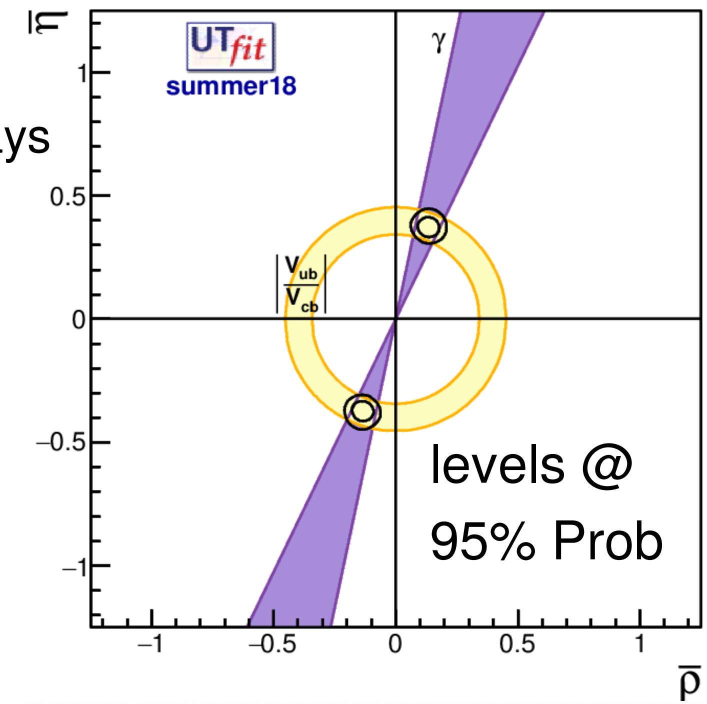
$$\bar{\eta} = 0.3493\,^{+0.0095}_{-0.0071}\ \text{(2\% unc.)}$$

$\bar{\rho}$ = 0.148 ± 0.013

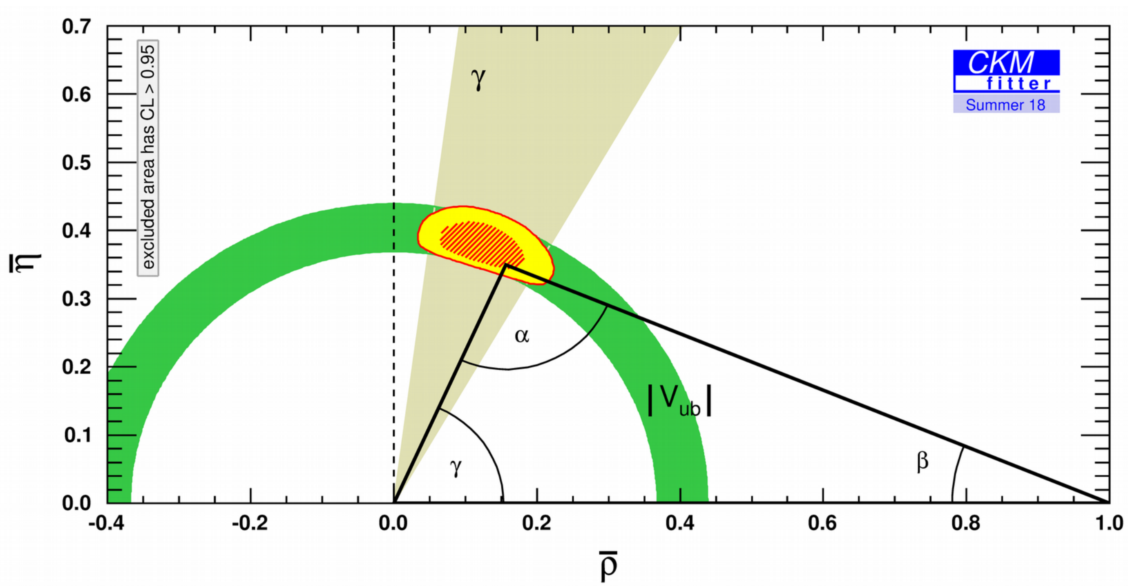
$\bar{\eta}$ = 0.348 ± 0.010

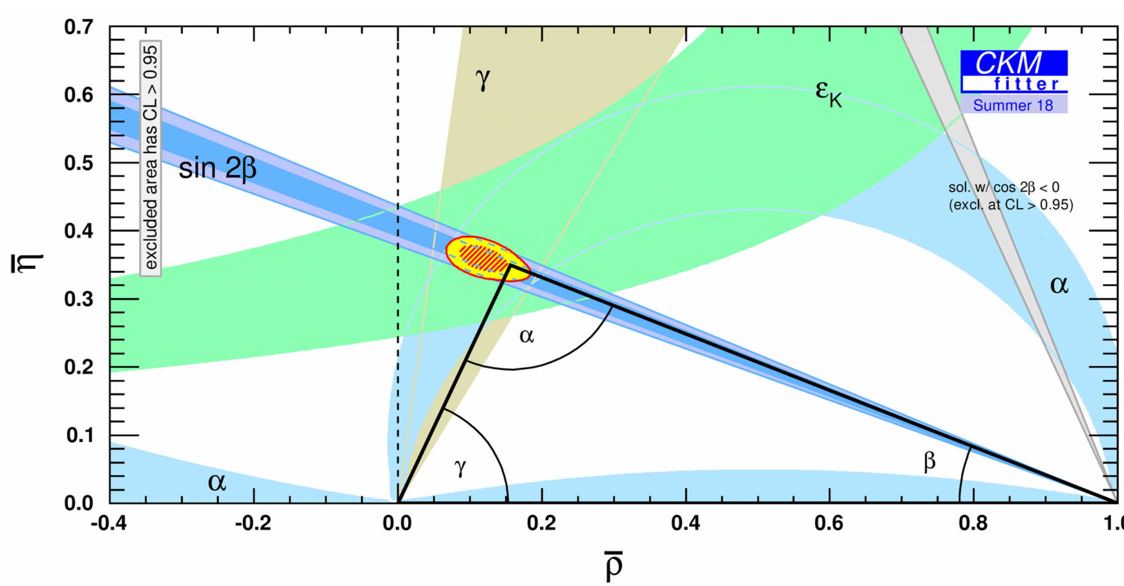
~3%

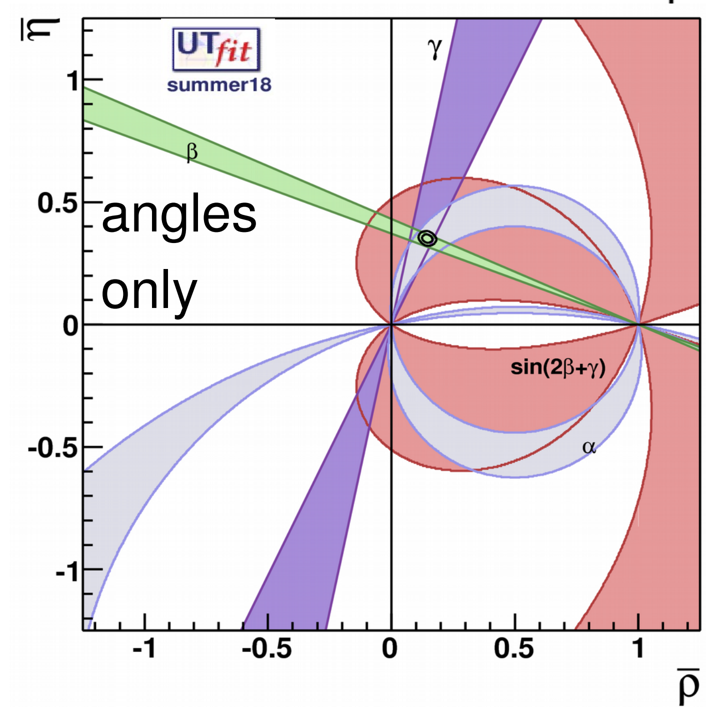
tree only and angles/CPV



tree-level processes: semileptonic and DK B decays

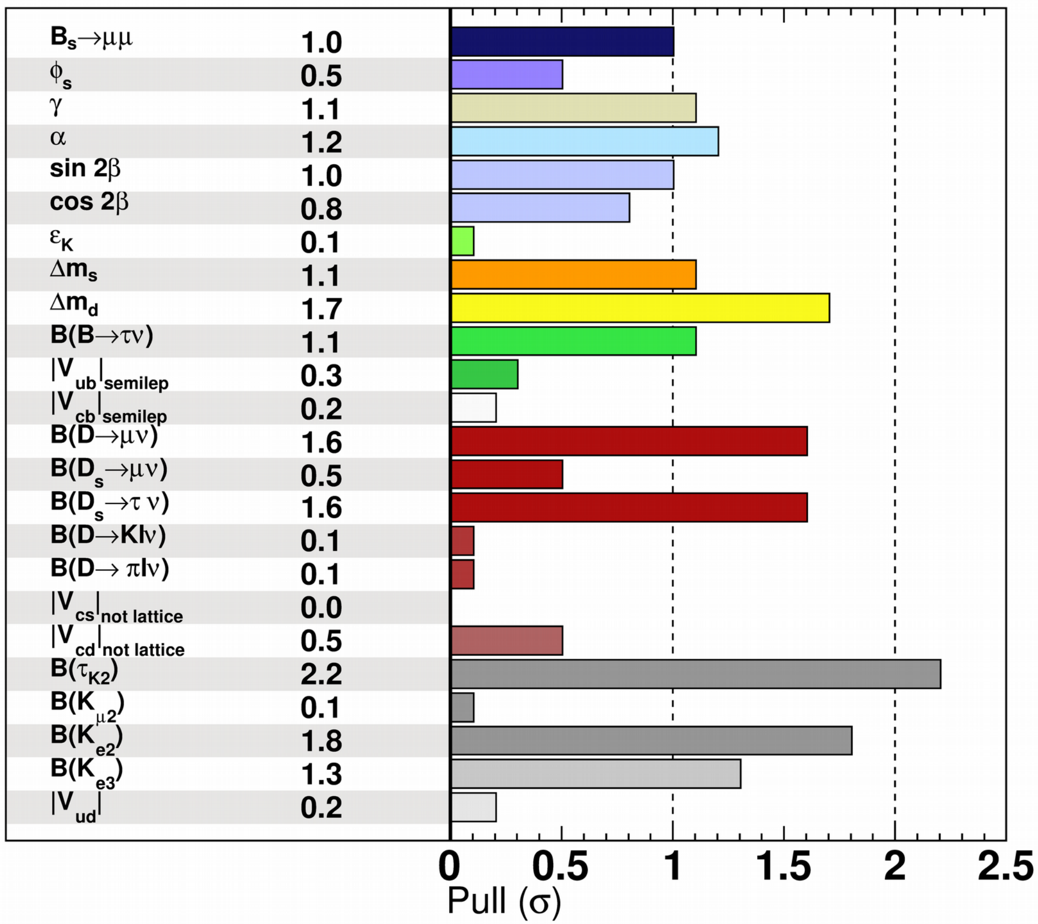






Compatibility of the constraints

obtained excluding
the given constraint
from the fit



Observables	Measurements	Prediction	Pull (#σ)
$\sin 2\beta$	0.689 ± 0.018	0.738 ± 0.033	~ 1.2
γ	70.0 ± 4.2	65.8 ± 2.2	~ 1
α	93.3 ± 5.6	90.1 ± 2.2	< 1
$\|V_{ub}\| \cdot 10^3$	3.72 ± 0.23	3.66 ± 0.11	< 1
$\|V_{ub}\| \cdot 10^3$ (incl)	4.50 ± 0.20	-	~ 3.8
$\|V_{ub}\| \cdot 10^3$ (excl)	3.65 ± 0.14	-	< 1
$\|V_{cb}\| \cdot 10^3$	40.5 ± 1.1	42.4 ± 0.7	~ 1.4
BR($B \to \tau\nu$) [10^{-4}]	1.09 ± 0.24	0.81 ± 0.05	~ 1.2
$A_{SL}^d \cdot 10^3$	-2.1 ± 1.7	-0.292 ± 0.026	~ 1
$A_{SL}^s \cdot 10^3$	-0.6 ± 2.8	0.013 ± 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 $\Delta F=2$ transitions

B_d and B_s mixing amplitudes

(2+2 real parameters):

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

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

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

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

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

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

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

new-physics-specific constraints

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

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

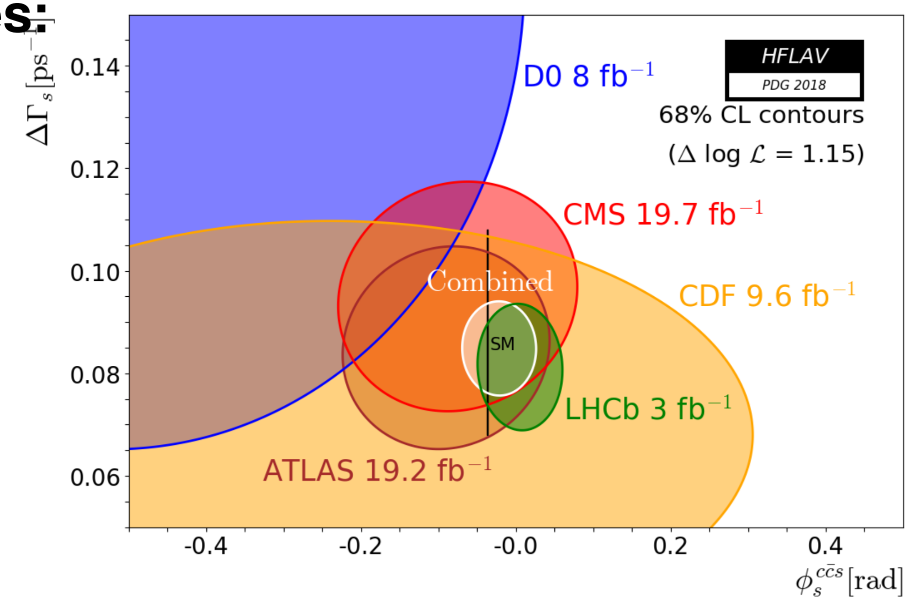
$$A^{\mu\mu}_{\rm SL} = \frac{f_d \chi_{d0} A^d_{\rm SL} + f_s \chi_{s0} A^s_{\rm SL}}{f_d \chi_{d0} + f_s \chi_{s0}}$$

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

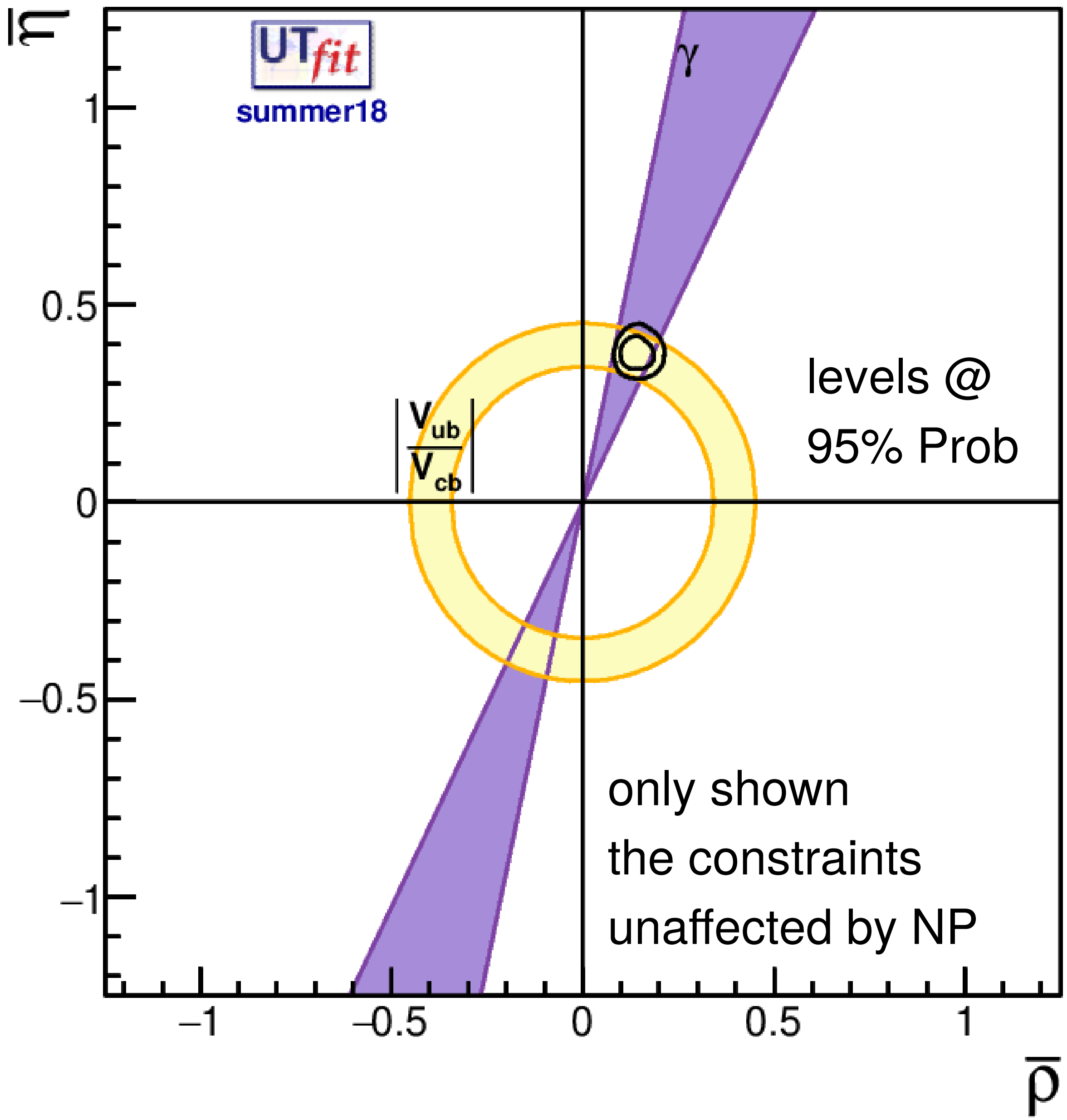
lifetime τ^{FS} in flavour-specific final states: average lifetime is a function to the width and the width difference

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



NP analysis results



$\bar{\rho} = 0.144 \pm 0.028$

$\bar{\eta} = 0.378 \pm 0.027$

SM is

$\bar{\rho} = 0.148 \pm 0.013$

$\bar{\eta} = 0.348 \pm 0.010$

NP parameter results

K system

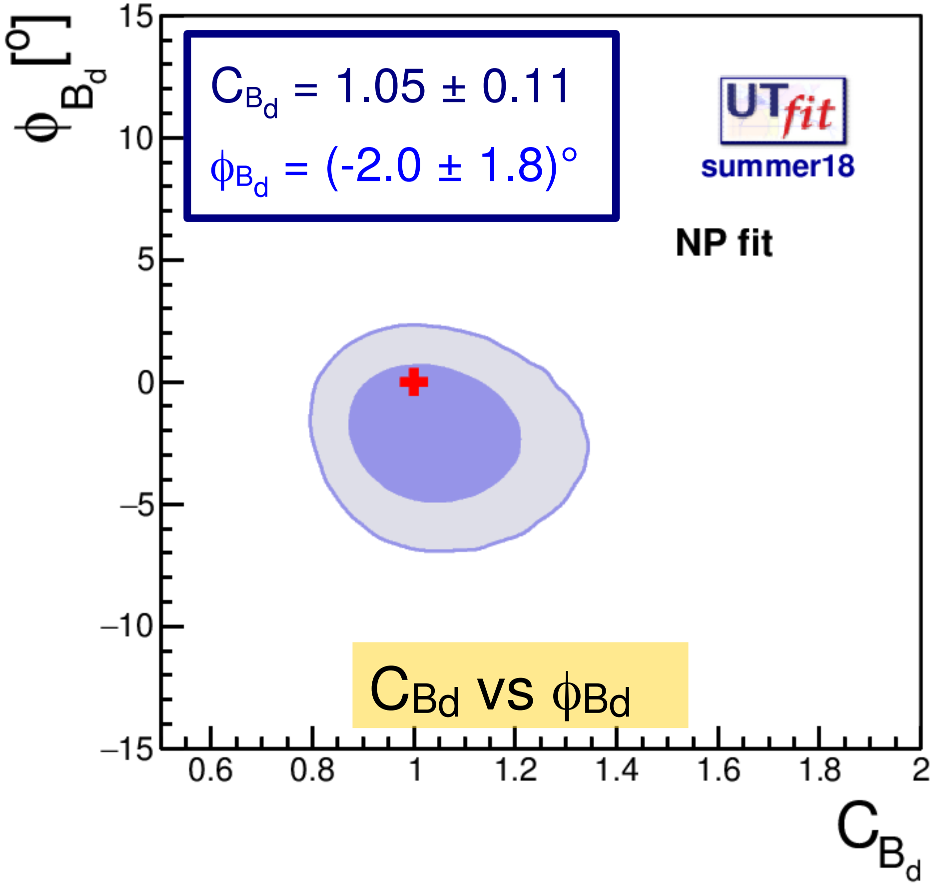
$C_{\varepsilon_K} = 1.11 \pm 0.12$

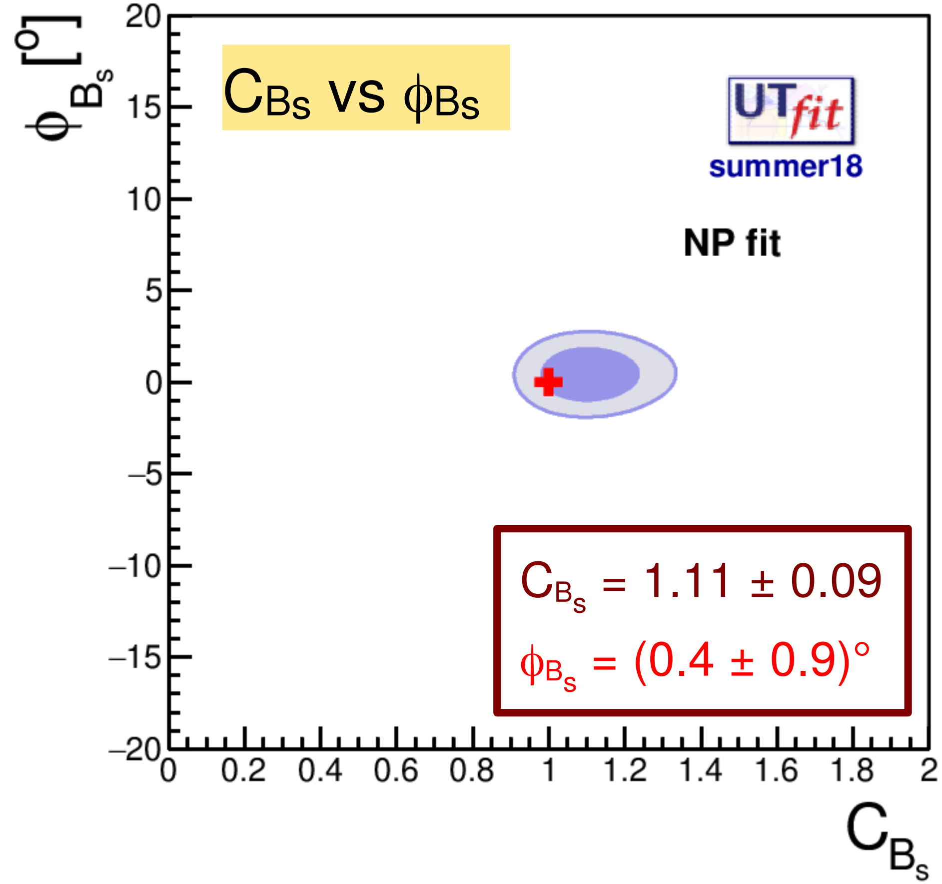
dark: 68%

light: 95%

SM: red cross

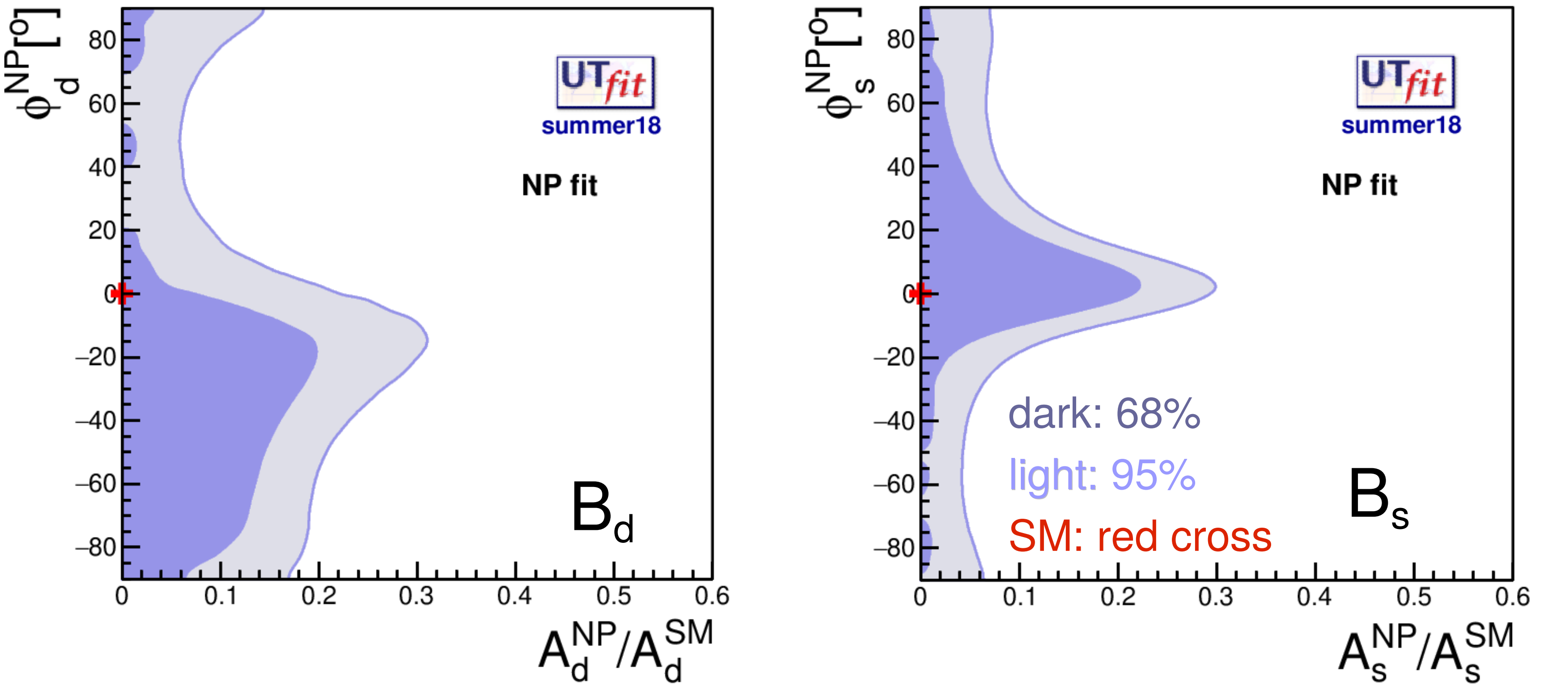
$$A_q = C_{B_q} e^{2i\phi_{B_q}} A_q^{SM} e^{2i\phi_q^{SM}}$$





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:

< 18% @68% prob. (30% @95%) in B_d mixing

< 20% @68% prob. (30% @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

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

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

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

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

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

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

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

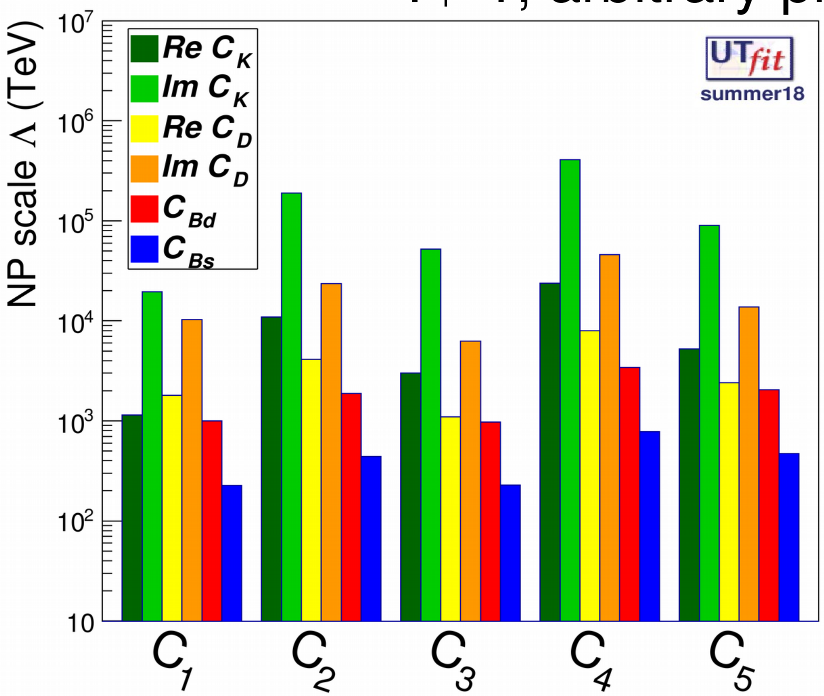
If no NP effect is seen lower bound on NP scale Λ

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

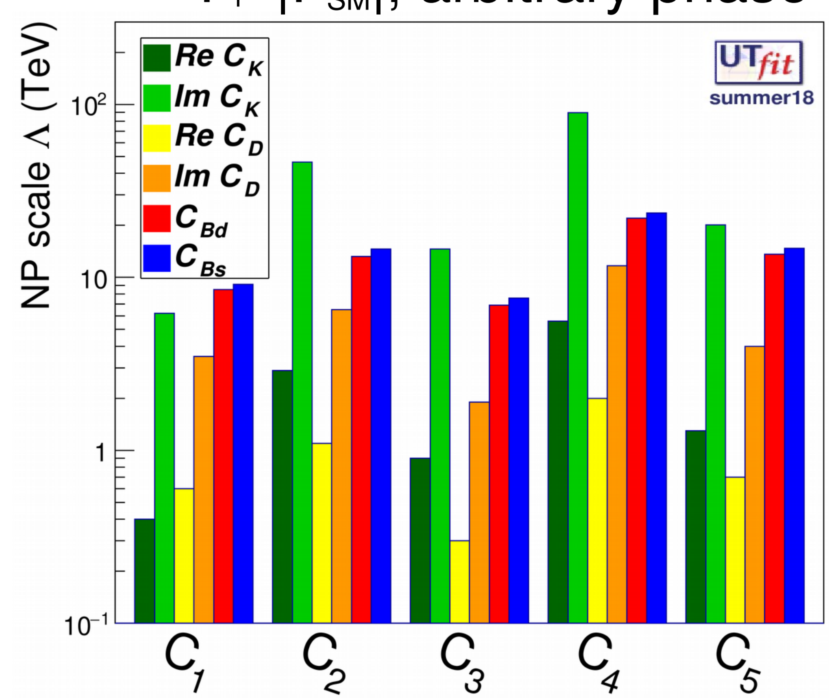
results from the Wilson coefficients

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

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



$\alpha \sim 1$ for strongly coupled NP



$\Lambda > 4.1\ 10^5$ TeV

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

$\Lambda > 90$ TeV

$\alpha \sim \alpha_W$ in case of loop coupling through weak interactions
$\Lambda > 1.2\ 10^4$ 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 UT analysis: provide the best determination of CKM parameters, test the consistency of the SM ("*direct*" vs "*indirect*" determinations) and provide predictions (from data..) for SM observables
- lots of new and updated inputs constantly arriving by experiments and lattice calculations: however for the moment the SM picture stays solid
- Still open discussion on semileptonic inclusive vs exclusive: is the V_{cb} puzzle solved? Inclusive V_{ub} remains the only outlier..
- 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.

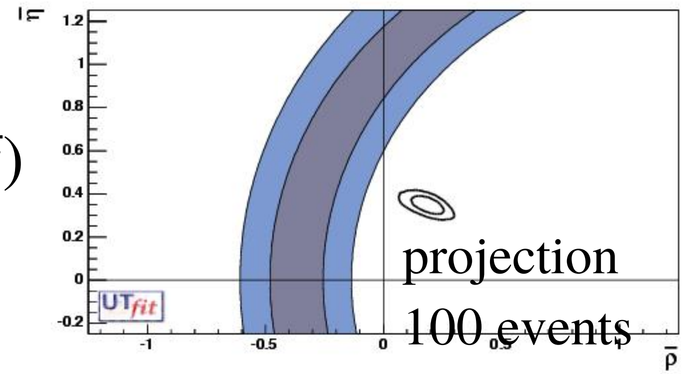
Back up slides

some old plots coming back to fashion:

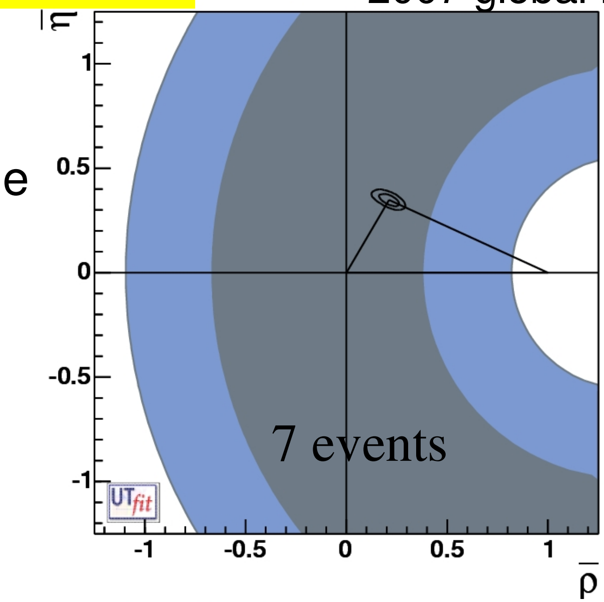
As NA62 and KOTO are analysing data:

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

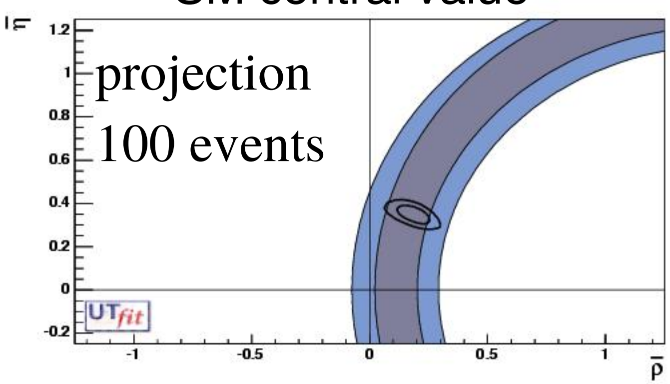
E949 central value

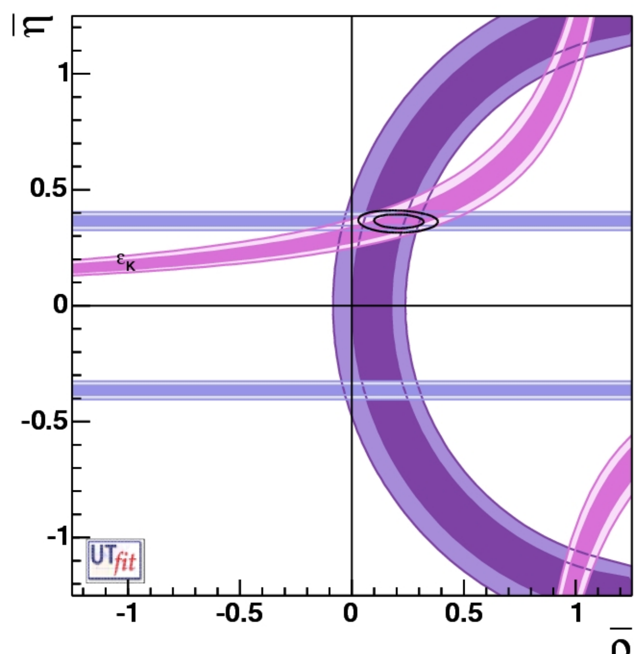


2007 global fit area



SM central value



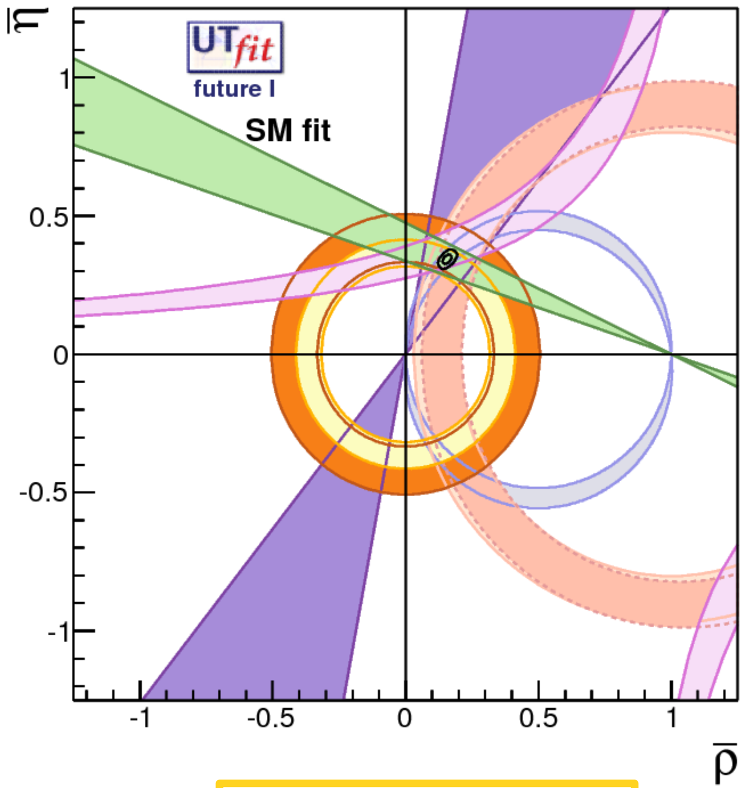


including
$BR(K^0 \to \pi^0 \nu \bar{\nu})$
SM central value

Look at the near future

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

preliminary

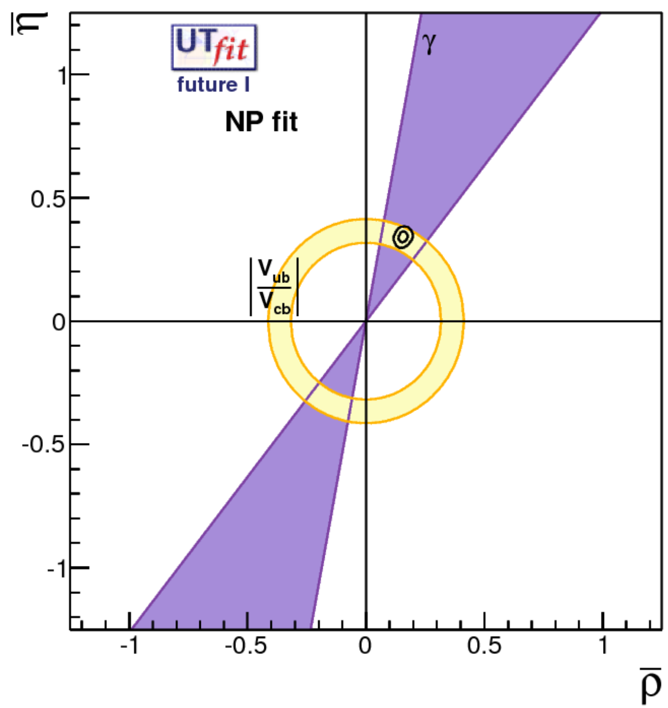


$\rho = \pm\ 0.015$
$\eta = \pm\ 0.015$

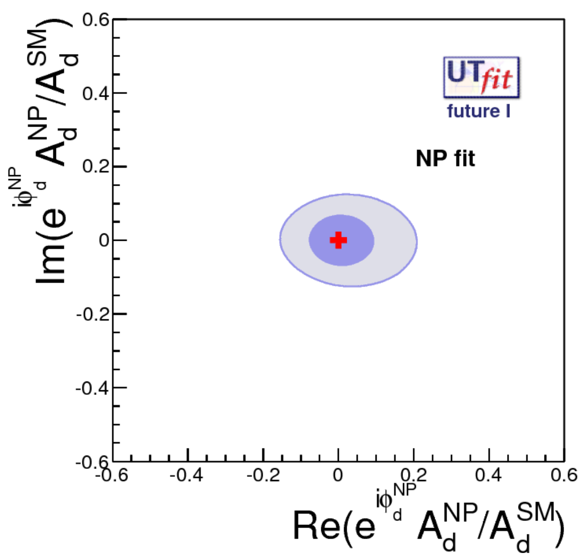
$\bar{\rho} = 0.154 \pm 0.015$
$\bar{\eta} = 0.344 \pm 0.013$

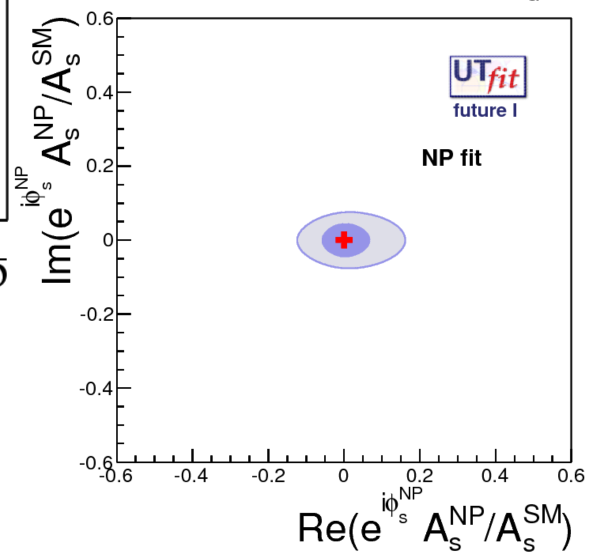
current sensitivity

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



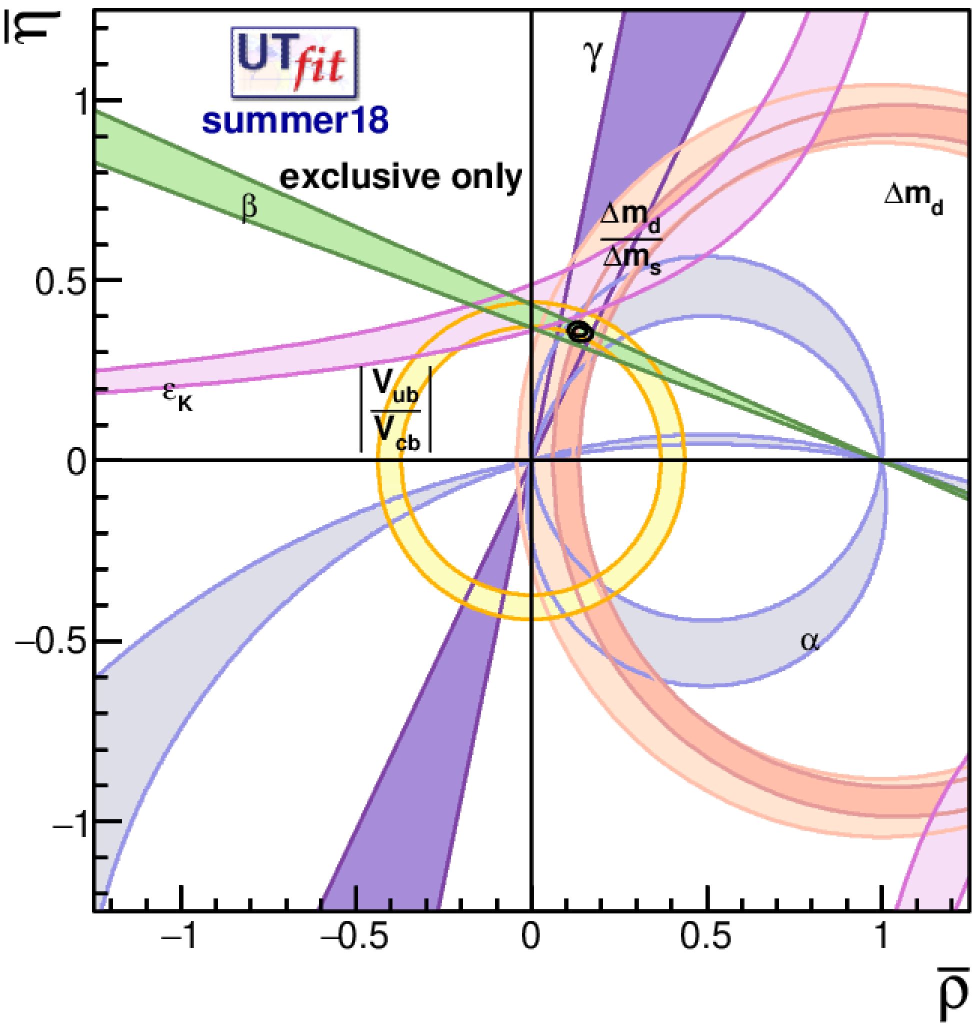
$\rho = \pm\ 0.016$
$\eta = \pm\ 0.019$



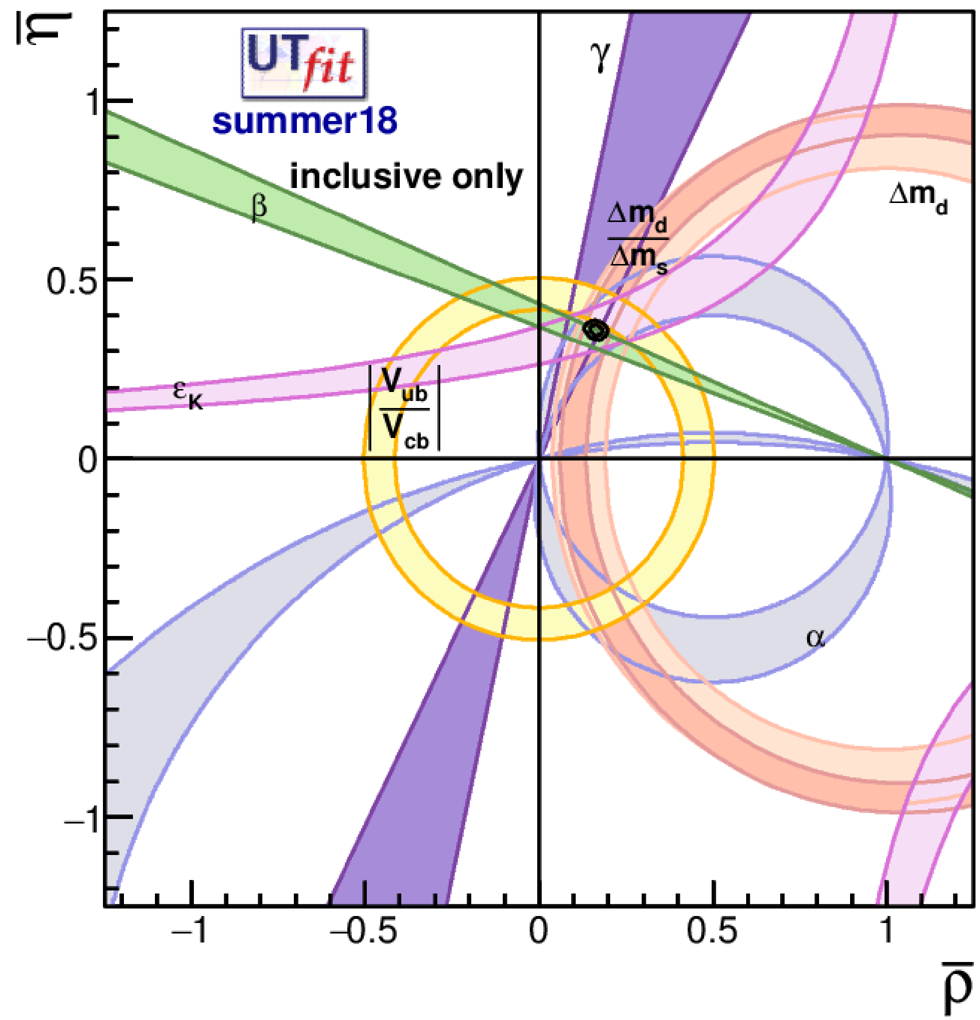


exclusives vs inclusives

only exclusive values

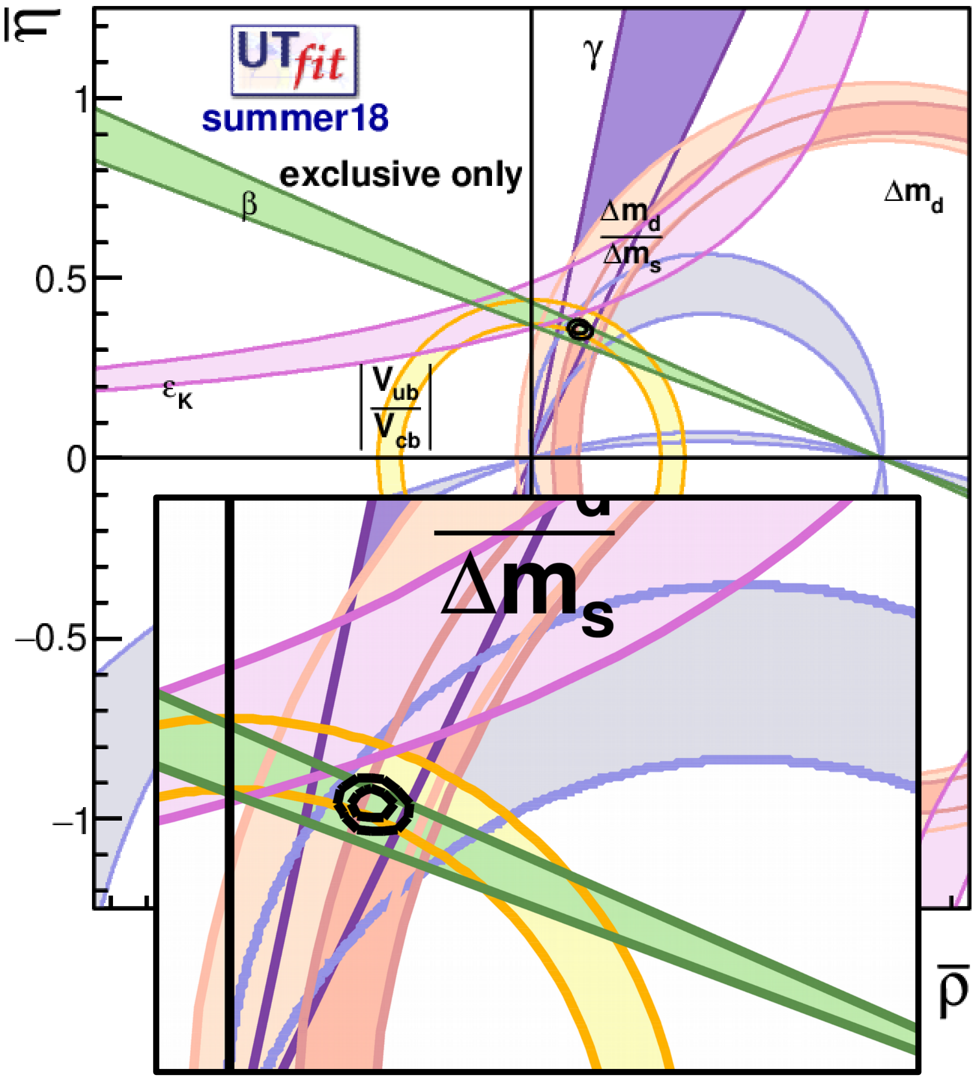


only inclusive values

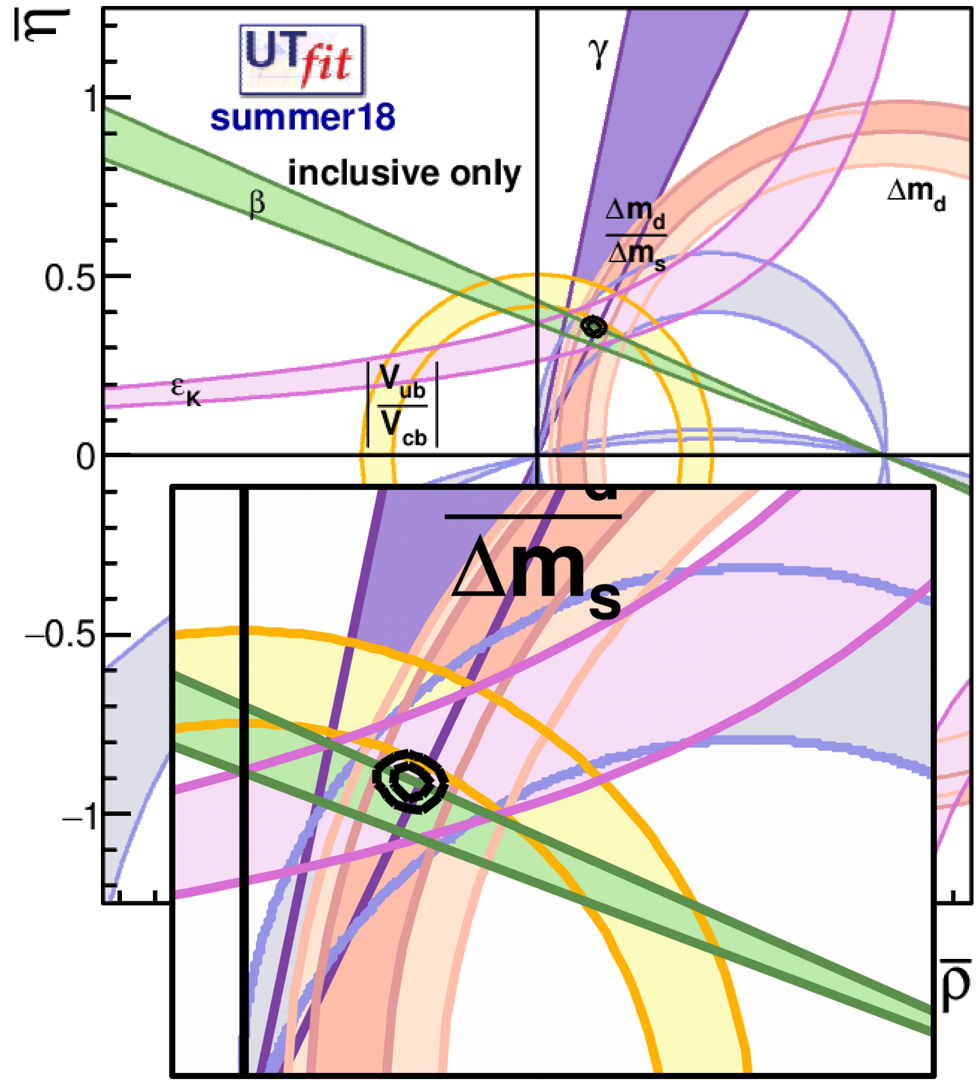


exclusives vs inclusives

only exclusive values

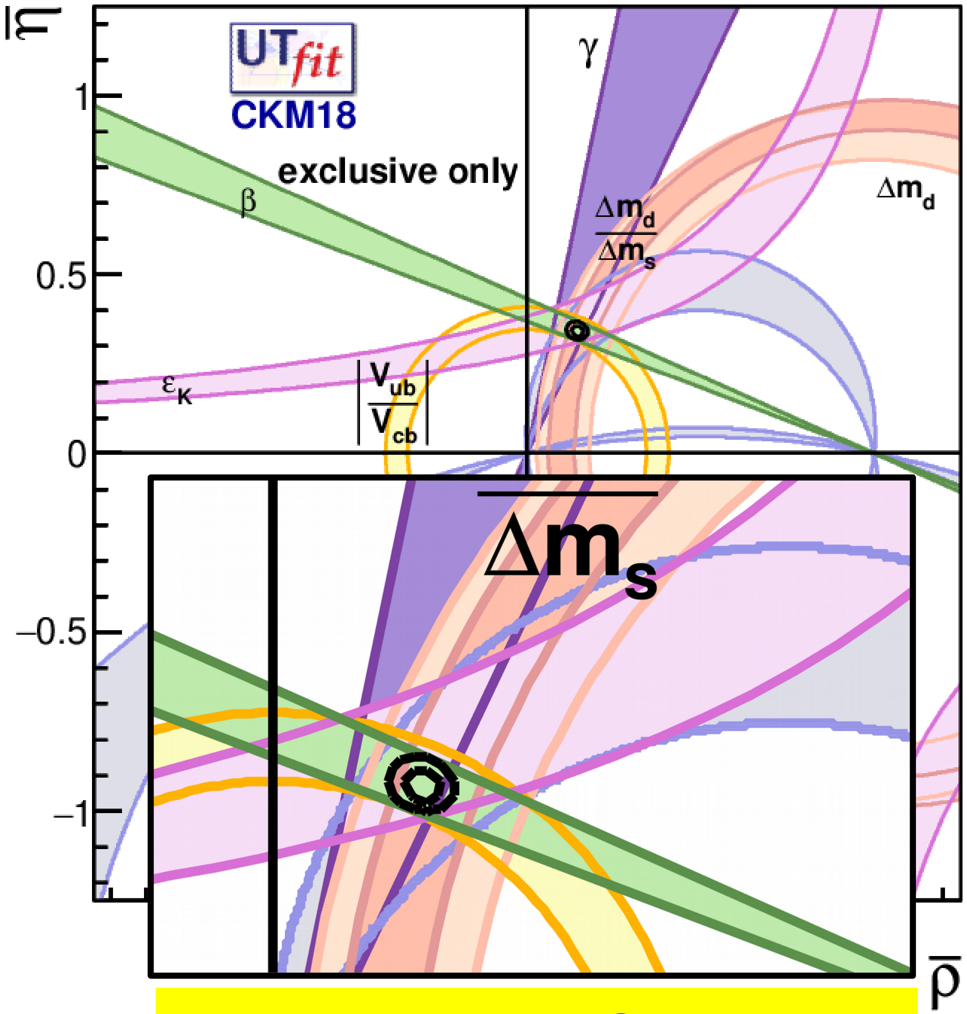


only inclusive values



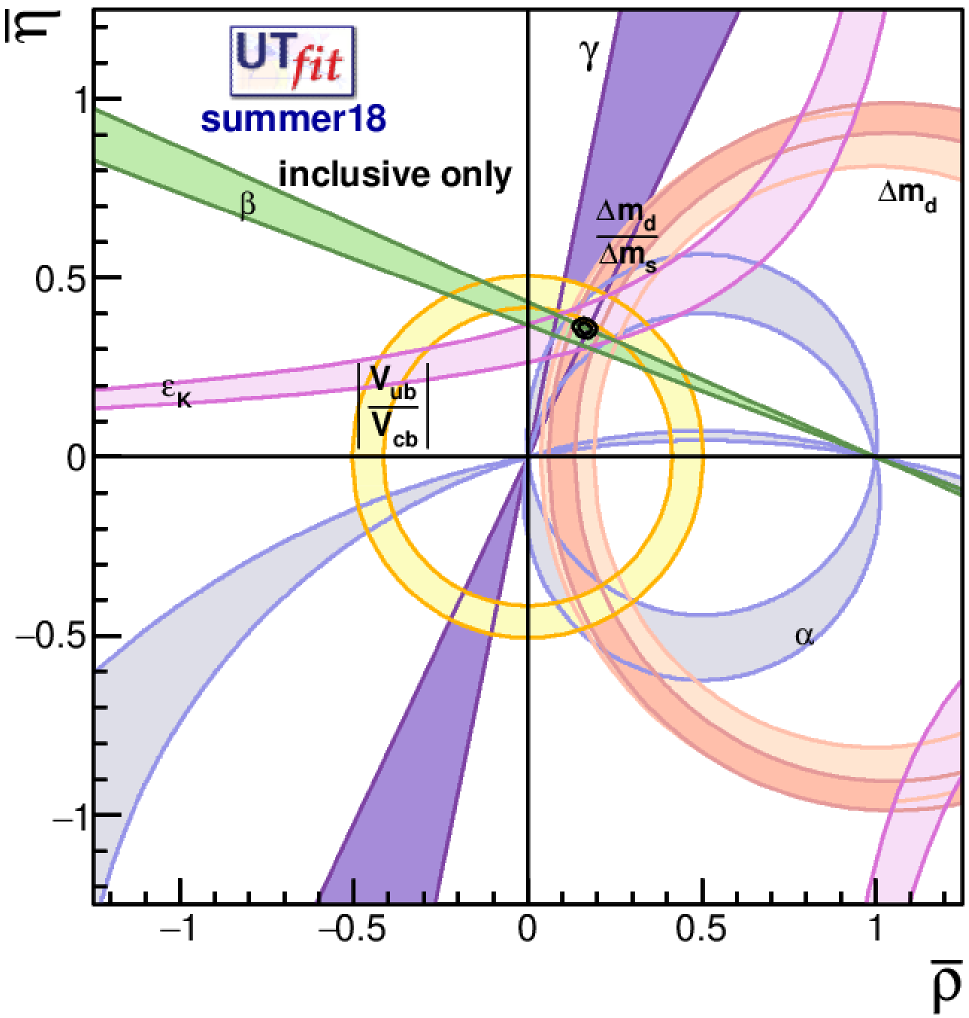
exclusives vs inclusives

only exclusive values



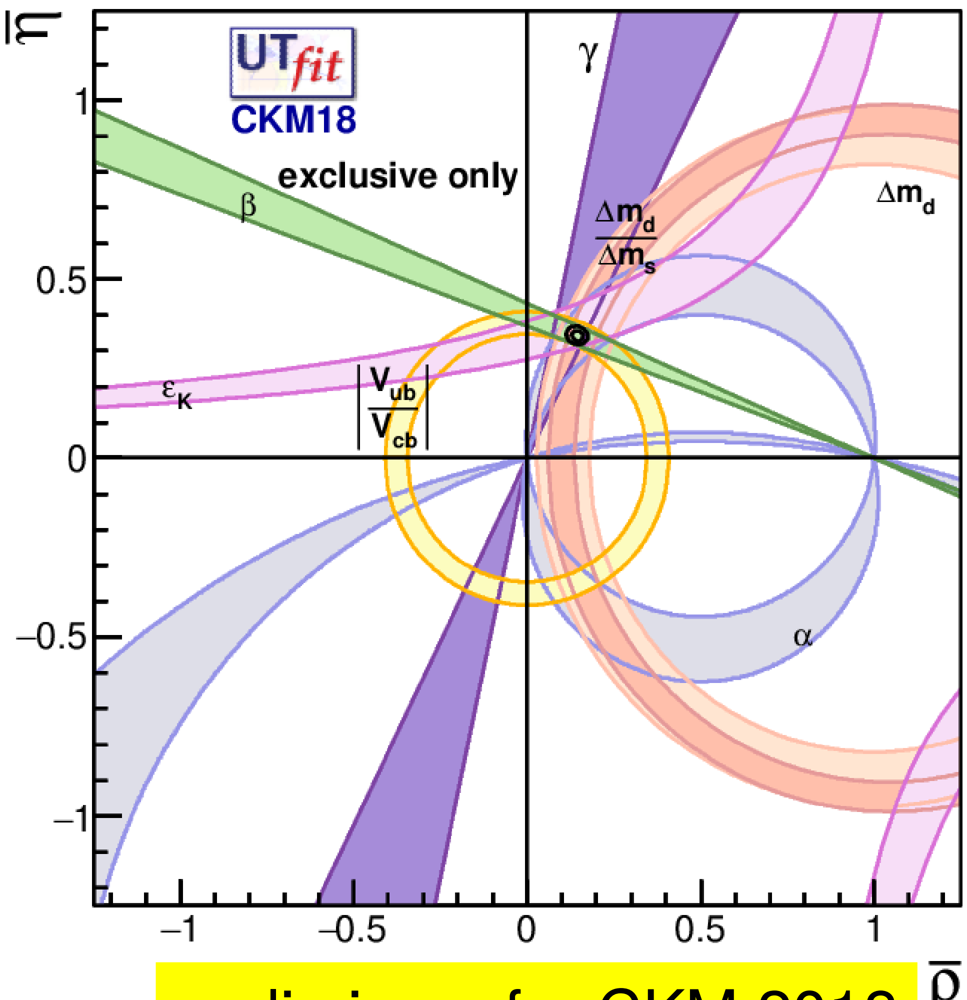
preliminary for CKM 2018

only inclusive values

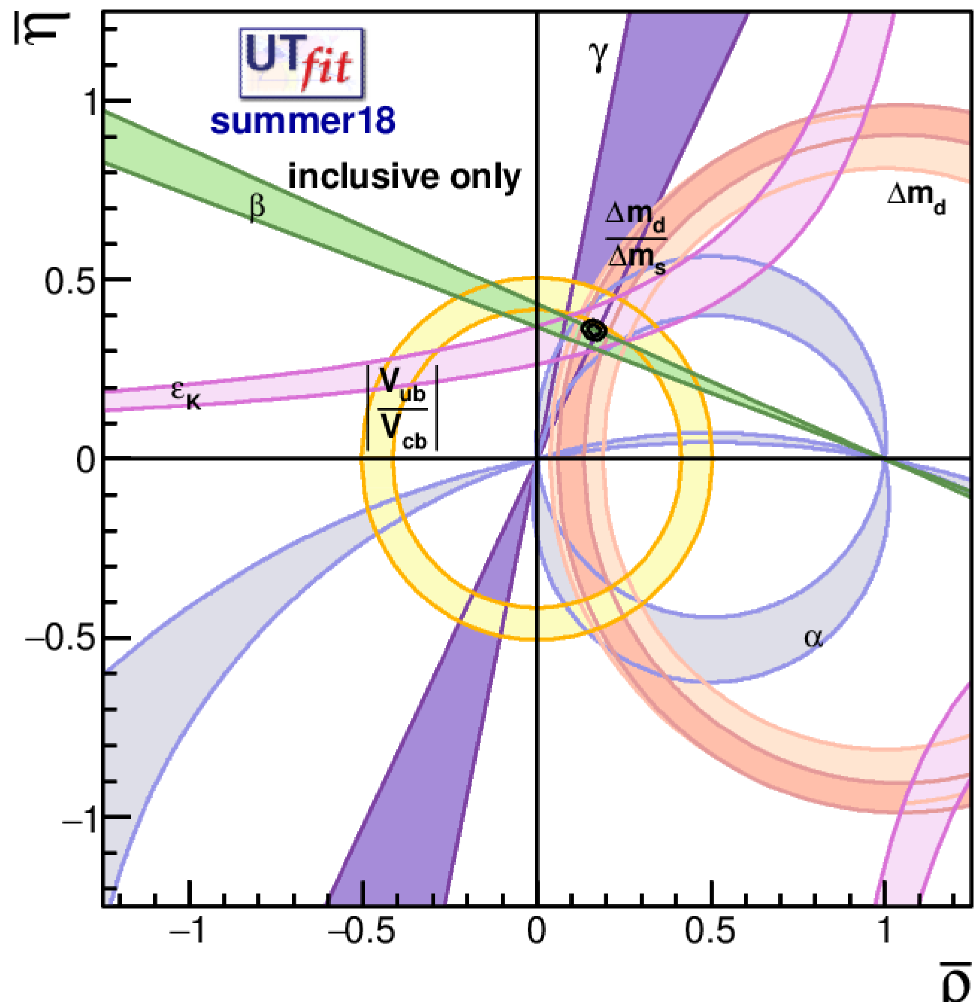


exclusives vs inclusives

only exclusive values



only inclusive values



preliminary for CKM 2018

Statistical approach

- ***CKM*fitter**: Frequentist statistics based on a χ^2 analysis
- χ^2_{min}: **goodness-of-fit** under SM (or NP), **estimators** for V_{CKM}
- $\Delta\chi^2$ (χ^2-distributed): **Confidence Level** (CL) intervals
- *Range* fit scheme (*R*fit) incorporates **theoretical uncertainties**
- Theo. inputs: published Lattice papers, **with error budgets**, different sources of syst. uncertainty are **combined linearly**, using FLAG reports as a guide to sort results

$$\mathcal{L} \stackrel{Rfit}{=} \mathcal{L}_{stat} \times \mathcal{L}_{theo},$$

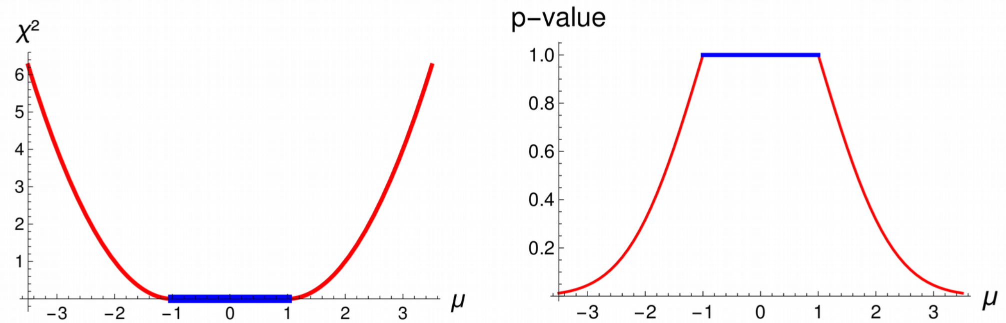
$$\chi^2 = -2\,\ell n\,\mathcal{L}$$

$\mathcal{L}_{stat}$: exp. data

$\mathcal{L}_{theo}$: had. inputs

[cf. Charles, Descotes-G., Niess, LVS '17]

Example in 1D, $0 \pm 1_{stat} \pm 1_{theo}$ ($N_{dof} = 1$)



χ^2: flat bottom, quadratic walls

Analysis and results

CKM	Process	Observables			Theoretical inputs		
$\|V_{ud}\|$	$0^+ \to 0^+ \ \beta$	$\|V_{ud}\|_{\rm nucl}$	$=$	$0.97420 \pm 0 \pm 0.00021$	Nuclear matrix elements		
$\|V_{us}\|$	$K \to \pi\ell\nu$	$\|V_{us}\|_{\rm SL} f_+^{K\to\pi}(0)$	$=$	0.2165 ± 0.0004	$f_+^{K\to\pi}(0)$	$=$	$0.9681 \pm 0.0014 \pm 0.0022$
	$K \to e\nu$	$\mathcal{B}(K \to e\nu)$	$=$	$(1.582 \pm 0.007) \cdot 10^{-5}$	f_K	$=$	$155.6 \pm 0.2 \pm 0.6$ MeV
	$K \to \mu\nu$	$\mathcal{B}(K \to \mu\nu)$	$=$	0.6356 ± 0.0011			
	$\tau \to K\nu$	$\mathcal{B}(\tau \to K\nu)$	$=$	$(0.6960 \pm 0.0096) \cdot 10^{-2}$			
$\frac{\|V_{us}\|}{\|V_{ud}\|}$	$K \to \mu\nu/\pi \to \mu\nu$	$\frac{\mathcal{B}(K \to \mu\nu)}{\mathcal{B}(\pi \to \mu\nu)}$	$=$	1.3367 ± 0.0029	f_K/f_π	$=$	$1.1959 \pm 0.0007 \pm 0.0029$
	$\tau \to K\nu/\tau \to \pi\nu$	$\frac{\mathcal{B}(\tau \to K\nu)}{\mathcal{B}(\tau \to \pi\nu)}$	$=$	$(6.438 \pm 0.094) \cdot 10^{-2}$			
$\|V_{cd}\|$	νN	$\|V_{cd}\|_{\rm not\ lattice}$	$=$	0.230 ± 0.011			
	$D \to \mu\nu$	$\mathcal{B}(D \to \mu\nu)$	$=$	$(3.74 \pm 0.17) \cdot 10^{-4}$	f_{D_s}/f_D	$=$	$1.175 \pm 0.001 \pm 0.004$
	$D \to \pi\ell\nu$	$\|V_{cd}\| f_+^{D\to\pi}(0)$	$=$	0.1426 ± 0.0019	$f_+^{D\to\pi}(0)$	$=$	$0.621 \pm 0.016 \pm 0.012$
$\|V_{cs}\|$	$W \to c\bar{s}$	$\|V_{cs}\|_{\rm not\ lattice}$	$=$	$0.94^{+0.32}_{-0.26} \pm 0.13$			
	$D_s \to \tau\nu$	$\mathcal{B}(D_s \to \tau\nu)$	$=$	$(5.55 \pm 0.24) \cdot 10^{-2}$	f_{D_s}	$=$	$247.8 \pm 0.3 \pm 2.0$ MeV
	$D_s \to \mu\nu$	$\mathcal{B}(D_s \to \mu\nu)$	$=$	$(5.39 \pm 0.16) \cdot 10^{-3}$			
	$D \to K\ell\nu$	$\|V_{cs}\| f_+^{D\to K}(0)$	$=$	0.7226 ± 0.0034	$f_+^{D\to K}(0)$	$=$	$0.741 \pm 0.010 \pm 0.012$
$\|V_{ub}\|$	semileptonic B	$\|V_{ub}\|_{\rm SL}$	$=$	$(3.98 \pm 0.08 \pm 0.22) \cdot 10^{-3}$	form factors, shape functions		
	$B \to \tau\nu$	$\mathcal{B}(B \to \tau\nu)$	$=$	$(1.08 \pm 0.21) \cdot 10^{-4}$	f_{B_s}/f_B	$=$	$1.205 \pm 0.004 \pm 0.006$
$\|V_{cb}\|$	semileptonic B	$\|V_{cb}\|_{\rm SL}$	$=$	$(41.8 \pm 0.4 \pm 0.6) \cdot 10^{-3}$	form factors, OPE matrix elements		
$\|V_{ub}/V_{cb}\|$	semileptonic Λ_b	$\frac{\mathcal{B}(\Lambda_p \to p\mu^-\bar{\nu})_{q^2>15}}{\mathcal{B}(\Lambda_p \to \Lambda_c\mu^-\bar{\nu})_{q^2>7}}$	$=$	$(0.947 \pm 0.081) \cdot 10^{-2}$	$\frac{\zeta(\Lambda_p \to p\mu^-\bar{\nu})_{q^2>15}}{\zeta(\Lambda_p \to \Lambda_c\mu^-\bar{\nu})_{q^2>7}}$	$=$	$1.471 \pm 0.096 \pm 0.290$
α	$B \to \pi\pi,\ \rho\pi,\ \rho\rho$	branching ratios, CP asymmetries			isospin symmetry		
β	$B \to (c\bar{c})K$	$\sin(2\beta)_{[c\bar{c}]}$	$=$	0.699 ± 0.017	subleading penguins neglected		
$\cos(2\beta)$	$B^0 \to D^{(*)}h^0$	$\cos(2\beta)$	$=$	0.91 ± 0.25			
γ	$B \to D^{(*)}K^{(*)}$	inputs for the 3 methods			GGSZ, GLW, ADS methods		
ϕ_s	$B_s \to J/\psi(KK, \pi\pi)$	$(\phi_s)_{b\to c\bar{c}s}$	$=$	-0.021 ± 0.031			
$V_{tq}^* V_{tq'}$	Δm_d	Δm_d	$=$	$0.5065 \pm 0.0019\ {\rm ps}^{-1}$	$\hat{B}_{B_s}/\hat{B}_{B_d}$	$=$	$1.007 \pm 0.013 \pm 0.014$
	Δm_s	Δm_s	$=$	$17.757 \pm 0.021\ {\rm ps}^{-1}$	$\hat{B}_{B_s}$	$=$	$1.327 \pm 0.016 \pm 0.030$
	$B_s \to \mu\mu$	$\mathcal{B}(B_s \to \mu\mu)$	$=$	$(2.8^{+0.7}_{-0.6}) \cdot 10^{-9} [\times(1-0.063)]$	f_{B_s}	$=$	$226.0 \pm 1.3 \pm 2.0$ MeV
$V_{td}^* V_{ts}$ and $V_{cd}^* V_{cs}$	ε_K	$\|\varepsilon_K\|$	$=$	$(2.228 \pm 0.011) \cdot 10^{-3}$	$\hat{B}_K$	$=$	$0.7567 \pm 0.0021 \pm 0.0123$
					κ_ε	$=$	$0.940 \pm 0.013 \pm 0.023$

black: no change; **blue**: slight change; **red**: update since ICHEP'16

(colors **do not** reflect the impact of the exp./theo. input!)