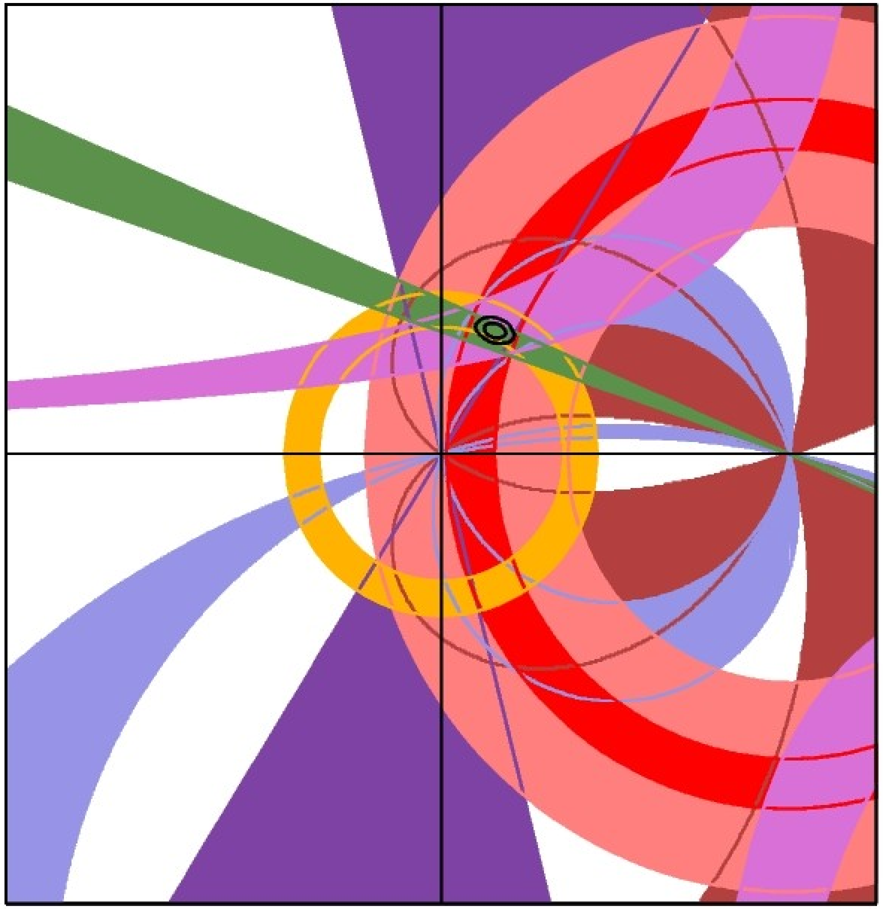
Flavour physics as a test of the standard model and a probe of new physics



Marcella Bona

NExT PhD Workshop
Cosener's House
Abingdon, UK
July 19th, 2011

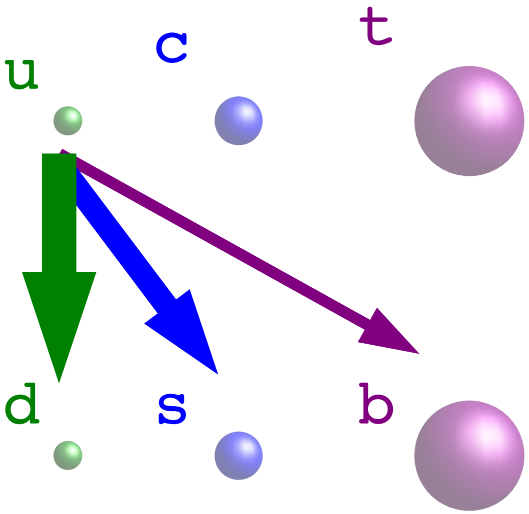
Outline

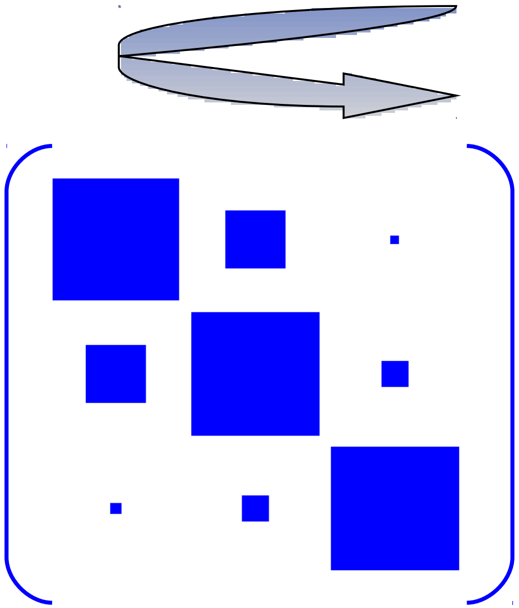
- very briefly:
  introduction and motivations
  - the tool: the Unitarity Triangle fit
- Standard Model fit
  - SM constraints
  - checking for tensions
  - SM predictions
- Beyond the Standard Model:
  - model-independent analysis
  - NP-specific constraints

Flavour mixing and CP violation in the Standard Model

- The CP symmetry is violated in any field theory having in the Lagrangian at least one phase that cannot be re-absorbed
- The mass eigenstates are not eigenstates of the weak interaction. This feature of the Standard Model Hamiltonian produces the (unitary) mixing matrix V_{CKM}.

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\bar\rho - i\bar\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\bar\rho - i\bar\eta) & -A\lambda^2 & 1 \end{pmatrix}$$





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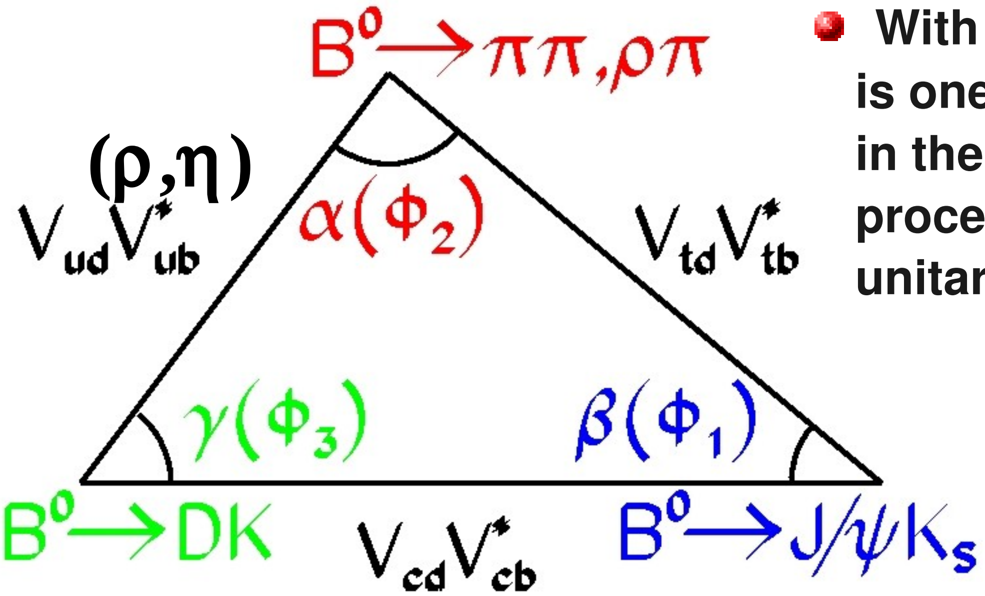


- With three families of quarks, there is one phase that allows CP violation in the SM. All the flavour mixing processes are related (through the unitarity of the V_{CKM}) to this phase.

Unitarity Triangle

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

All the angles are related to the CP asymmetries of specific B decays

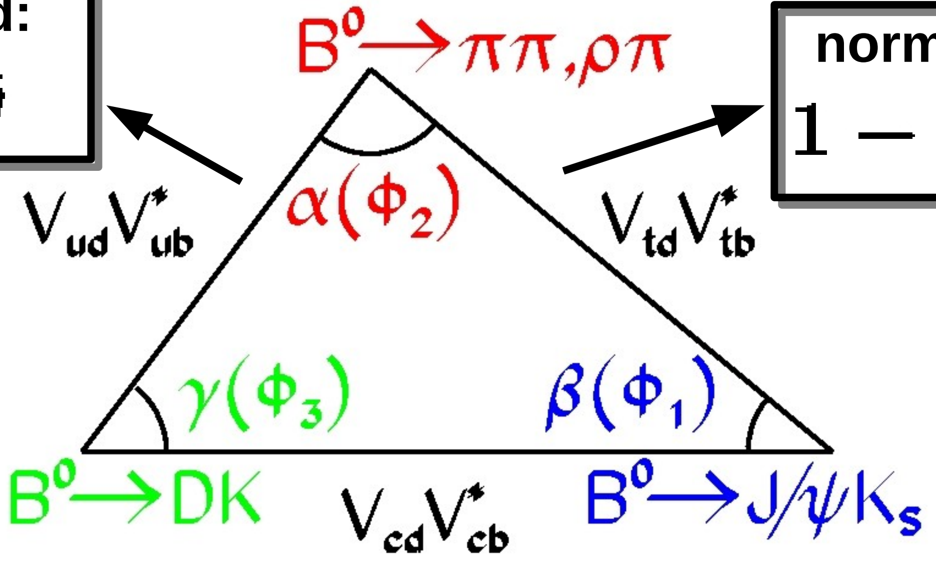
CKM matrix and Unitarity Triangle

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

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

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

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



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

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

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

UT*fit*

www.utfit.org

**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**

the method and the 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

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

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

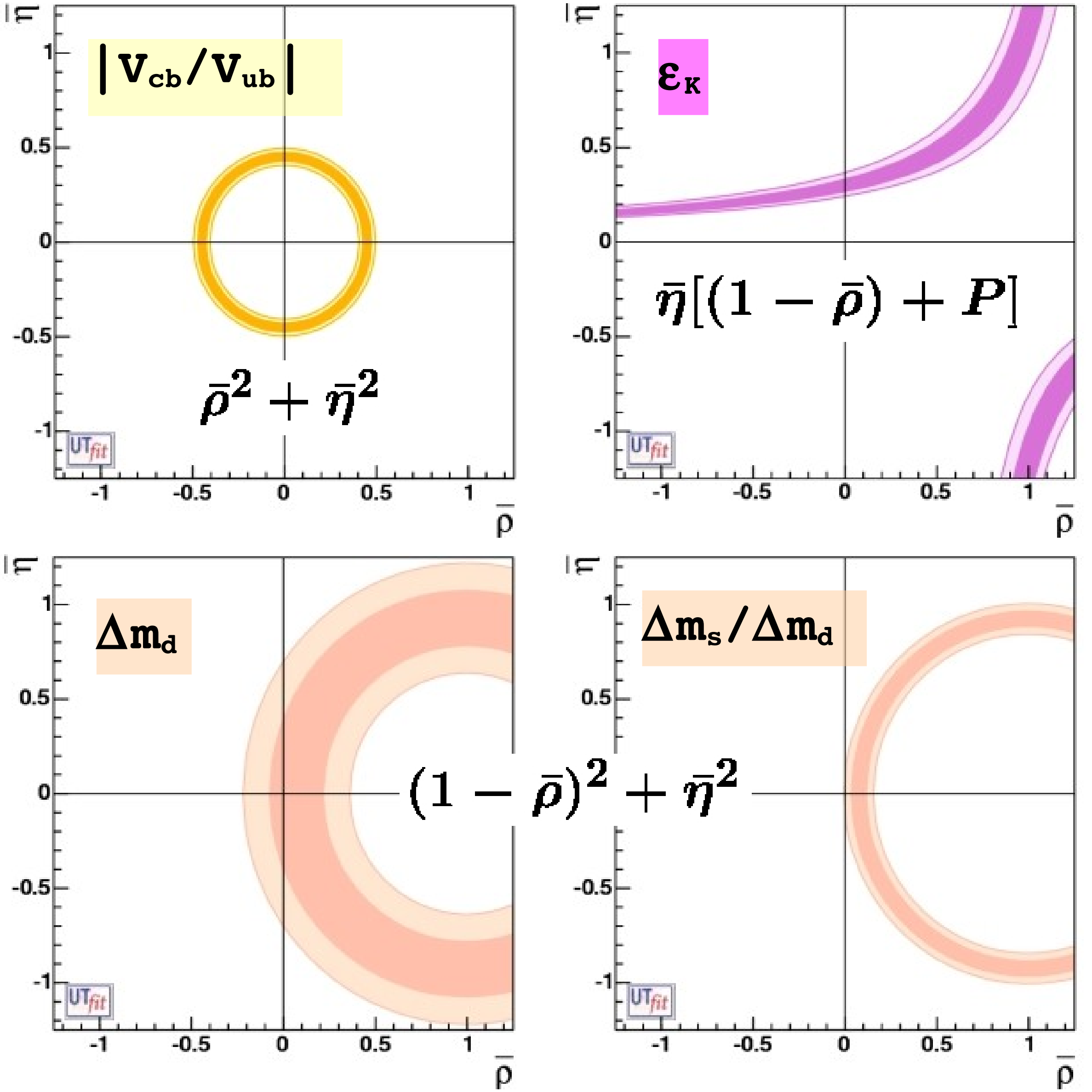
$(b \to u)/(b \to c)$	$\bar{\rho}^2 + \bar{\eta}^2$	$\bar{\Lambda}, \lambda_1, F(1), \ ...$
ϵ_K	$\bar{\eta}[(1-\bar{\rho}) + P]$	B_K }
Δm_d	$(1-\bar{\rho})^2 + \bar{\eta}^2$	$f_B^2 B_B$
$\Delta m_d / \Delta m_s$	$(1-\bar{\rho})^2 + \bar{\eta}^2$	ξ
$A_{CP}(J/\psi K_S)$	$\sin 2\beta$	

, mt

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

the LEP-style analysis in the $\bar{\rho}$-$\bar{\eta}$ plane:



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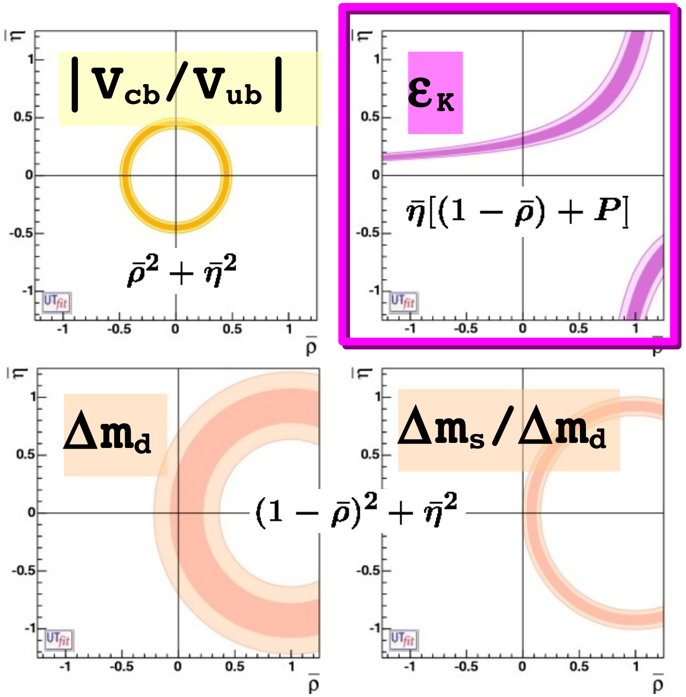
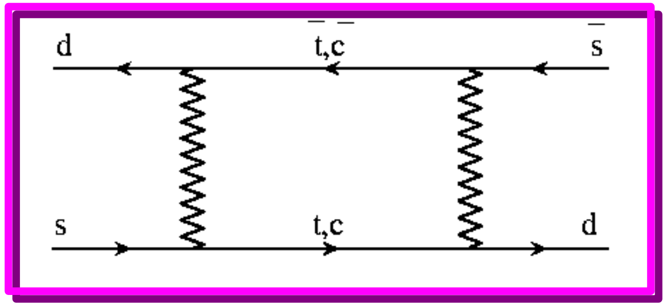


ε_K from $\bar{K}$-K mixing



$\varepsilon_K = (2.228 \pm 0.011) \cdot 10^{-3}$ PDG

$$B_K = \frac{<K|J_\mu J^\mu|\overline{K}>}{<K|J_\mu|0><0|J^\mu|\overline{K}>}$$

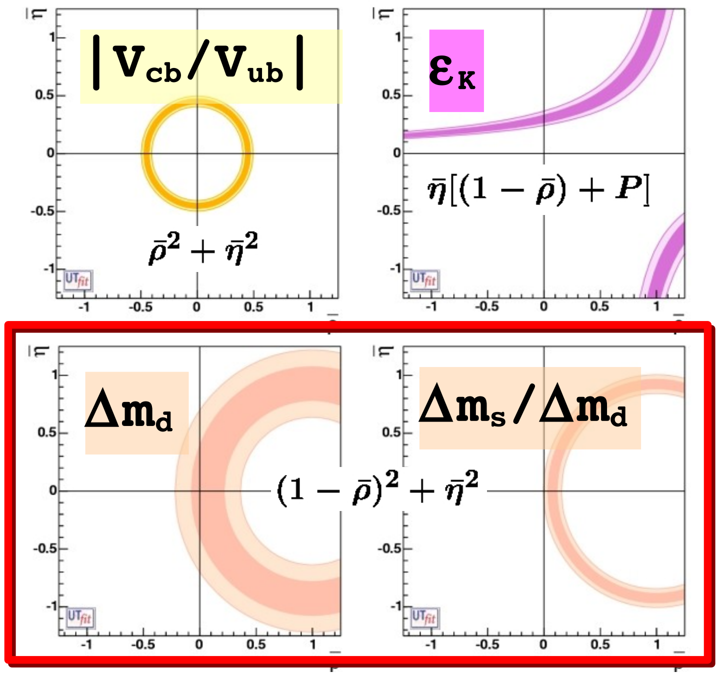
$B_K = 0.731 \pm 0.036$

from lattice QCD

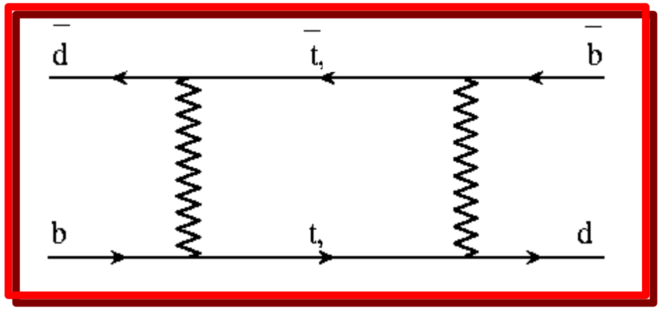
$$|\varepsilon_K| = C_\varepsilon B_K A^2\lambda^6\bar{\eta}\{-\eta S_0(x_c)(1-\lambda^2/2)+\eta_3 S_0(x_c,x_t)+\eta_2 S_0(x_t)A^2\lambda^4(1-\bar{\rho})\}$$

S_0 = Inami-Lim functions for c-c, c-t, e t-t contributions (from perturbative calculations)

the LEP-style analysis in the $\bar{\rho}$-$\bar{\eta}$ plane:



Δm_q from $\bar{B}_q$-B_q mixing q=d.s



Δm_d = 0.507 ± 0.005 ps^{-1} **WA**

Δm_s = 17.70 ± 0.08 ps^{-1} **CDF +LHCb**

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

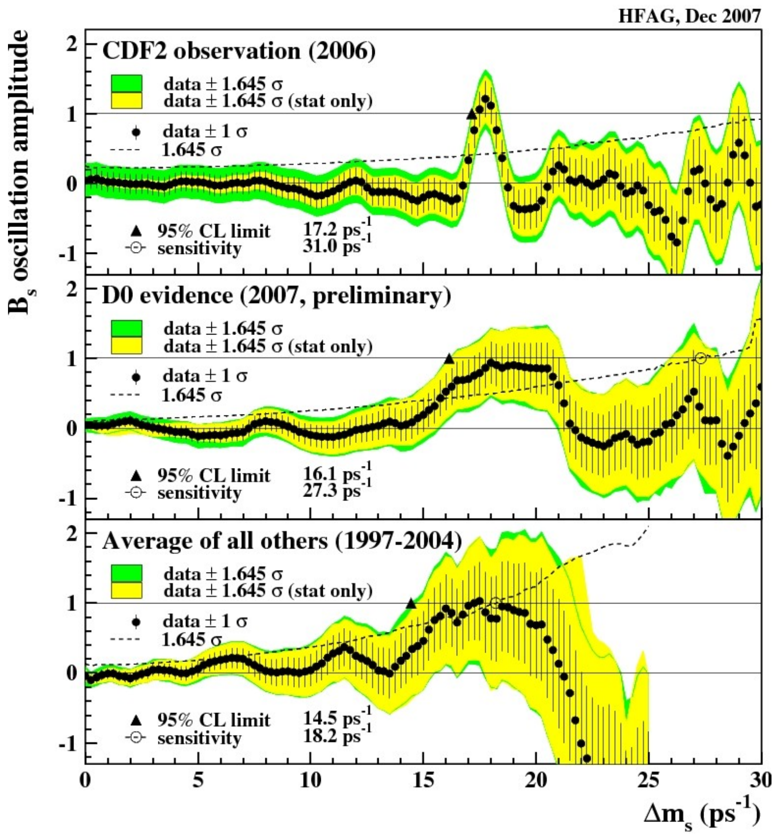
$$\Delta m_d \approx [(1-\rho)^2+\eta^2]\frac{f_{B_s}^2 B_{B_s}}{\xi^2}$$

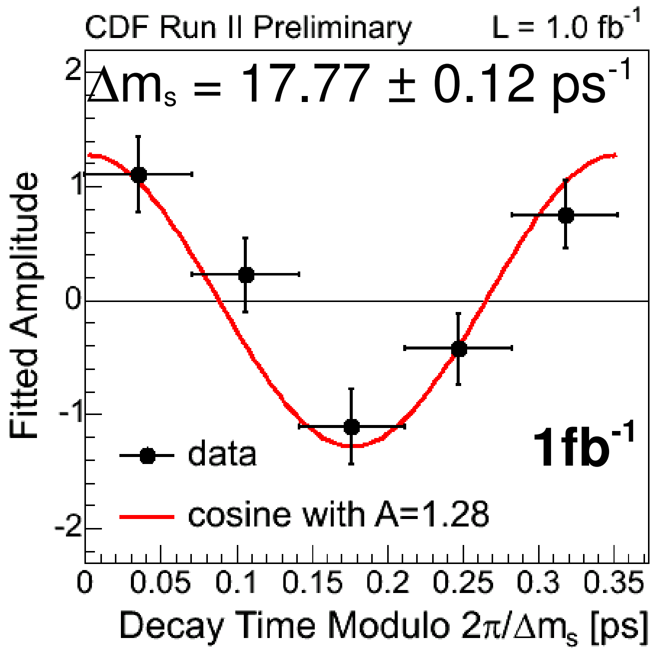
$$\Delta m_s \approx f_{B_s}^2 B_{B_s}$$

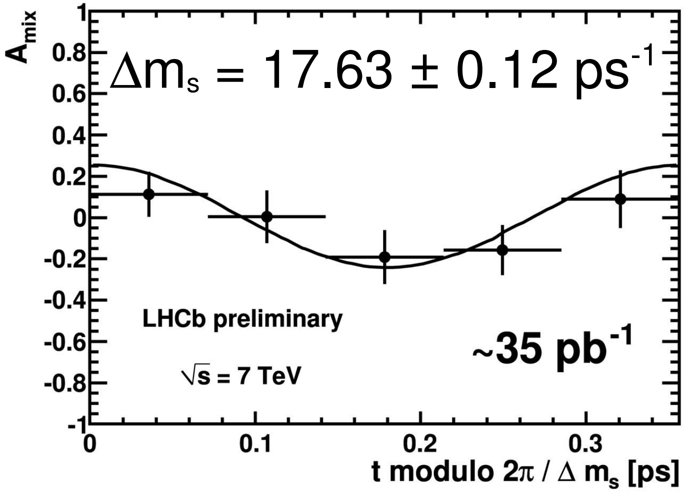
S = Inami-Lim function
for the t-t contribution
(from perturbative calculations)

B_{B_q} and f_{B_q} from lattice QCD

the LEP-style analysis in the $\overline{\rho}$-$\overline{\eta}$ plane:



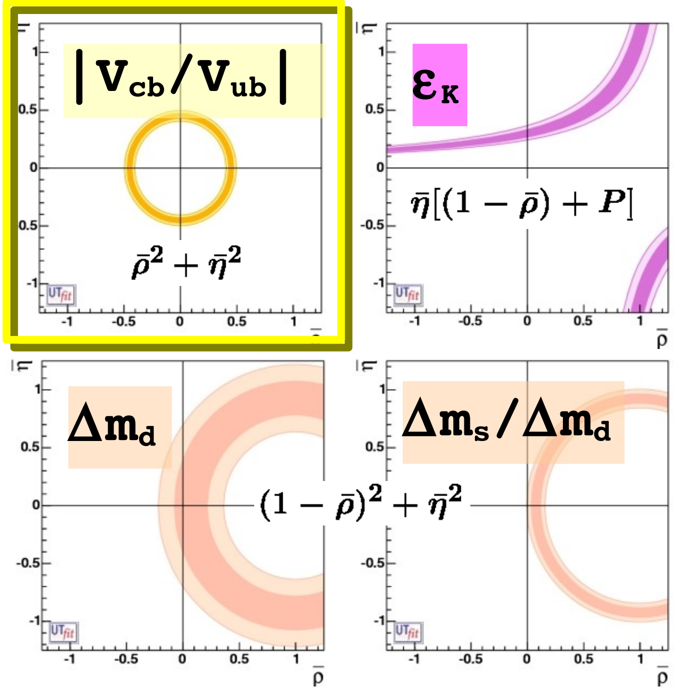




New world average from CDF and LHCb

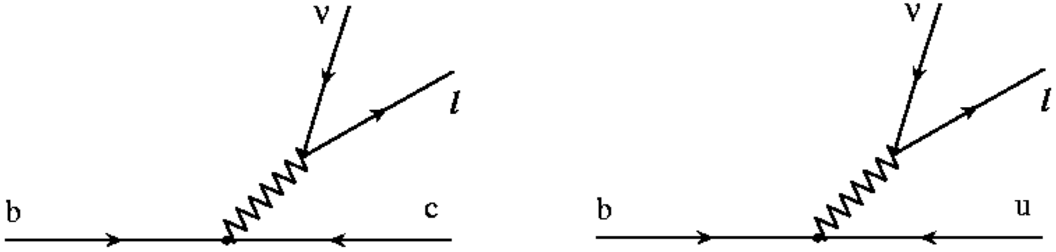
$\Delta m_s = 17.70 \pm 0.08$ ps^{-1}

the LEP-style analysis in the $\bar{\rho}$-$\bar{\eta}$ plane:



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

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



tree diagrams

b → c and b → u transition

- **negligible new physics contributions**
- **inclusive and exclusive semileptonic B decay branching ratios**

QCD corrections to be included

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

V_{cb} and V_{ub}

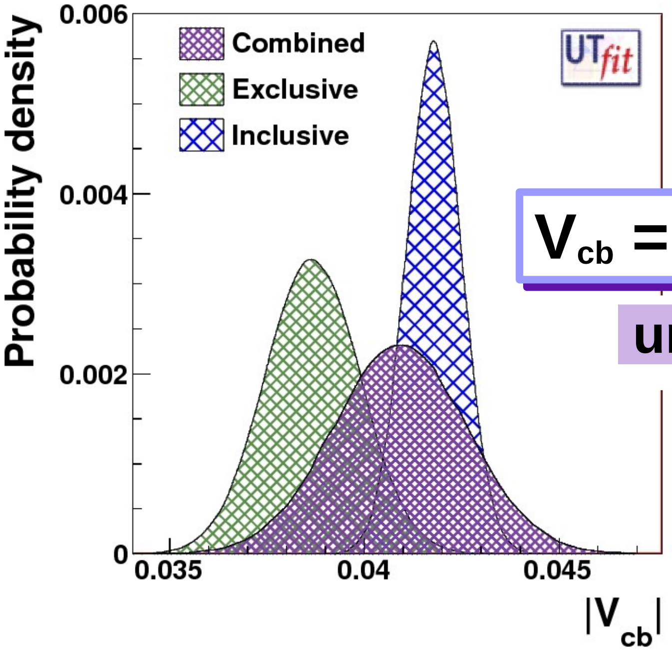
Laiho *et al*

V_{cb} *(excl)* = $(38.6 \pm 1.2)\ 10^{-3}$

HFAG

V_{cb} *(incl)* = $(41.7 \pm 0.7)\ 10^{-3}$

~2.2σ discrepancy



UTfit input value

$V_{cb} = (40.9 \pm 1.7)\ 10^{-3}$

uncertainty ~ 4%

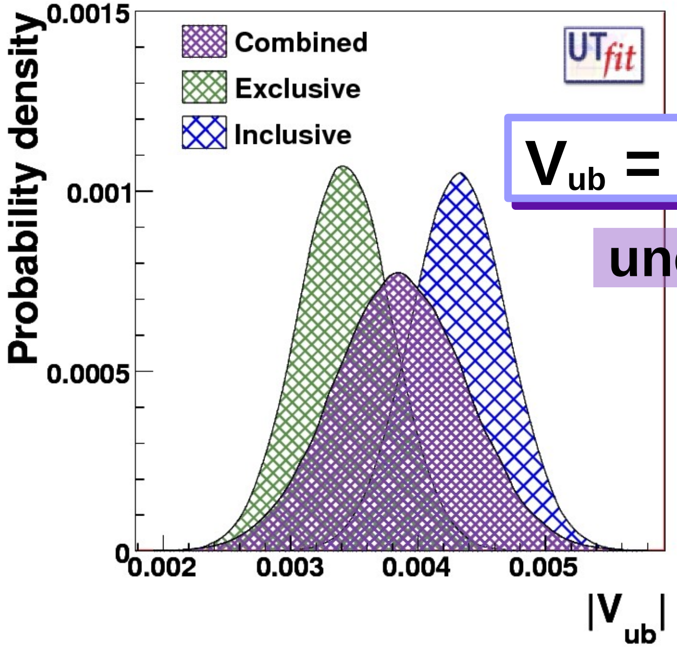
Laiho *et al*

V_{ub} *(excl)* = $(3.42 \pm 0.37)\ 10^{-3}$

UTfit from HFAG

V_{ub} *(incl)* = $(4.32 \pm 0.38)\ 10^{-3}$

~1.7σ discrepancy

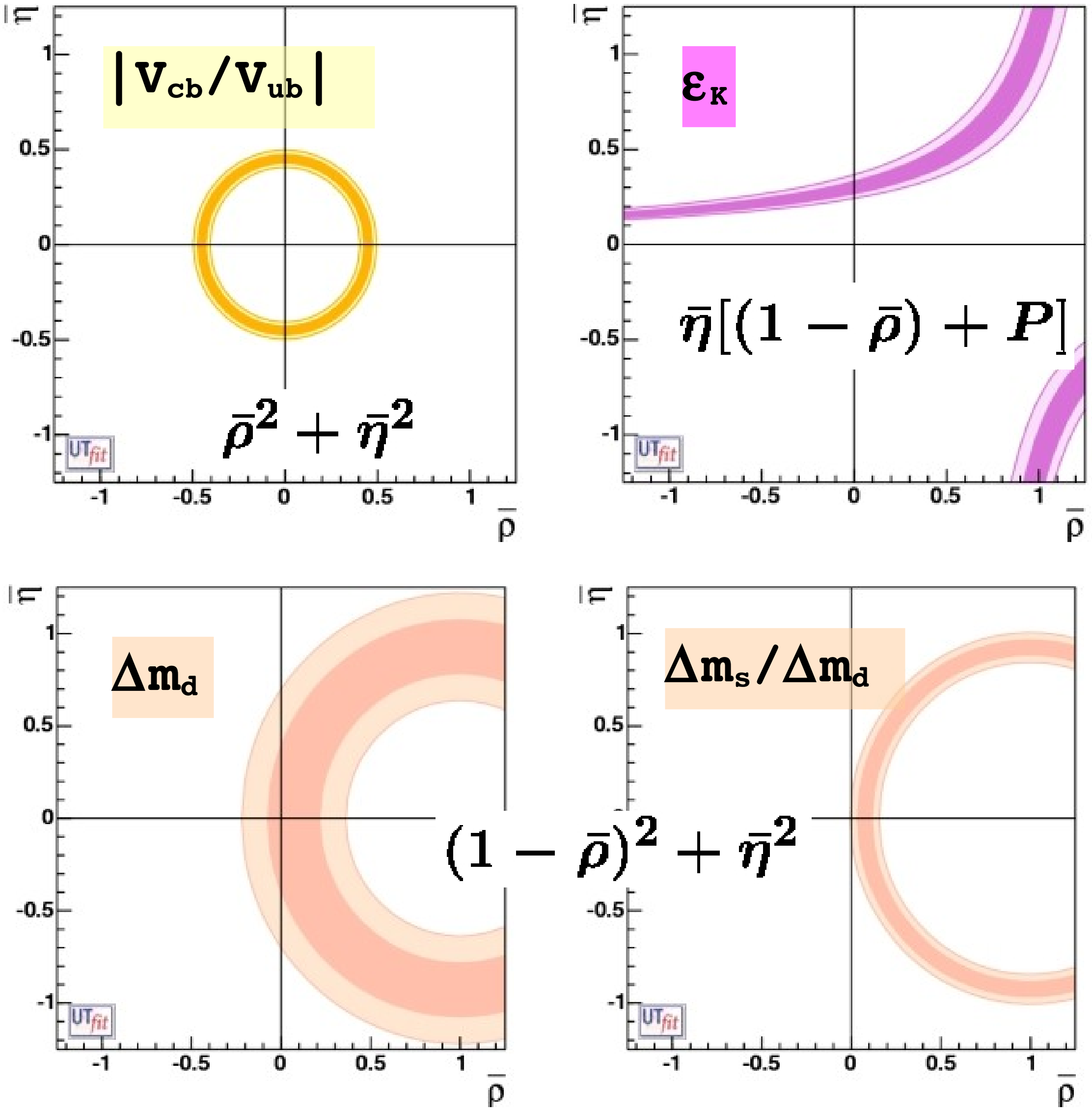


UTfit input value

$V_{ub} = (3.86 \pm 0.52)\ 10^{-3}$

uncertainty ~ 13%

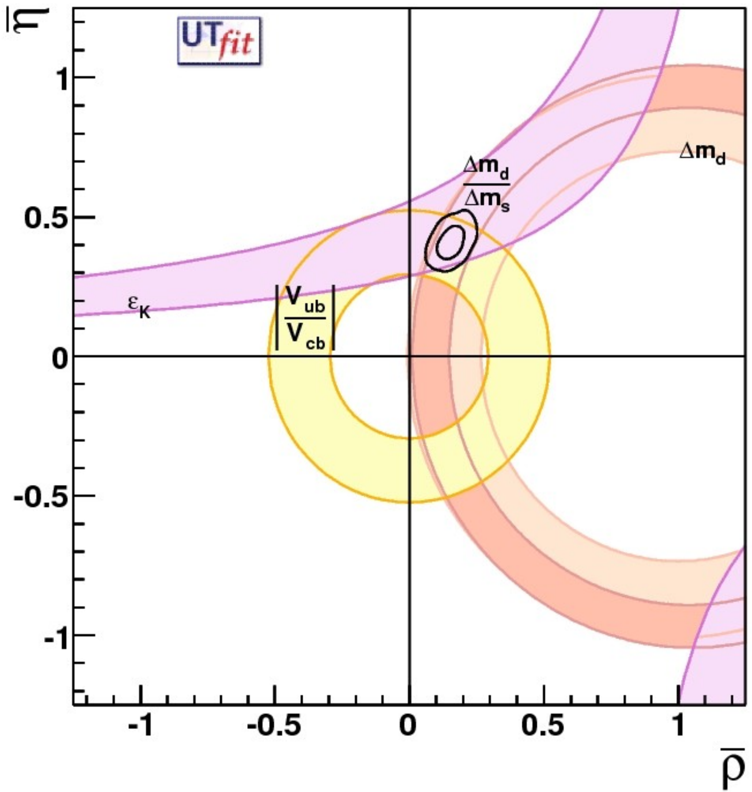
the LEP-style analysis in the $\bar{\rho}$-$\bar{\eta}$ plane:



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

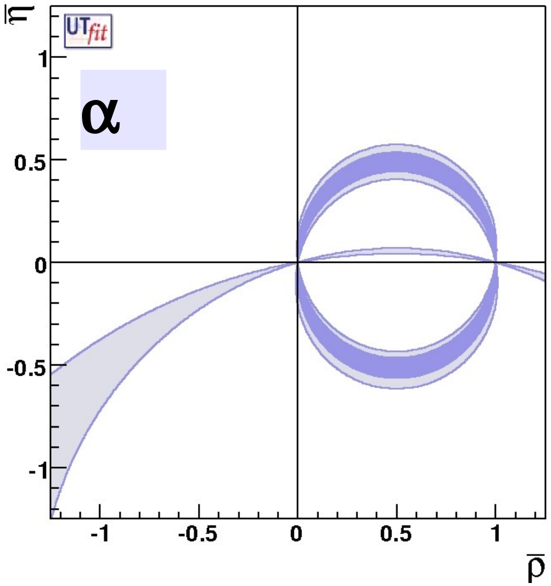
$$\bar{\eta}[(1-\bar{\rho})+P]$$

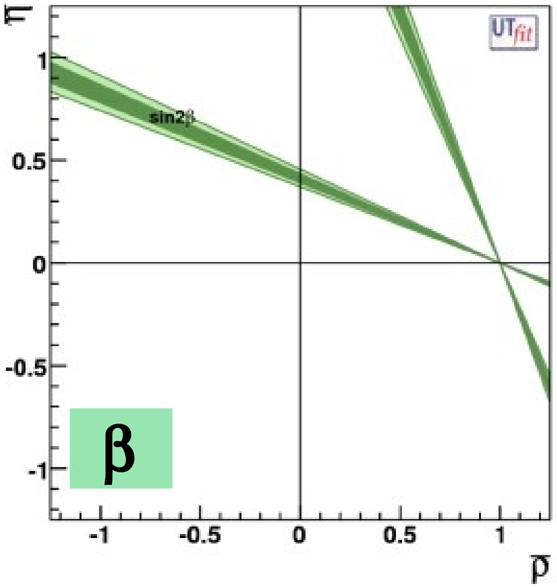
$$(1-\bar{\rho})^2+\bar{\eta}^2$$

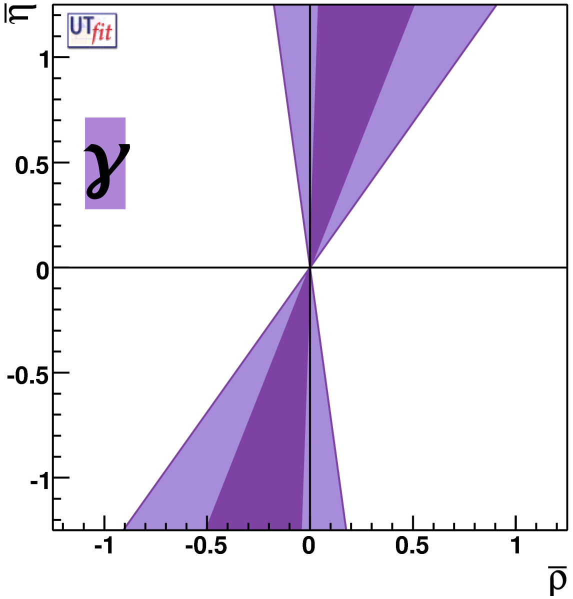


$\bar{\rho}$ = 0.157 ± 0.037
$\bar{\eta}$ = 0.409 ± 0.043

angle constraints in the $\bar{\rho}$-$\bar{\eta}$ plane:

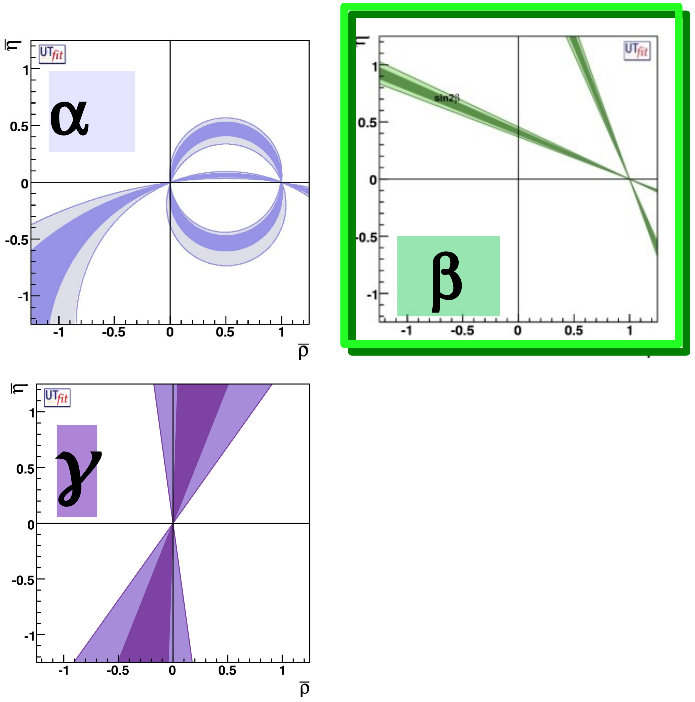




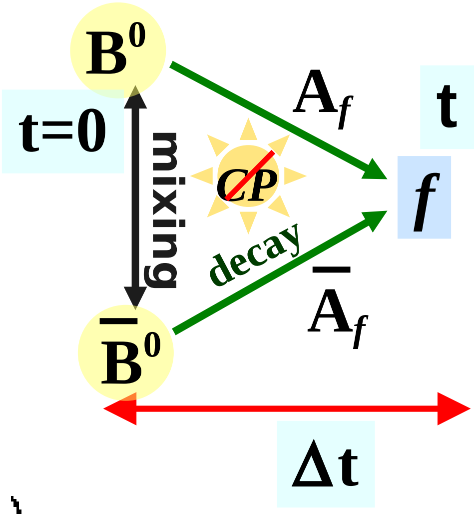


B-factory results

angle constraints in the $\bar{\rho}$-$\bar{\eta}$ plane:



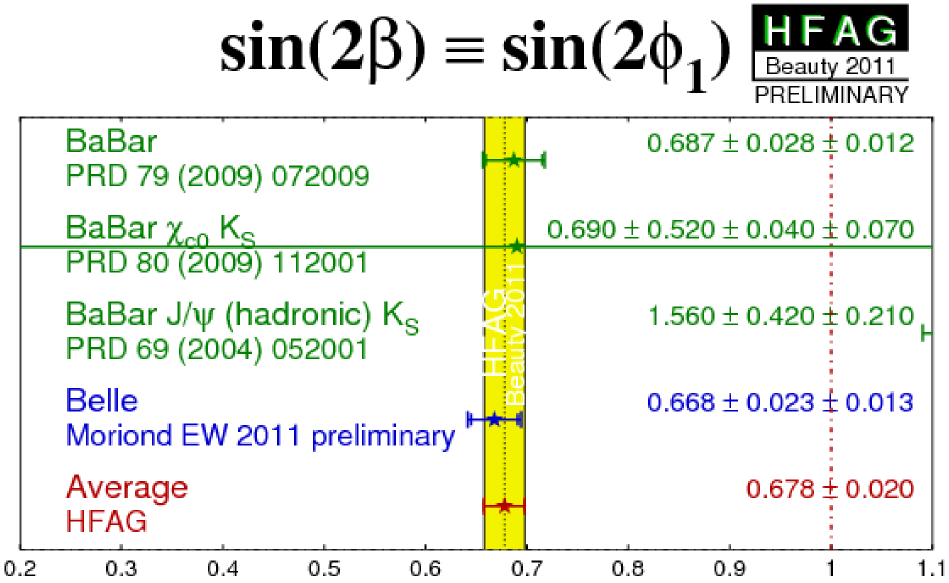
sin2β from time-dependent A_{CP} in B → J/ψK



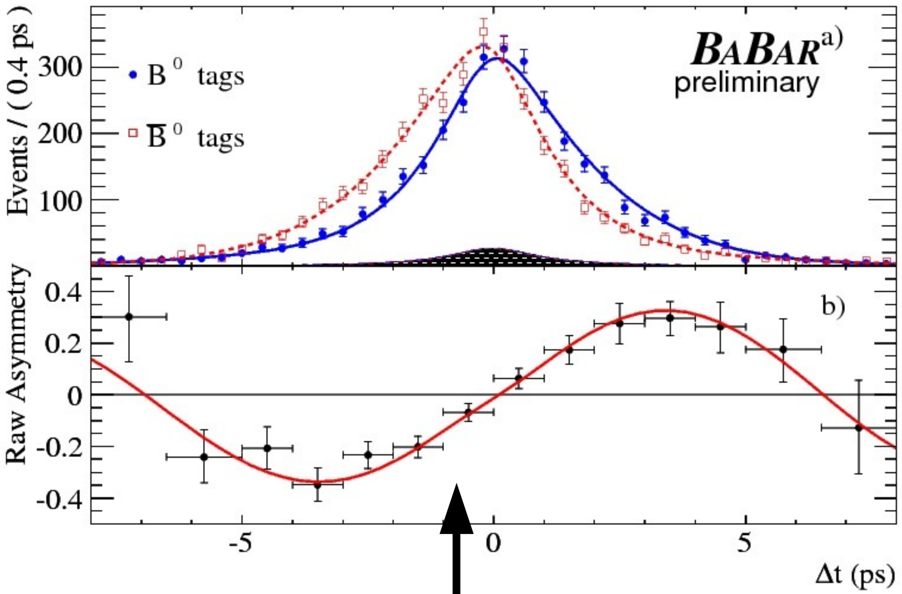
$$a_{f_{CP}}(t) = \frac{\mathrm{Prob}(B^0(t)\to f_{CP}) - \mathrm{Prob}(\overline{B^0}(t)\to f_{CP})}{\mathrm{Prob}(\overline{B^0}(t)\to f_{CP}) + \mathrm{Prob}(B^0(t)\to f_{CP})} = C_f \cos\Delta m_d t \; + \; S_f \sin\Delta m_d t$$

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

Latest sin2β results:




TM & © Nelvana



raw asymmetry
as function of Δt

BABAR Collaboration
Physical Review D 79:072009, 2009

BaBar with 465 10^6 $\overline{B}$B pairs

sin2β = 0.666 ± 0.031 ± 0.013

Belle with 772 10^6 $\overline{B}$B pairs

sin2β = 0.663 ± 0.025 *± 0.013*

Belle Collaboration
Moriond EW 2011, preliminary

UTfit values

sin2β(J/ψK^0) = 0.664 ± 0.022

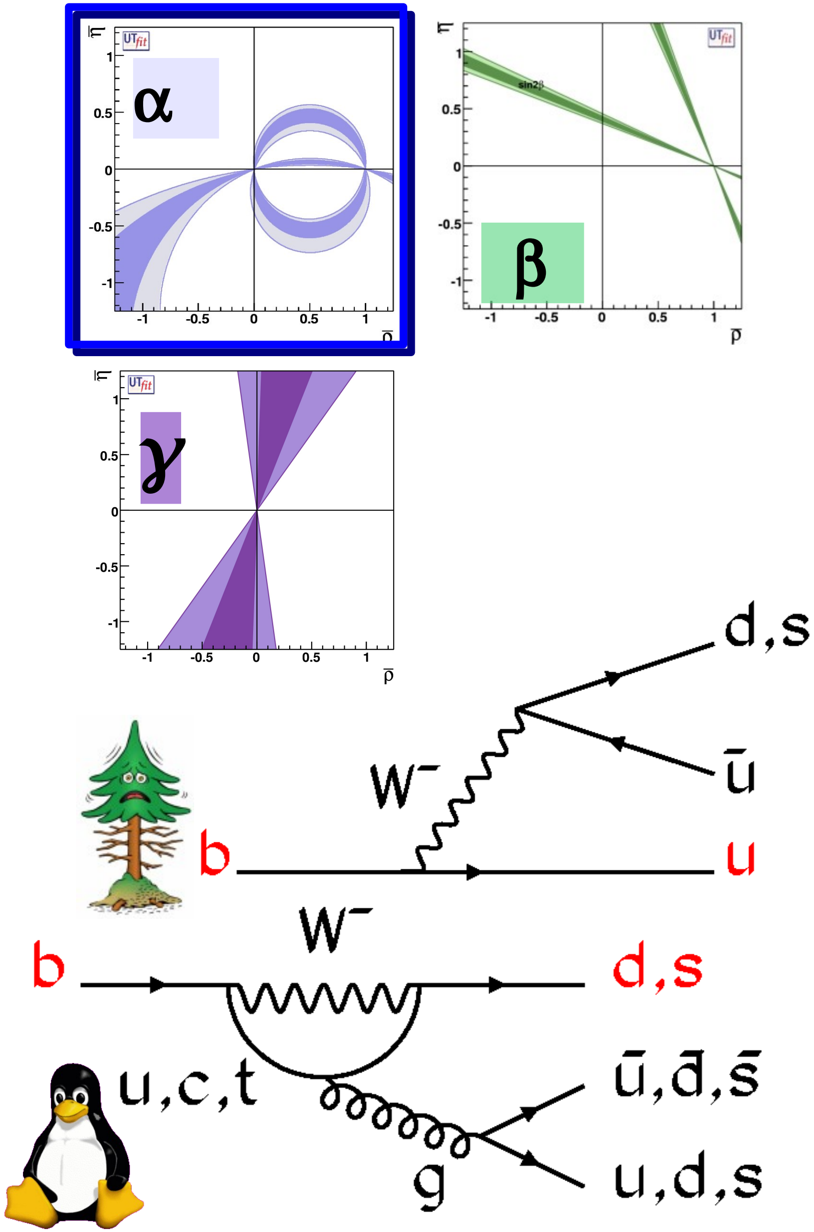
WA

data-driven theoretical uncertainty

ΔS = 0.000 ± 0.012

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

angle constraints in the $\bar{\rho}$-$\bar{\eta}$ plane:



α: CP violation in $B^0 \to \pi^+\pi^-$

- considering the tree (T) only:

$$\lambda_{\pi\pi} = e^{2ia}$$

$$C_{\pi\pi} = 0$$

$$S_{\pi\pi} = \sin(2\alpha)$$

- adding the penguins (P):

$$\lambda_{\pi\pi} = e^{2i\alpha}\frac{1+|P/T|e^{i\delta}e^{i\gamma}}{1+|P/T|e^{i\delta}e^{-i\gamma}}$$

$$C_{\pi\pi} \propto \sin(\delta)$$

$$S_{\pi\pi} = \sqrt{1-C^2_{\pi\pi}}\,\sin(2\alpha_{eff})$$

angle constraints in the $\bar{\rho}$-$\bar{\eta}$ plane:

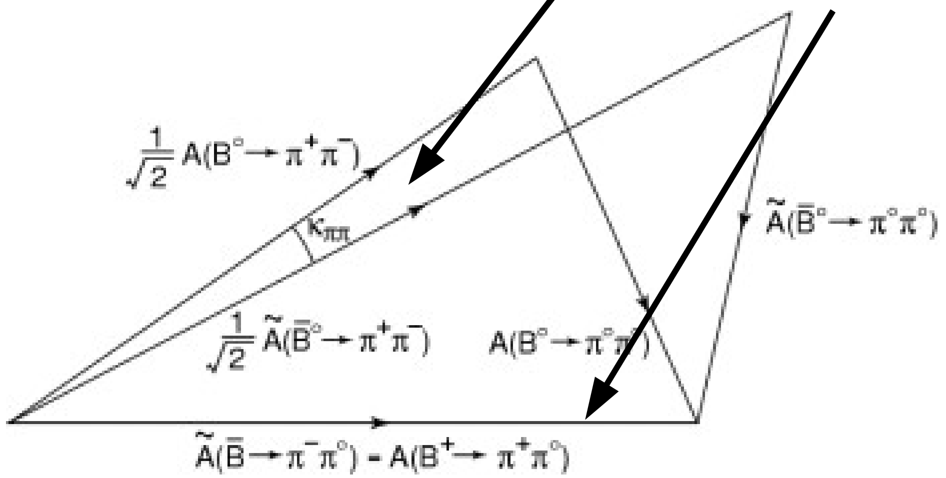
from $\alpha_{eff} \rightarrow$ to α: isospin analysis

- $B \rightarrow \pi^+\pi^-$, $\pi^+\pi^0$, $\pi^0\pi^0$ decays are connected from isospin relations
- π π states can have I = 2 or I = 0
  - the gluonic penguins contribute only to the I = 0 state (ΔI=1/2)
  - $\pi^+\pi^0$ is a **pure I = 2** state (ΔI = 3/2) and it gets contribution only from the **tree diagram**
  - triangular relations allow for the determination of the phase difference induced on α:

$$2\alpha_{eff} = 2\alpha + \kappa_{\pi\pi}$$

$$|A^{+0}|=|A^{-0}|$$

Both BR(B^0) and BR($\bar{B}^0$) have to be measured in all the $\pi\pi$ channels

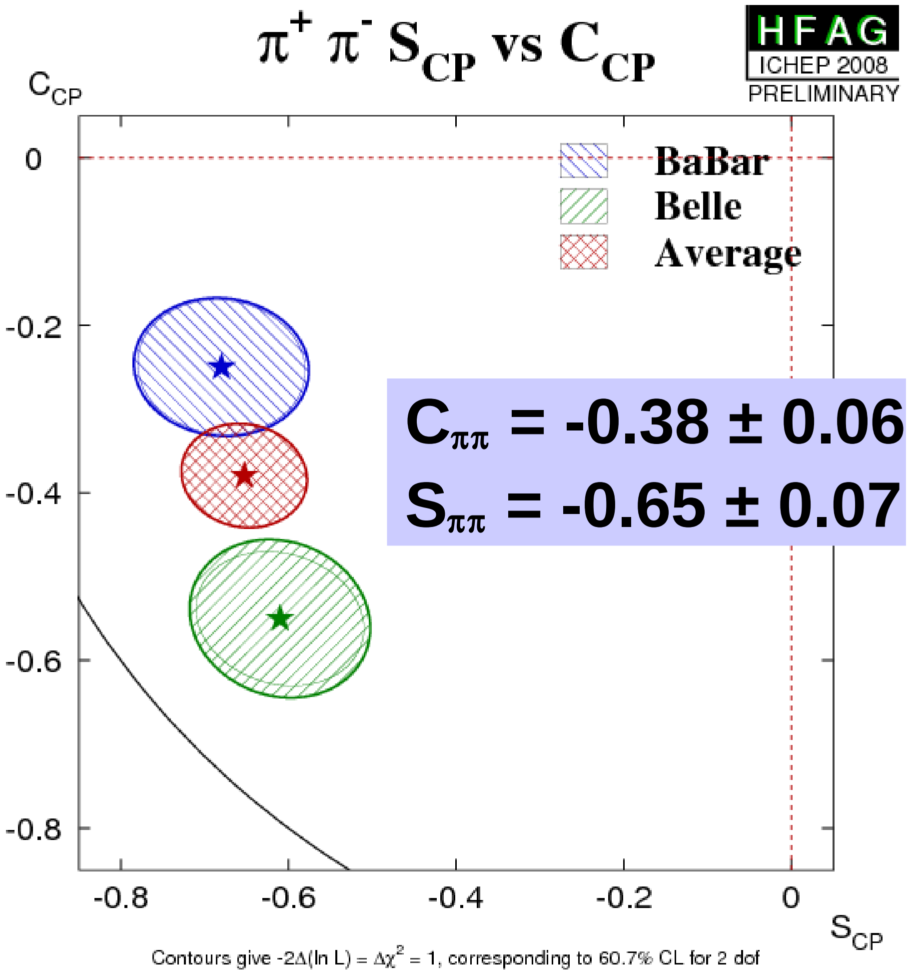


angle constraints in the $\overline{\rho}$-$\overline{\eta}$ plane:

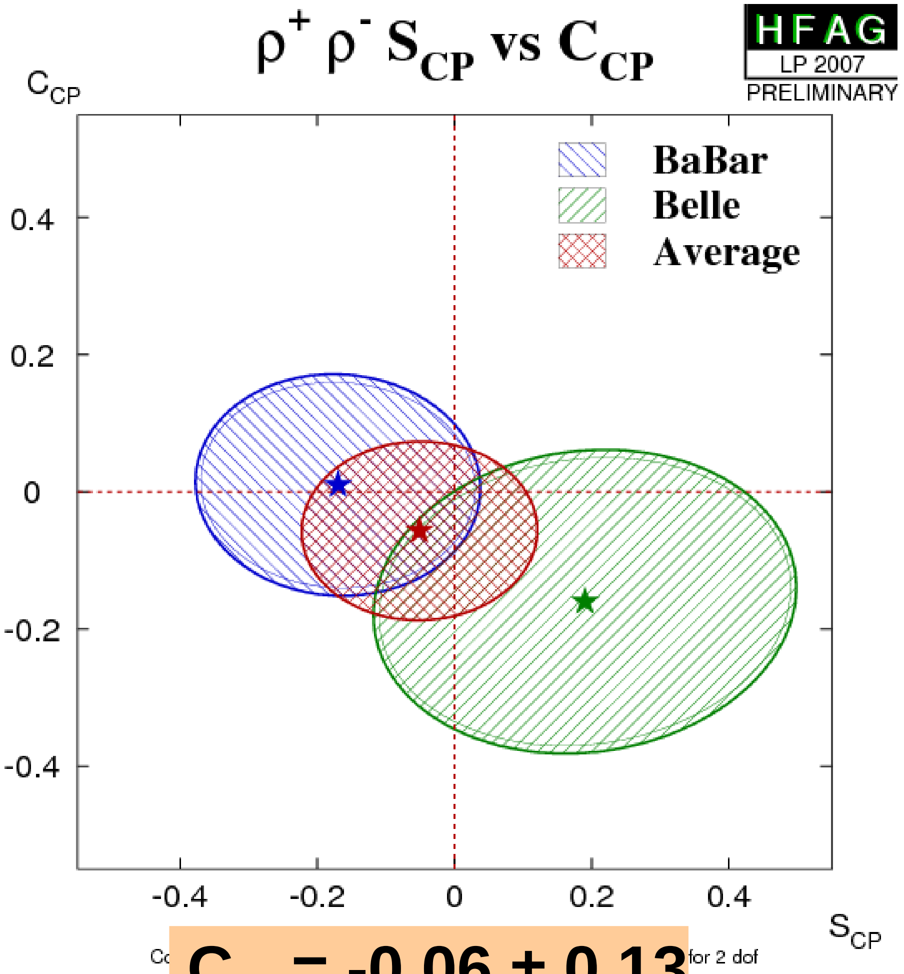
α result for $\pi^+\pi^-$ and $\rho^+\rho^-$

Belle Collaboration
PRL 98 (2007) 211801

BABAR Collaboration
arXiv:0807.4226 [hep-ex]

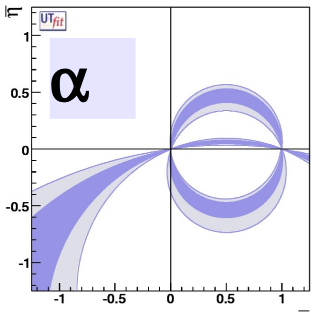


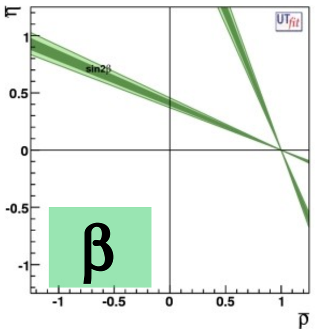
$C_{\pi\pi}$ = -0.38 ± 0.06
$S_{\pi\pi}$ = -0.65 ± 0.07

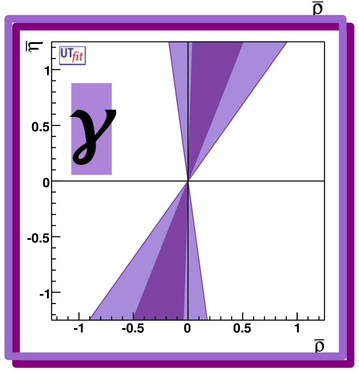


$C_{\rho\rho}$ = -0.06 ± 0.13
$S_{\rho\rho}$ = -0.05 ± 0.17

angle constraints in the $\bar{\rho}$-$\bar{\eta}$ plane:

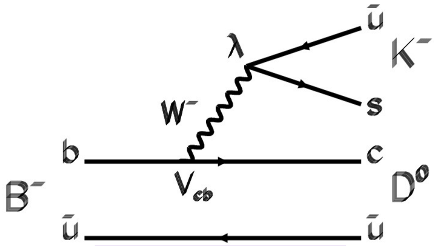






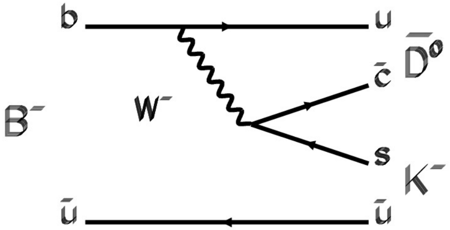
γ and DK trees

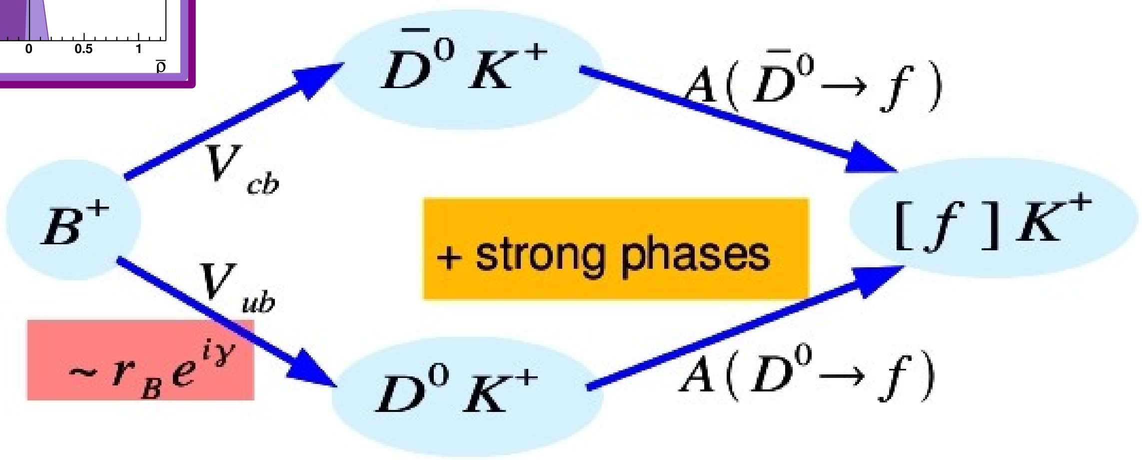
- $D^{(*)}K^{(*)}$ decays: from BRs and BR ratios, no time-dependent analysis, just rates
- the phase γ is measured exploiting interferences: two amplitudes leading to the same final states
- some rates can be really small: ~ 10^{-7}



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

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





$\bar{D}^0 K^+$

$A(\bar{D}^0 \rightarrow f)$

B^+

V_{cb}

V_{ub}

+ strong phases

$[f]K^+$

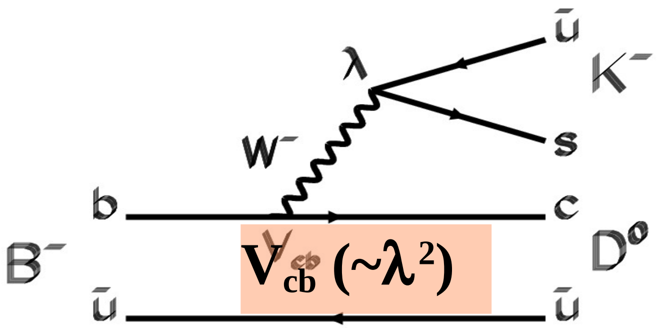
$\sim r_B e^{i\gamma}$

$D^0 K^+$

$A(D^0 \rightarrow f)$

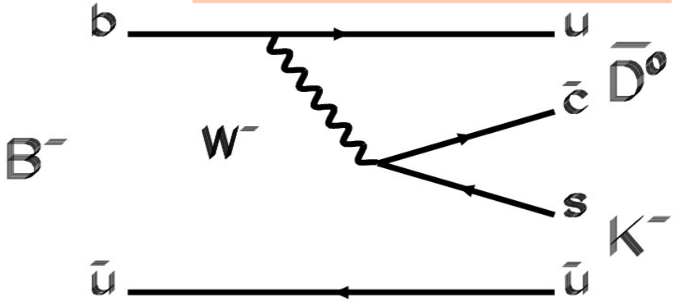
$B \rightarrow D^{(*)0}(\bar{D}^{(*)0})K^{(*)}$ decays can proceed both through V_{cb} and V_{ub} amplitudes

sensitivity to γ: the ratio r_B



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

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



δ_B = strong phase diff.

$$A(B^- \to D^0 K^-) = A_B \qquad A(B^- \to \bar{D}^0 K^-) = A_B r_B e^{i(\delta_B - \gamma)}$$

$$A(B^+ \to \bar{D}^0 K^+) = A_B \qquad A(B^+ \to D^0 K^+) = A_B r_B e^{i(\delta_B + \gamma)}$$

r_B = amplitude ratio

$$r_B = \left| \frac{B^- \to \bar{D}^0 K^-}{B^- \to D^0 K^-} \right| = \sqrt{\bar{\eta}^2 + \bar{\rho}^2} \times F_{CS}$$

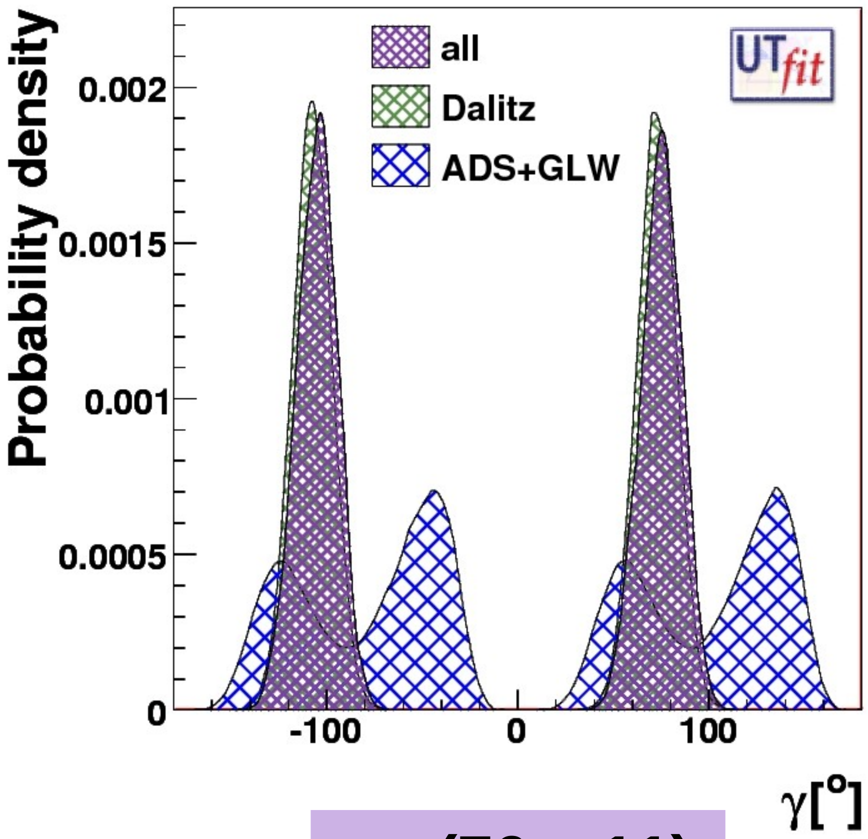
$\swarrow$ ~0.36

$\swarrow$ hadronic contribution channel-dependent

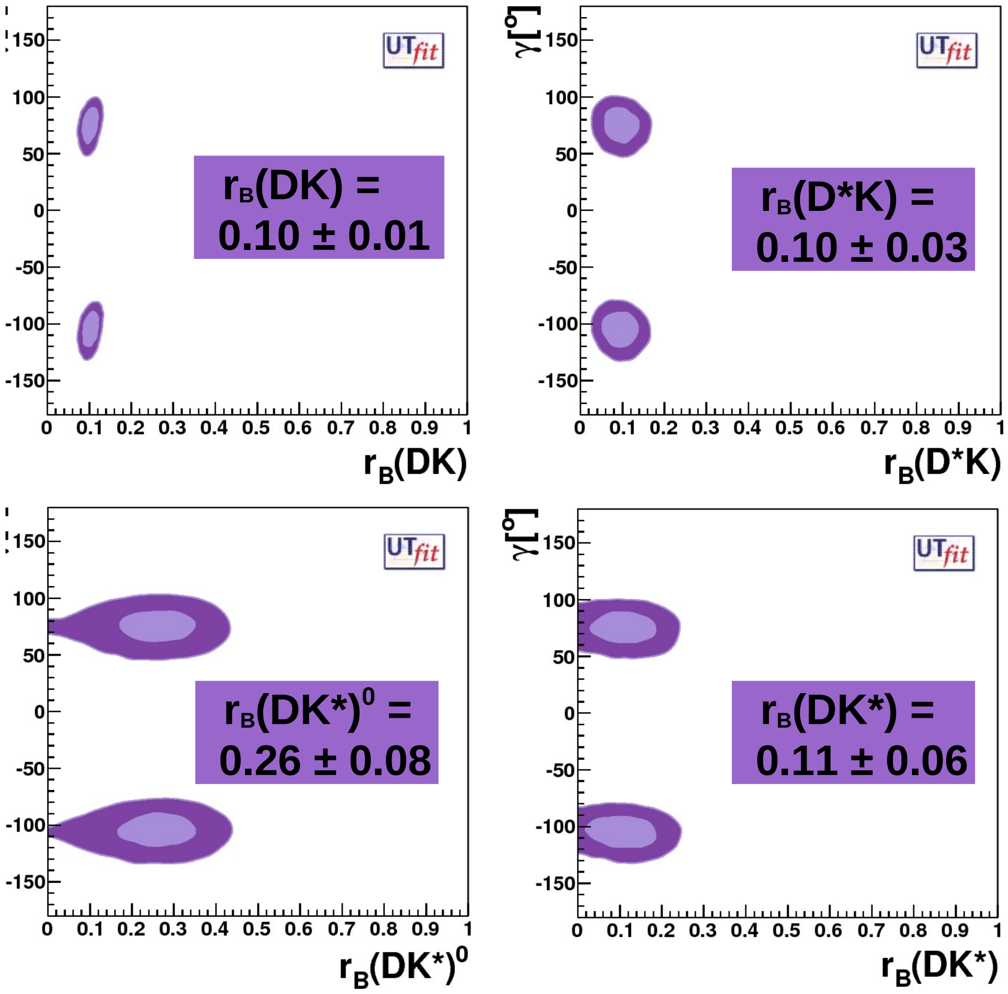
- in $B^+ \to D^{(*)0} K^+$: r_B is ~0.1
- while in $B^0 \to D^{(*)0} K^0$ r_B could be ~0.2-0.4
- to be measured: $r_B(DK)$, $r^*_B(D^*K)$ and $r^s_B(DK^*)$

angle constraints in the $\bar{\rho}$-$\bar{\eta}$ plane:

γ and DK trees



$\gamma = (76 \pm 11)^o$



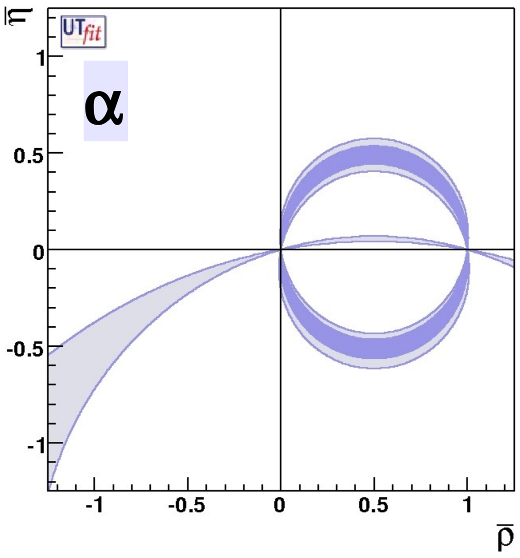
$r_B(DK) = 0.10 \pm 0.01$

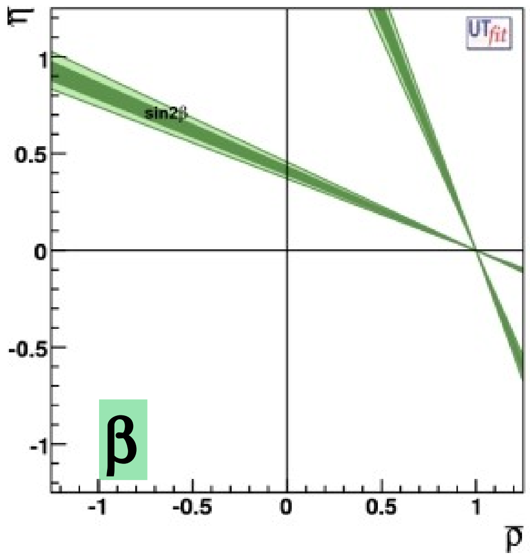
$r_B(D^*K) = 0.10 \pm 0.03$

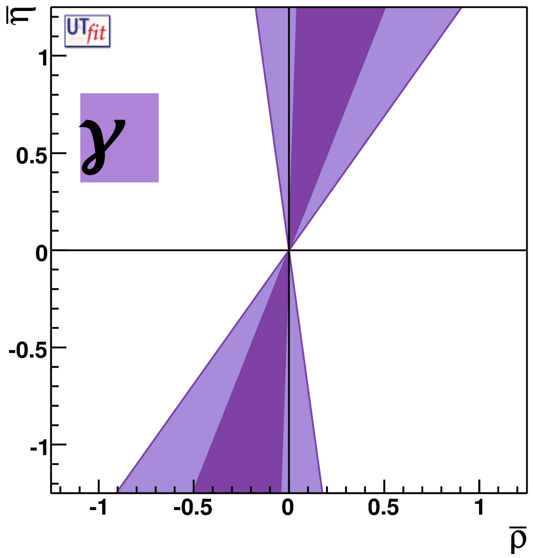
$r_B(DK^*)^0 = 0.26 \pm 0.08$

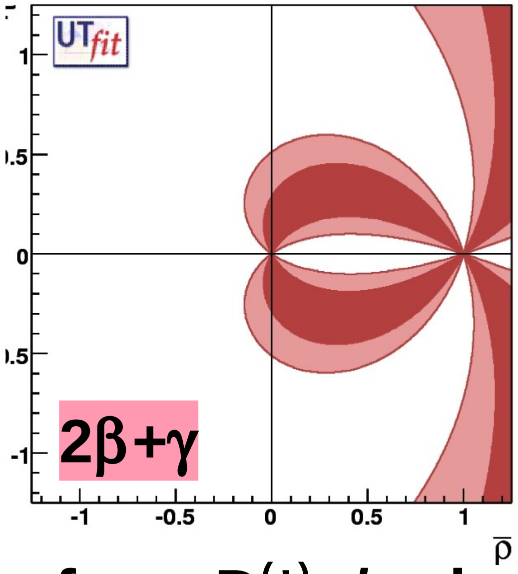
$r_B(DK^*) = 0.11 \pm 0.06$

angle constraints in the $\bar{\rho}$-$\bar{\eta}$ plane:



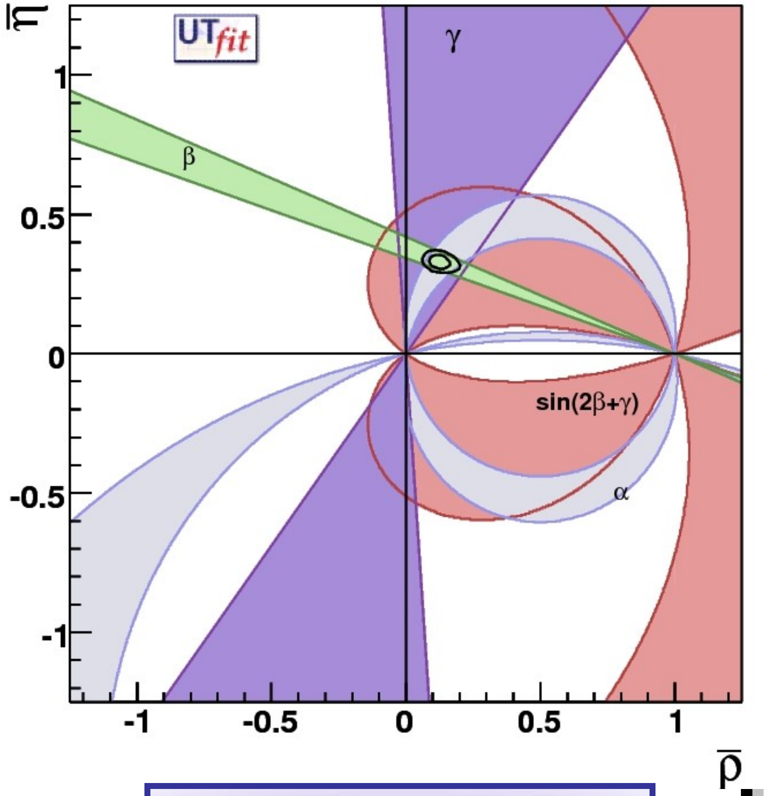






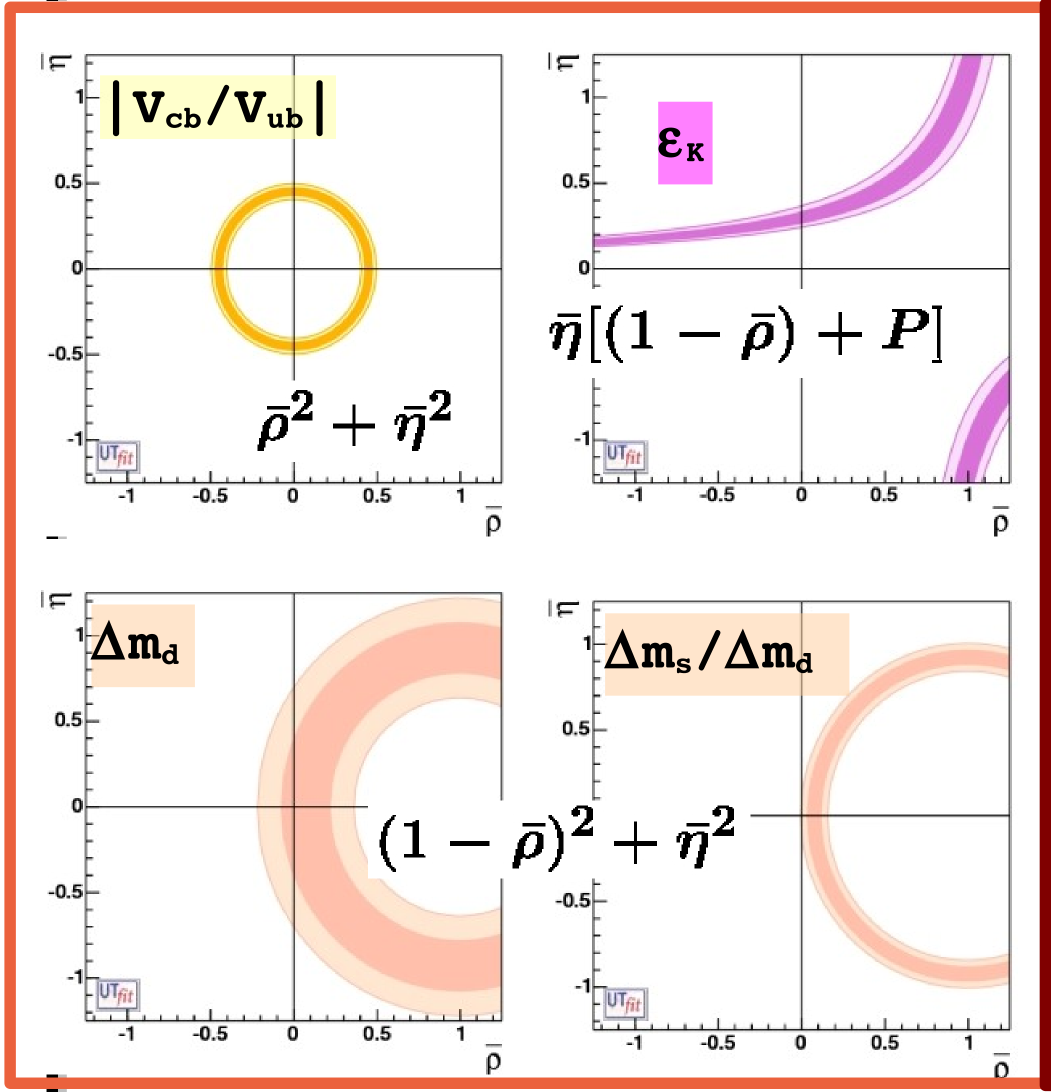
from $D^{(*)}\pi/\rho$ decays

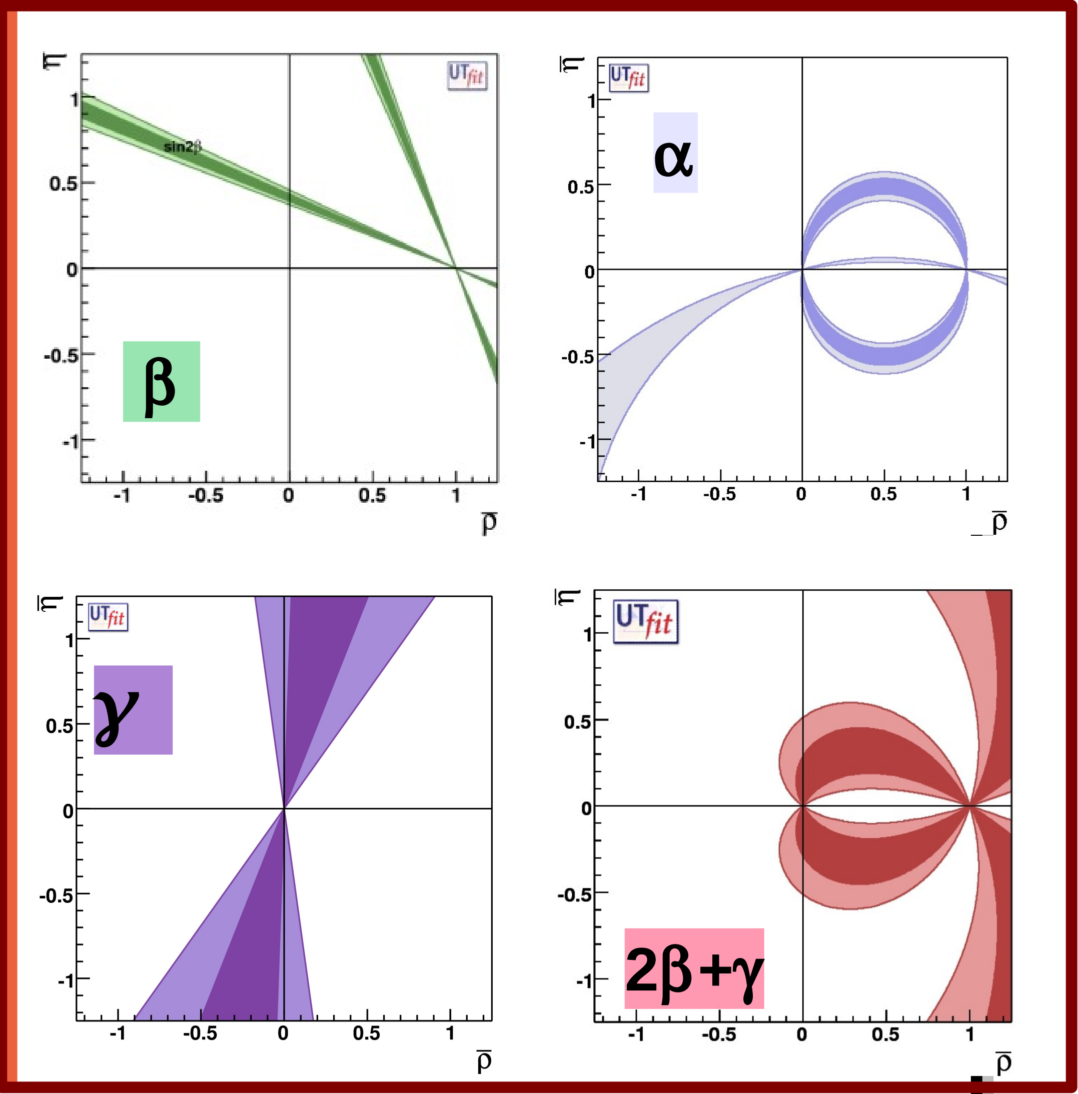
levels @ 95% Prob



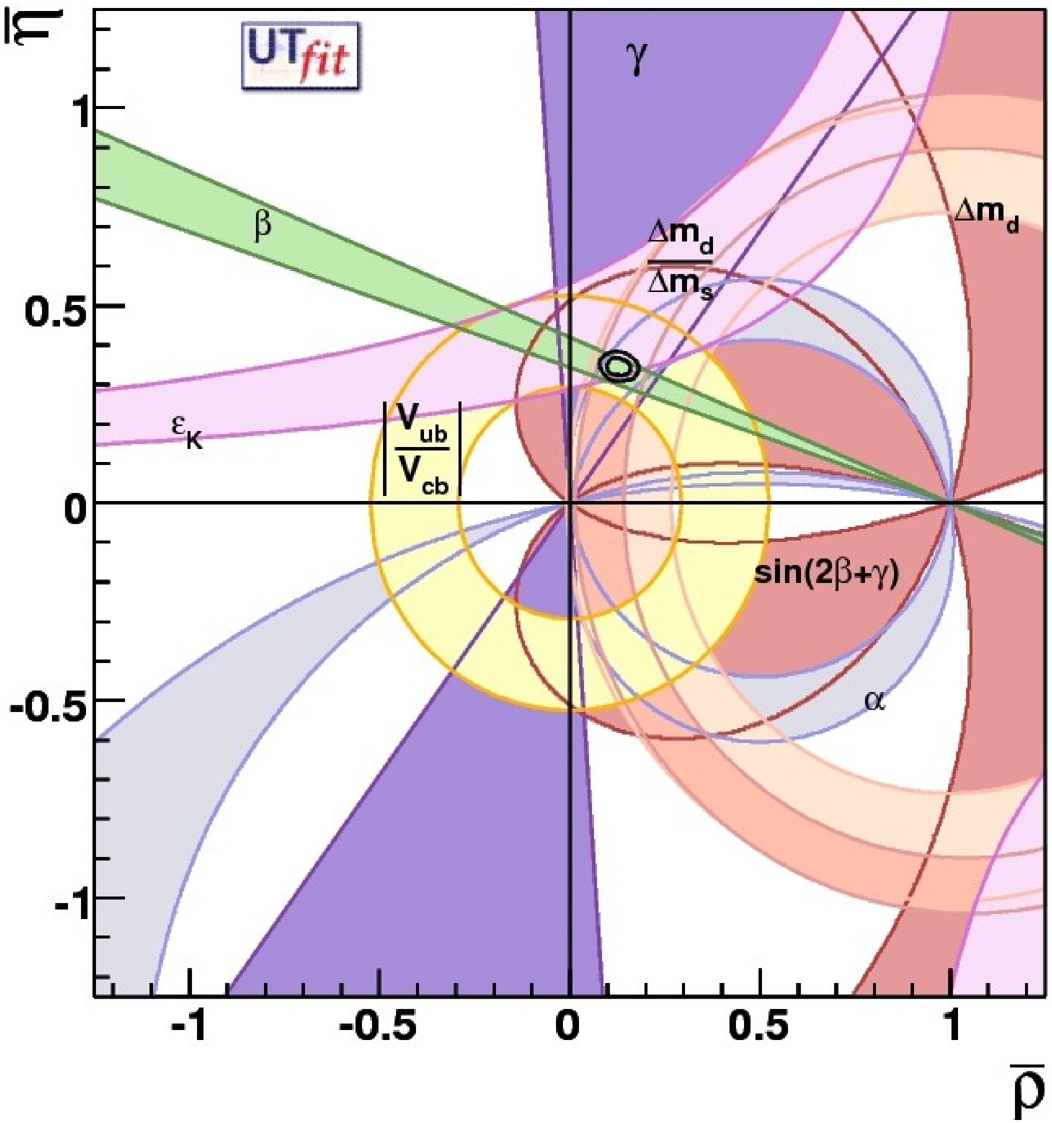
$\bar{\rho}$ = 0.127 ± 0.027
$\bar{\eta}$ = 0.329 ± 0.016

Unitarity Triangle analysis in the SM:





Unitarity Triangle analysis in the SM:



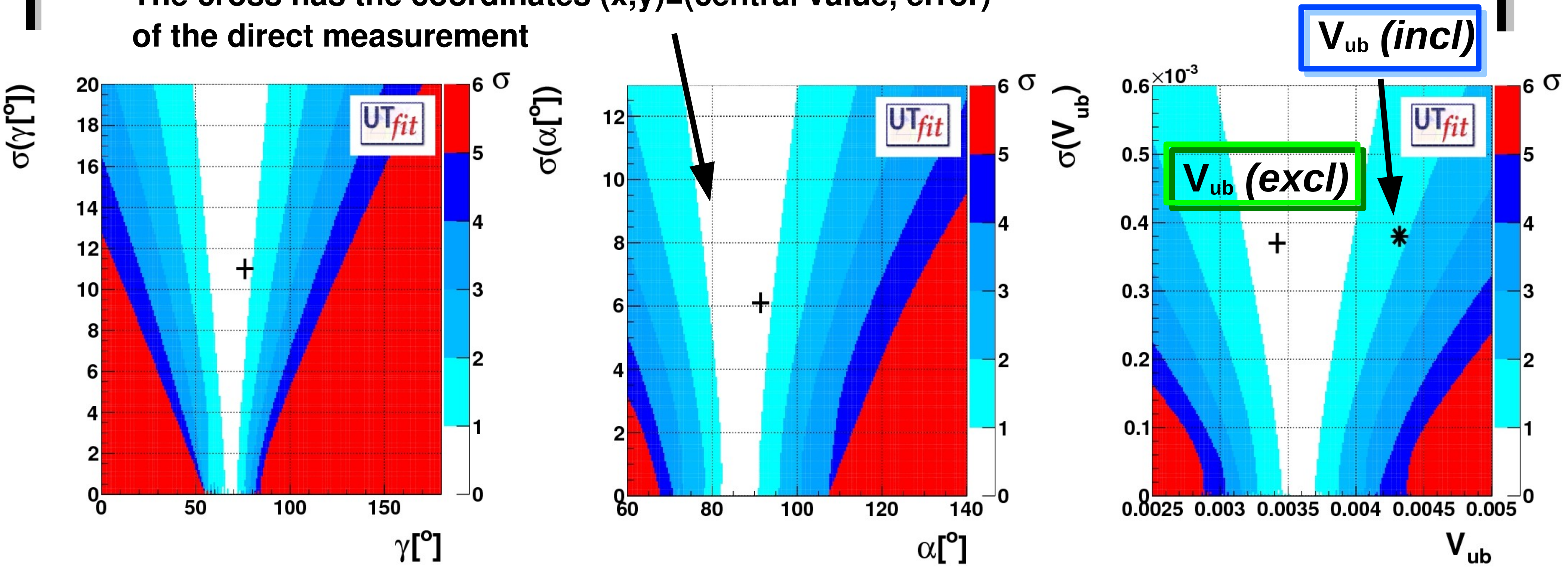
$\bar{\rho}$ = 0.129 ± 0.022
$\bar{\eta}$ = 0.346 ± 0.015

- ◉ Data in agreement
- ◉ NP, if any, seems not to introduce additional CP or flavour violation in b ↔ d transitions at current experimental precision

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 flavor physics

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

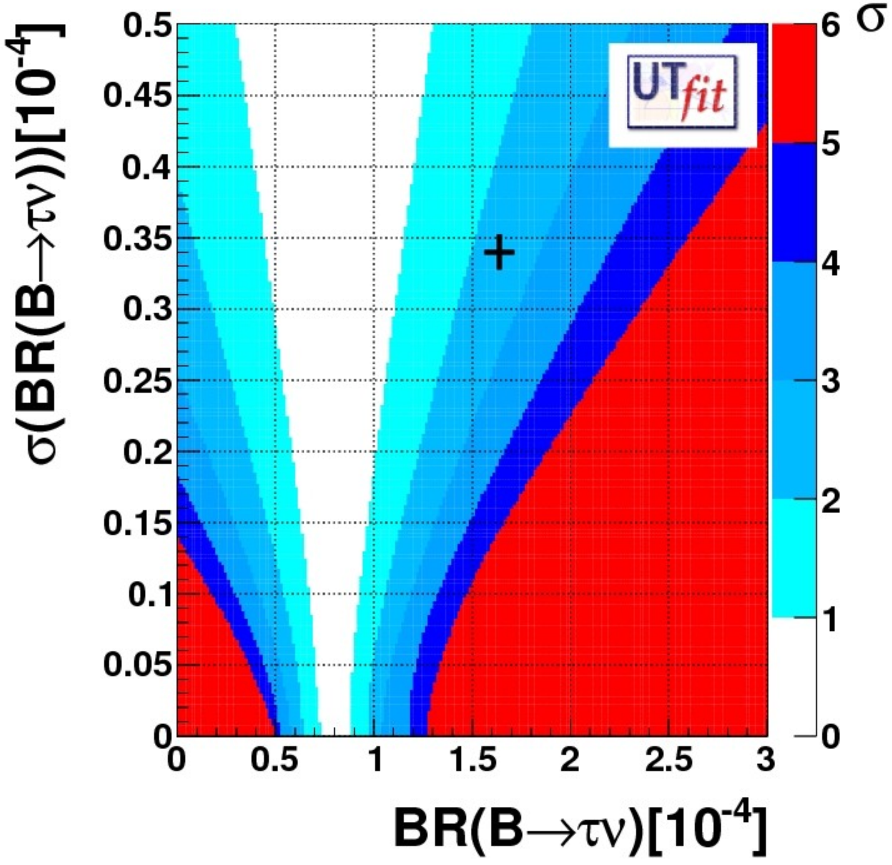


Color code: agreement between the predicted values and the measurements at better than 1, 2, ...nσ

some standard model determinations: B→τν

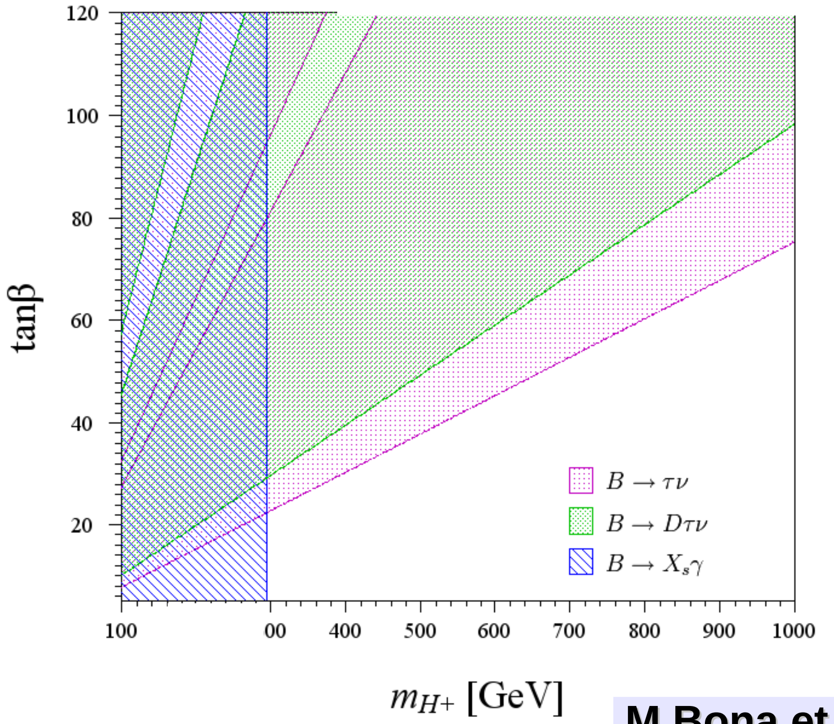
current HFAG world average
BR(B→τν) = (1.64 ± 0.34) 10^{-4}

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



SM prediction enhanced or reduced by factor r_H:

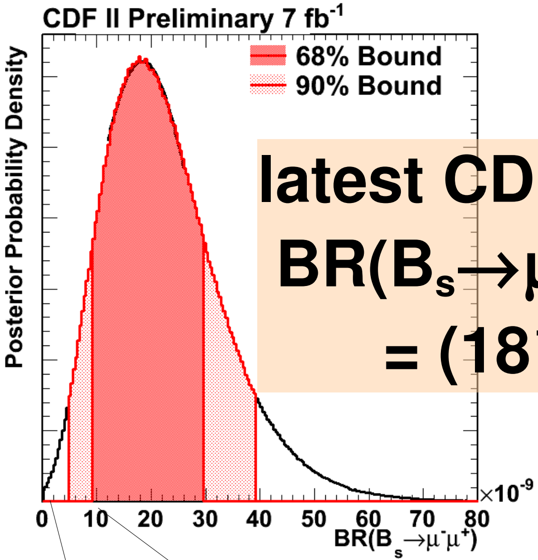
$$R_{2HDM} = \left(1 - \tan^2\beta \frac{m_B^2}{m_{H^+}^2}\right)^2$$



indirect determination from UT_b
BR(B→τν) = (0.79 ± 0.08) 10^{-4}

M.Bona et al.
0908.3470 [hep-ph]

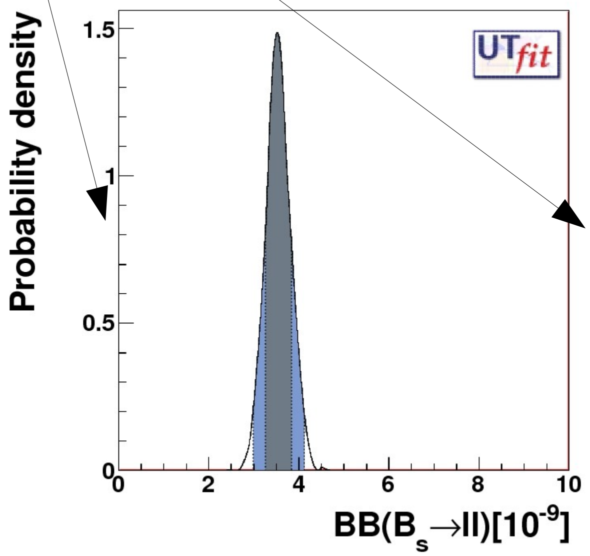
more standard model determinations: $B_s\to\mu\mu$

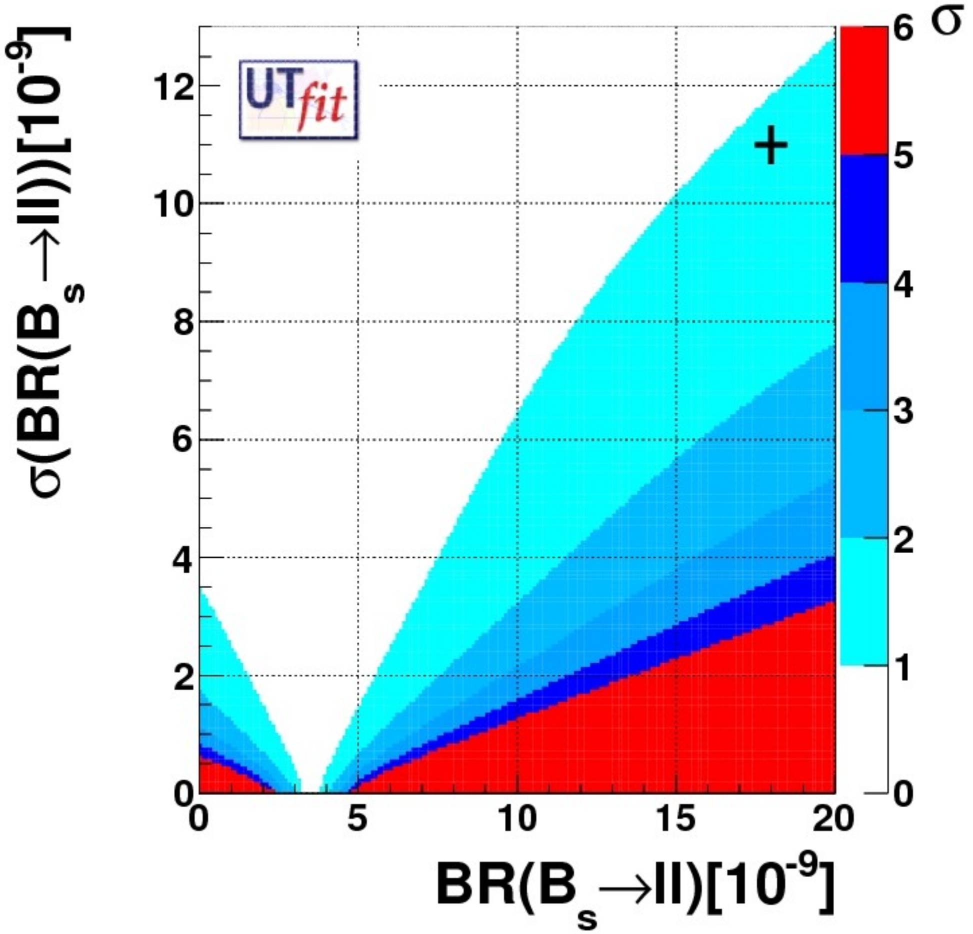


latest CDF result:

BR($B_s\to\mu\mu$)

$= (18^{+11}_{-9})\ 10^{-9}$





indirect determination from UT

BR($B_s\to ll$) = $(3.54 \pm 0.29)\ 10^{-9}$

UT analysis including new physics (NP)

Consider for example B_s mixing process.
Given the SM amplitude, we can define

$$C_{B_s} e^{-2i\phi_{B_s}} = \frac{\langle \overline{B}_s | H_{\mathrm{eff}}^{\mathrm{SM}} + H_{\mathrm{eff}}^{\mathrm{NP}} | B_s \rangle}{\langle \overline{B}_s | H_{\mathrm{eff}}^{\mathrm{SM}} | B_s \rangle} = 1 + \frac{A_{\mathrm{NP}}\, e^{-2i\phi_{\mathrm{NP}}}}{A_{\mathrm{SM}}\, e^{-2i\beta_s}}$$

All NP effects can be parameterized in terms of one complex parameter for each meson mixing, to be determined in a simultaneous fit with the CKM parameters (now there are enough experimental constraints to do so).

For kaons we use *Re* and *Im*, since the two exp. constraints ε_K and Δm_K are directly related to them (with distinct theoretical issues)

$$C_{\varepsilon_K} = \frac{\mathrm{Im}\langle K^0 | H_{eff}^{full} | \overline{K}^0 \rangle}{\mathrm{Im}\langle K^0 | H_{eff}^{SM} | \overline{K}^0 \rangle}$$

$$C_{\Delta m_K} = \frac{\mathrm{Re}\langle K^0 | H_{eff}^{full} | \overline{K}^0 \rangle}{\mathrm{Re}\langle K^0 | H_{eff}^{SM} | \overline{K}^0 \rangle}$$

UT analysis including NP

M.Bona *et al* (UTfit)
Phys.Rev.Lett. 97:151803,2006

	ρ, η	C_{Bd}, ϕ_{Bd}	$C_{\varepsilon K}$	$C_{Bs}, {}_{Bs}$
V_{ub}/V_{cb}	X			
γ (DK)	X			
ε_K	X		X	
sin2β	X	X		
Δm_d	X	X		
α	X	X		
A_{SL} B_d	X	X X		
$\Delta\Gamma_d/\Gamma_d$	X	X X		
$\Delta\Gamma_s/\Gamma_s$	X			X X
Δm_s				X
A_{CH}	X	X X		X X

model independent assumptions

SM → SM+NP

SM	SM+NP
tree level	
$(V_{ub}/V_{cb})^{SM}$	$(V_{ub}/V_{cb})^{SM}$
γ^{SM}	γ^{SM}
Bd Mixing	
β^{SM}	$\beta^{SM}+\phi_{Bd}$
α^{SM}	$\alpha^{SM}- \phi_{Bd}$
Δm_d	$C_{Bd}\Delta m_d$
Bs Mixing	
$\Delta m_s{}^{SM}$	$C_{Bs}\Delta m_s{}^{SM}$
$\beta_s{}^{SM}$	$\beta_s{}^{SM}+\phi_{Bs}$
K Mixing	
$\varepsilon_K{}^{SM}$	$C\varepsilon_K\ \varepsilon_K{}^{SM}$

new-physics-specific constraints

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

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

semileptonic asymmetry:

sensitive to NP effects in both size and phase

$$A_{\rm SL}^s \times 10^2 \;=\; -0.17 \pm 0.91$$

D0
Phys.Rev.D82:012003,2010

same-side dilepton charge asymmetry:

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

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

D0 arXiv:1106.6308

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

lifetime $\tau^{\rm FS}$ in flavour-specific final states:

average lifetime is a function to the width and the width difference (independent data sample)

HFAG

$$\tau_{B_s}^{\rm FS}\ [\rm ps] \;=\; 1.417 \pm 0.042$$

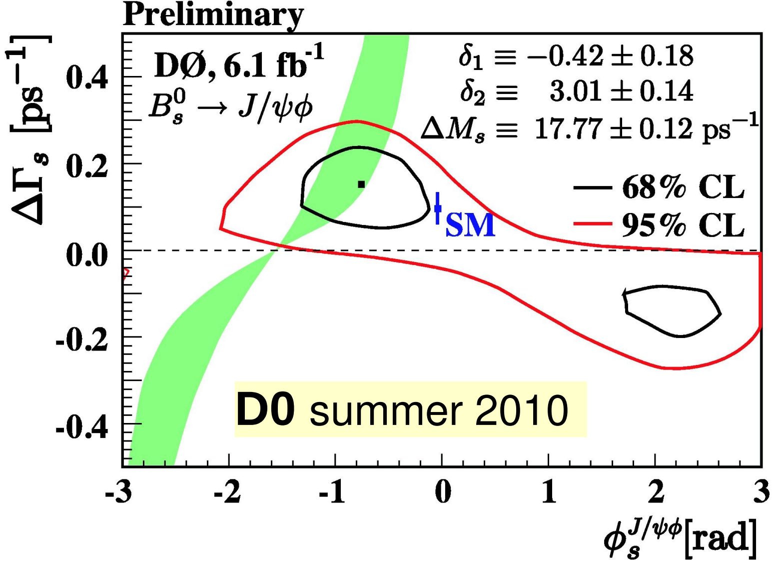
$$\tau_{B_s}^{FS} = \frac{1}{\Gamma_s}\,\frac{1 - \left(\frac{\boxed{\Delta\Gamma_s}}{2\Gamma_s}\right)^2}{1 + \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}$$

Dunietz
et al.,
hep-ph
0012219

new-physics-specific constraints

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

- Angular analysis as a function of proper time and b-tagging
- Additional sensitivity from the $\Delta\Gamma_s$ terms



ϕ_s and $\Delta\Gamma_s$: 2D experimental likelihood from D0

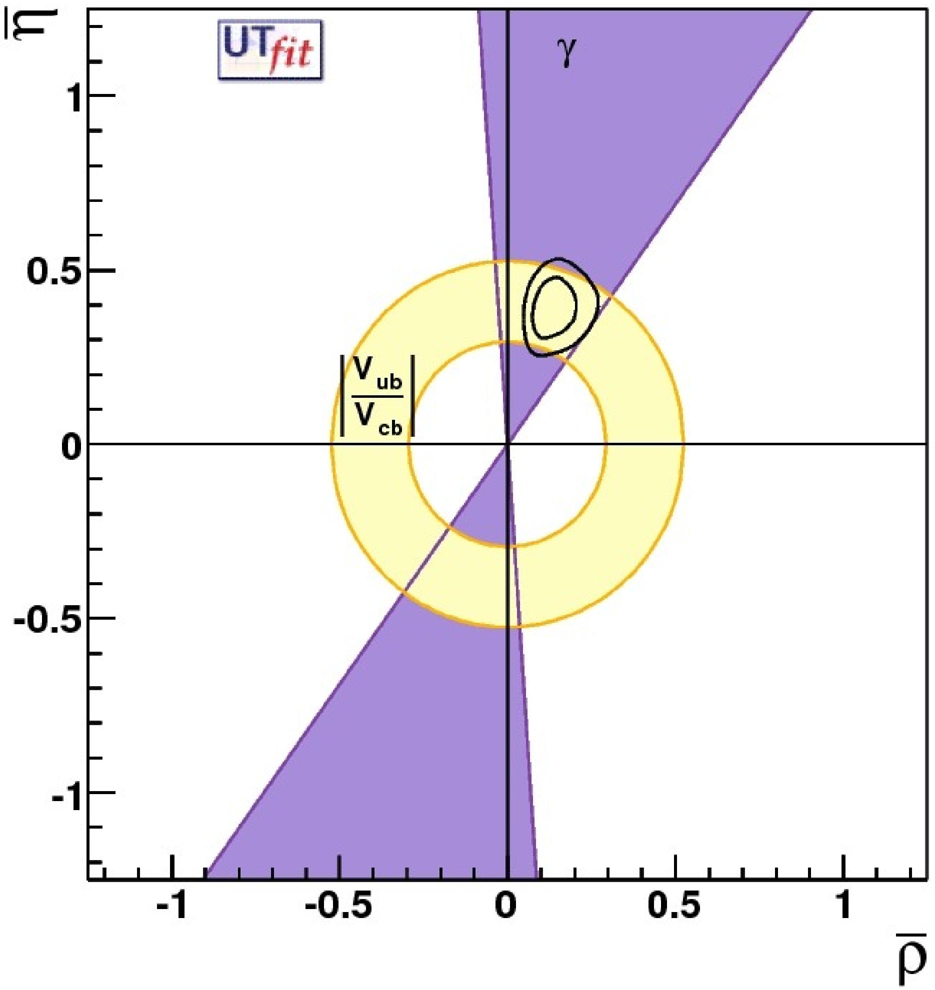
for $\Delta\Gamma_s$

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

$C_{\rm pen}$ and $\phi_{\rm pen}$ are parameterize possible NP contributions from b → s penguins

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

UT analysis including NP



$\bar{\rho}$ = 0.145 ± 0.045
$\bar{\eta}$ = 0.389 ± 0.054

Allowing for NP we go back to the SM solution

$\bar{\rho}$ = 0.129 ± 0.022
$\bar{\eta}$ = 0.346 ± 0.015

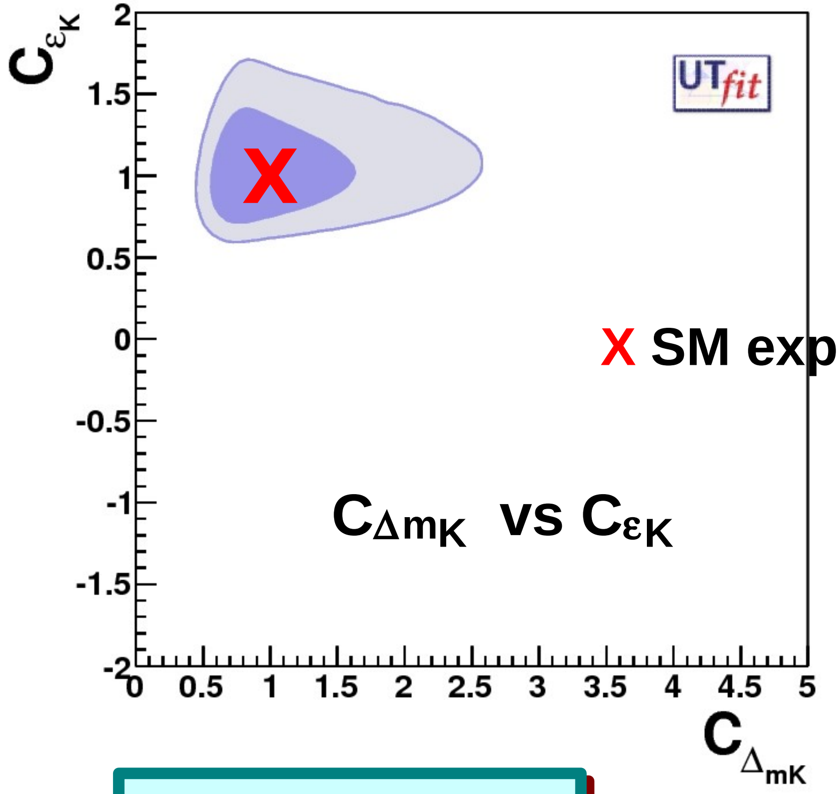
before the B factories:
the uncertainty on CKM parameters with NP was the limiting factor.

NP parameters in the K & B$_d$ sectors

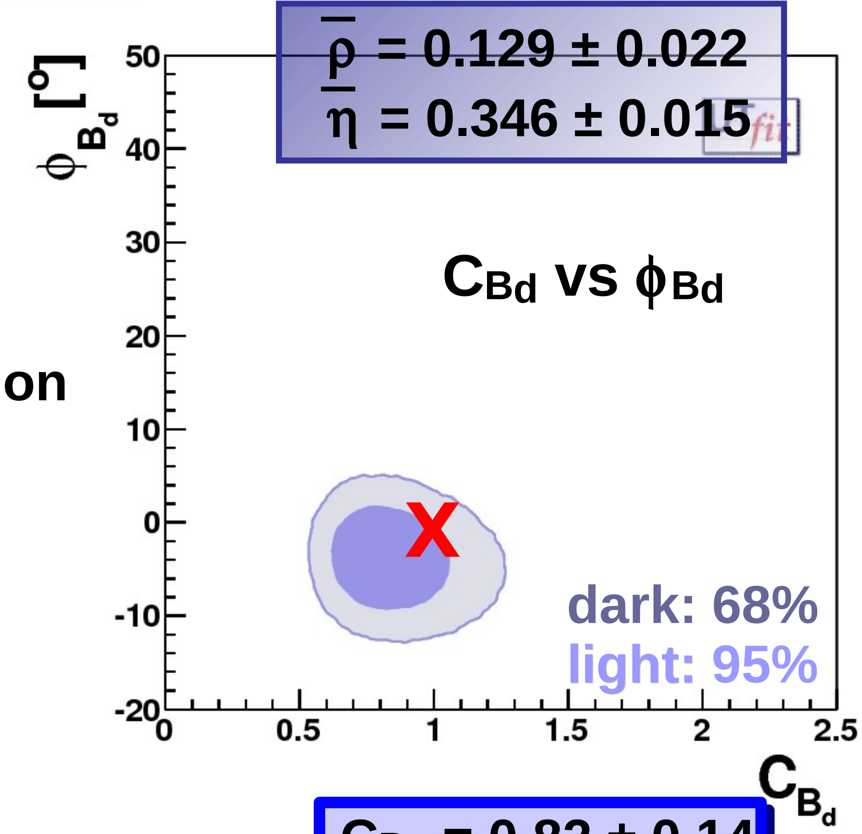
$$\mathrm{Im}\,A_K = C_\varepsilon\,\mathrm{Im}\,A_K^{SM}$$
$$\mathrm{Re}\,A_K = C_{\Delta m_K}\,\mathrm{Re}\,A_K^{SM}$$

$$\Delta m_K = C_{\Delta m_K}(\Delta m_K)^{SM}$$
$$\varepsilon_K = C_\varepsilon\,\varepsilon_K^{SM}$$

$$C_{B_q}\,e^{2i\phi_{B_q}} = \frac{\langle B_q|H_{\mathrm{eff}}^{\mathrm{full}}|\bar{B}_q\rangle}{\langle B_q|H_{\mathrm{eff}}^{\mathrm{SM}}|\bar{B}_q\rangle}$$



X SM expectation



$\bar{\rho}$ = 0.129 ± 0.022

$\bar{\eta}$ = 0.346 ± 0.015

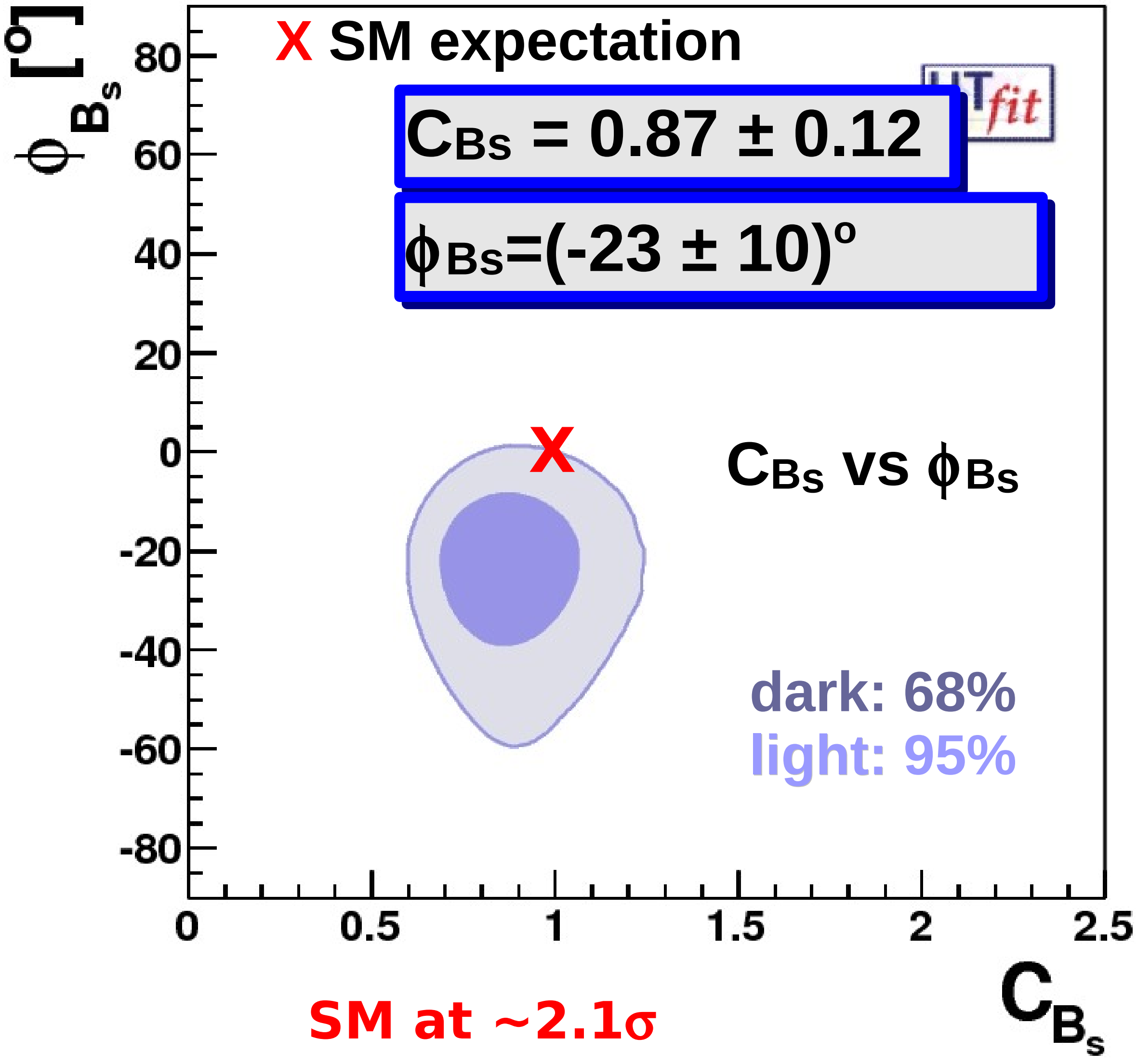
$C_{\varepsilon K}$ = 1.02 ± 0.19

$C_{\Delta m K}$ = 0.96 ± 0.34

C_{Bd} = 0.82 ± 0.14

ϕ_{Bd}=(-3.9 ± 3.6)°

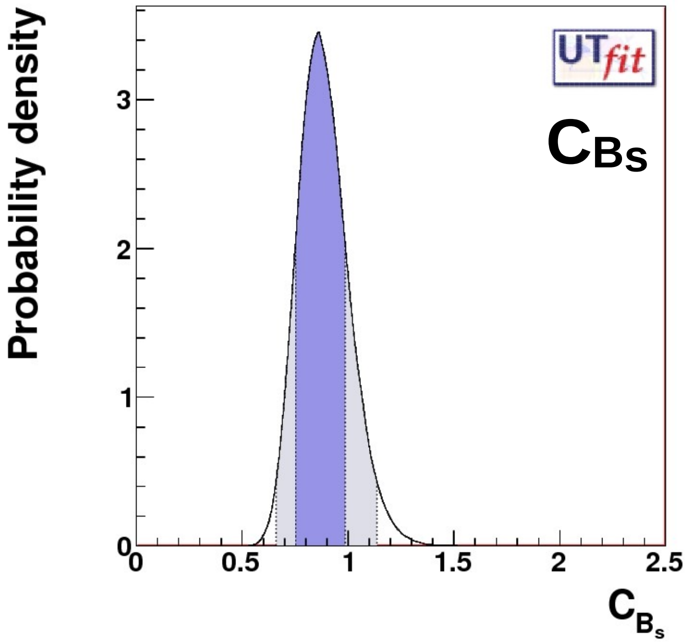
NP parameters in the B_s sector

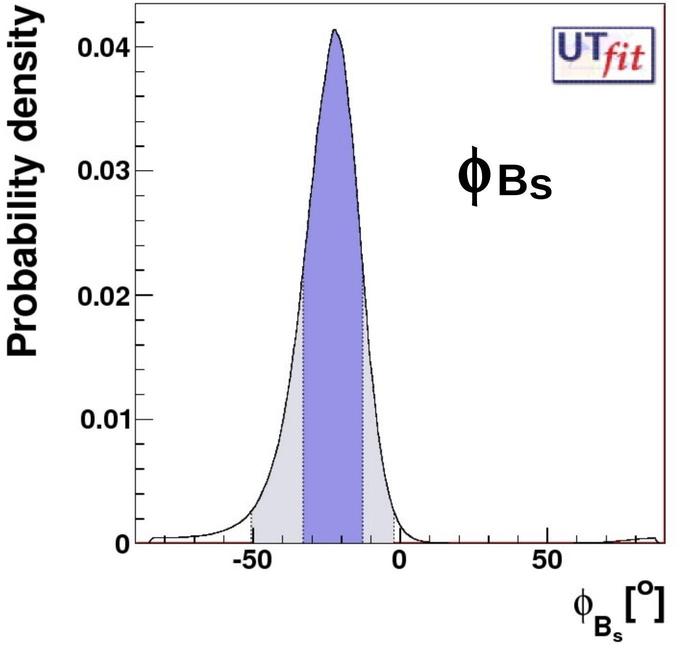


$C_{Bs} = 0.87 \pm 0.12$

$\phi_{Bs}=(-23 \pm 10)^o$

SM at ~2.1σ



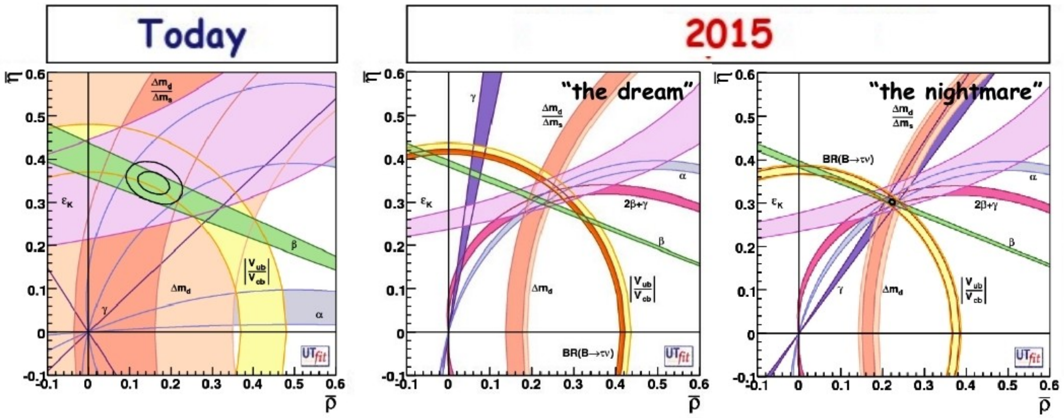


some conclusions

- ◉ test of the SM consistency and the CKM mechanism: comparison between inputs and indirect determinations
    - ◎ using all the available inputs from experiments and theoretical and lattice QCD calculation
    - ◎ extraction of the most accurate SM predictions

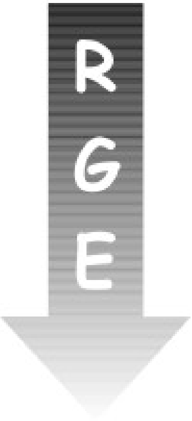
- ◉ model-independent new physics:
    - ◎ overconstraining of the SM fit allows for extraction of generic amplited and phase for all the systems (K, B_d, B_s)
    - ◎ scale analysis: putting bounds on the Wilson coefficients give insights into the NP scale in different NP scenarios

- ◉ LHCb and SuperB will reach better precision and provide new measurements
    - ◎ the 2015(?!?) scenario is including also improvements on lattice calculation



Back up slides

Testing the TeV scale



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

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

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

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

Effective BSM Hamiltonian for ΔF=2 transitions

Most general form of the effective Hamiltonian for ΔF=2 processes

$$\mathcal{H}_{\rm eff}^{K-\bar{K}} = \sum_{i=1}^{5} C_i \, Q_i^{sd} + \sum_{i=1}^{3} \tilde{C}_i \, \tilde{Q}_i^{sd}$$

$$\mathcal{H}_{\rm eff}^{B_q-\bar{B}_q} = \sum_{i=1}^{5} C_i \, Q_i^{bq} + \sum_{i=1}^{3} \tilde{C}_i \, \tilde{Q}_i^{bq}$$

The Wilson coefficients C_i have in general the form

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

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 ΔF=2 transitions)

Contribution to the mixing amplitutes

analytic expression for the contribution to the mixing amplitudes

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

arXiv:0707.0636: ***for "magic numbers" a,b and c***, **$\eta = \alpha_s(\Lambda)/\alpha_s(m_t)$**

analogously for the K system

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

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.

Testing the TeV scale

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

The dependence of C on Λ changes on flavor 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

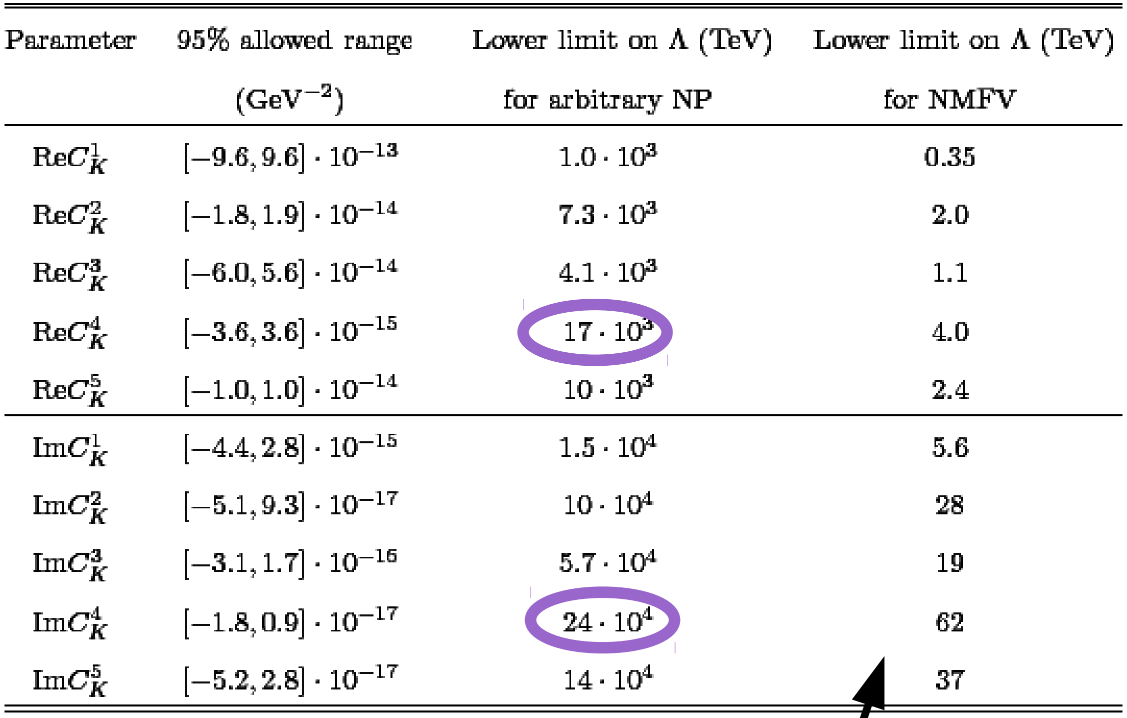
- $\alpha \sim 1$ for strongly coupled NP
- $\alpha \sim \alpha_W$ (α_S) in case of loop coupling through weak (strong) interactions

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

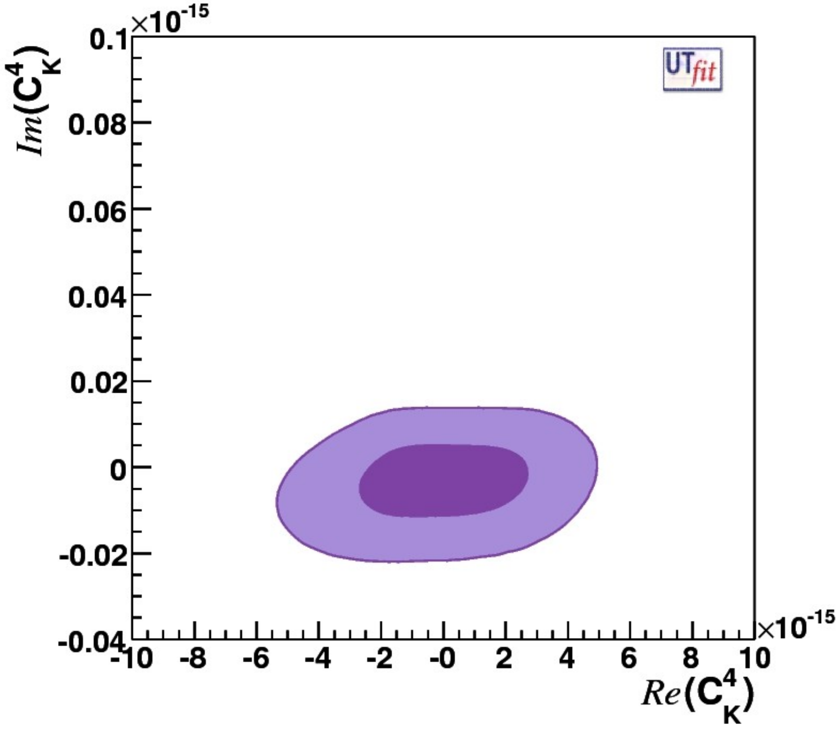
If no NP effect is seen
lower bound on NP scale Λ
if NP is seen
upper bound on NP scale Λ

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	Lower limit on Λ (TeV) for NMFV
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

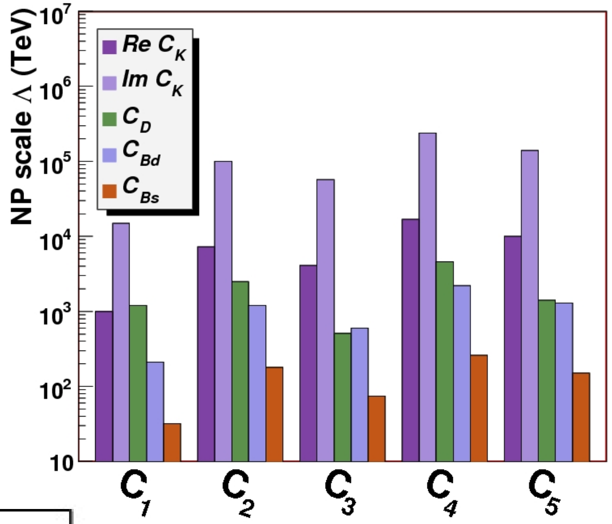


To obtain the lower bound for loop-mediated contributions, one simply multiplies the bounds by α_s ~ 0.1 or by α_W ~ 0.03.

Upper and lower bound on the scale

Lower bounds on NP scale from K and B_d physics (TeV at 95% prob.)

Scenario	strong/tree	α_s loop	α_W loop
MFV	5.5	0.5	0.2
NMFV	62	6.2	2
General	24000	2400	800



Upper bounds on NP scale from B_s:

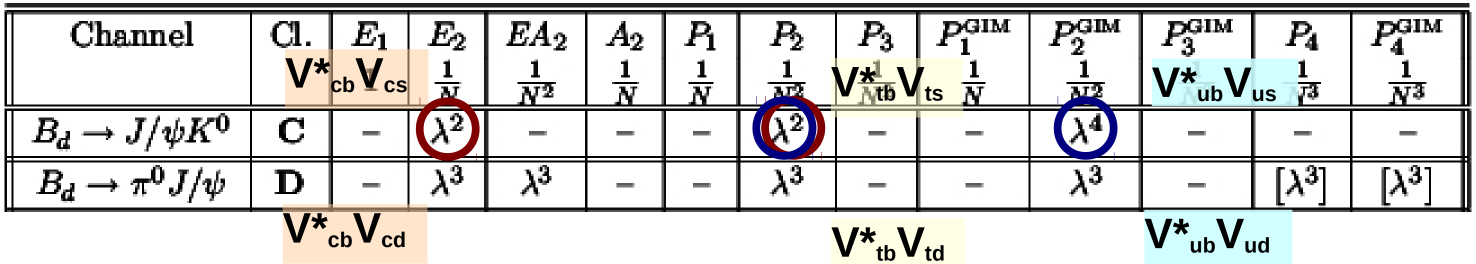
Scenario	strong/tree	α_s loop	α_W loop
NMFV	35	4	2
General	800	80	30

- the general case was already problematic (well known flavour puzzle)
- NMFV has problems with the size of the B_s effect vs the (insufficient) suppression in B_d and (in particular) K mixing
- MFV is OK for the size of the effects, but the B_s phase cannot be generated

Data suggest some hierarchy in NP mixing which is stronger than the SM one

Theory error on sin2β:

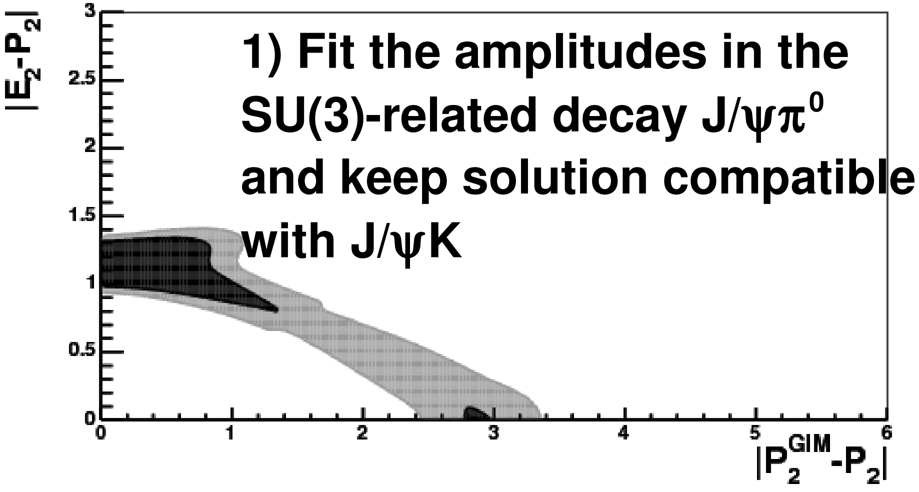
A.Buras, L.Silvestrini
Nucl.Phys.B569:3-52(2000)



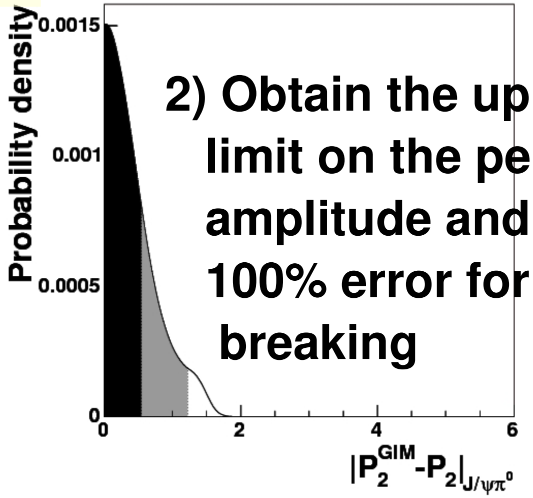
Channel	Cl.	E_1	E_2	EA_2	A_2	P_1	P_2	P_3	P_1^{GIM}	P_2^{GIM}	P_3^{GIM}	P_4	P_4^{GIM}
			$\frac{1}{N}$	$\frac{1}{N^2}$	$\frac{1}{N}$	$\frac{1}{N}$	$\frac{1}{N^2}$	$\frac{1}{N}$	$\frac{1}{N}$	$\frac{1}{N^2}$	$\frac{1}{N}$	$\frac{1}{N^3}$	$\frac{1}{N^3}$
$B_d \to J/\psi K^0$	C	–	λ^2	–	–	–	λ^2	–	–	λ^4	–	–	–
$B_d \to \pi^0 J/\psi$	D	–	λ^3	λ^3	–	–	λ^3	–	–	λ^3	–	$[\lambda^3]$	$[\lambda^3]$

$V^*_{cb}V_{cs}$ $V^*_{tb}V_{ts}$ $V^*_{ub}V_{us}$

$V^*_{cb}V_{cd}$ $V^*_{tb}V_{td}$ $V^*_{ub}V_{ud}$

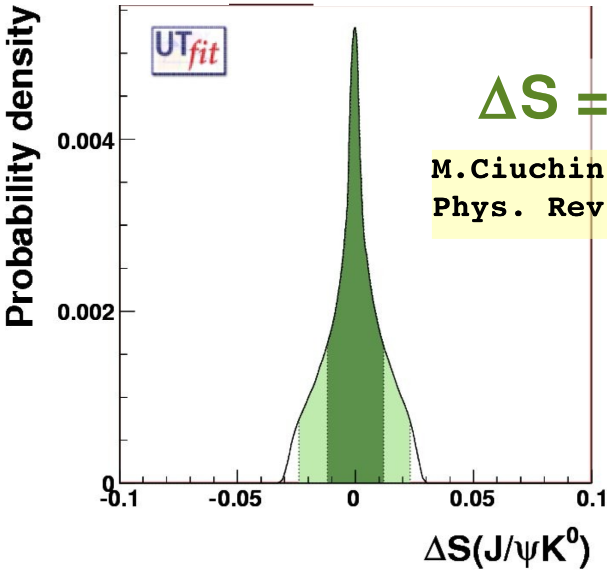


1) Fit the amplitudes in the SU(3)-related decay J/ψπ^0 and keep solution compatible with J/ψK



2) Obtain the upper limit on the penguin amplitude and add 100% error for SU(3) breaking

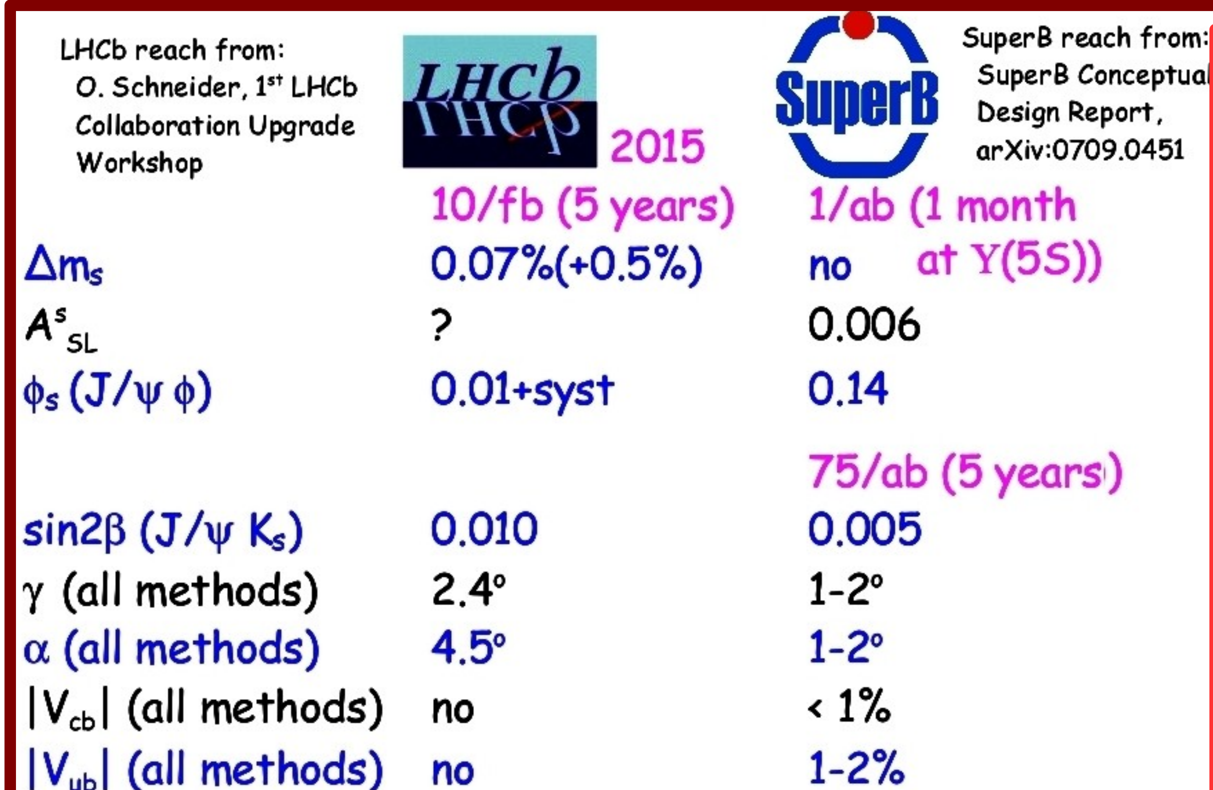
3) Fit the amplitudes in J/ψK^0 imposing the upper bound on the CKM suppressed amplitude and extract the error on sin2β



ΔS = 0.000 ± 0.012

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

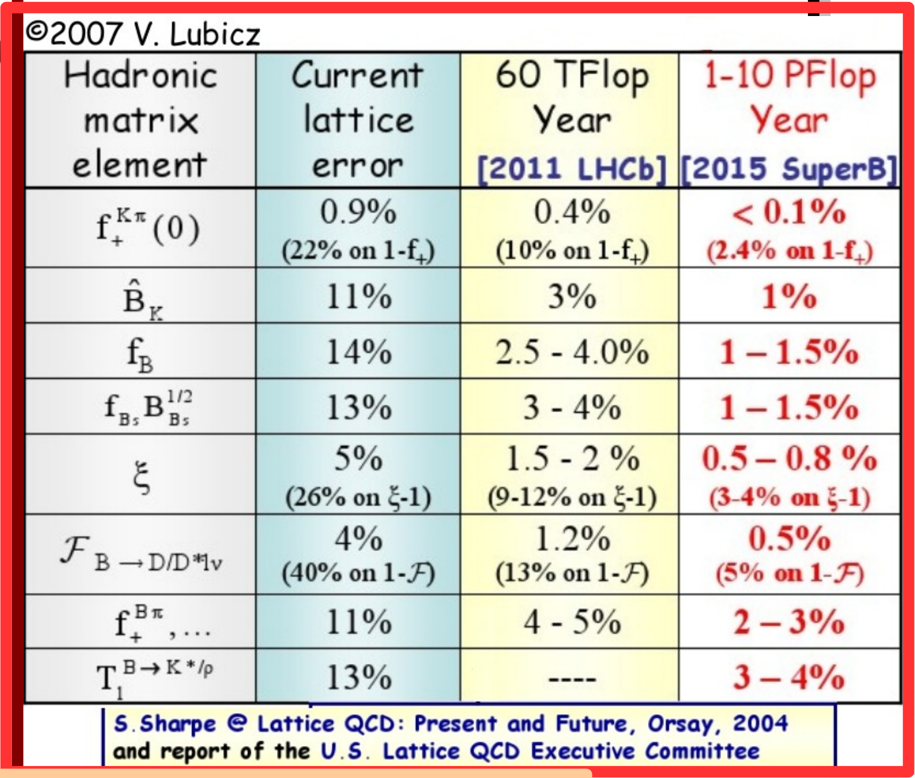
The future of CKM fits



LHCb reach from:
O. Schneider, 1st LHCb Collaboration Upgrade Workshop

SuperB reach from:
SuperB Conceptual Design Report, arXiv:0709.0451

	LHCb 2015	SuperB
	10/fb (5 years)	1/ab (1 month at Υ(5S))
Δm_s	0.07%(+0.5%)	no
A^s_{SL}	?	0.006
ϕ_s $(J/\psi\,\phi)$	0.01+syst	0.14
		75/ab (5 years)
$\sin 2\beta$ $(J/\psi\,K_s)$	0.010	0.005
γ (all methods)	2.4°	1-2°
α (all methods)	4.5°	1-2°
$\lvert V_{cb}\rvert$ (all methods)	no	< 1%
$\lvert V_{ub}\rvert$ (all methods)	no	1-2%



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Hadronic matrix element	Current lattice error	60 TFlop Year [2011 LHCb]	1-10 PFlop Year [2015 SuperB]
$f_+^{K\pi}(0)$	0.9% (22% on 1-f_+)	0.4% (10% on 1-f_+)	< 0.1% (2.4% on 1-f_+)
$\hat{B}_K$	11%	3%	1%
f_B	14%	2.5 - 4.0%	1 – 1.5%
$f_{B_s}B_{B_s}^{1/2}$	13%	3 - 4%	1 – 1.5%
ξ	5% (26% on ξ-1)	1.5 - 2 % (9-12% on ξ-1)	0.5 – 0.8 % (3-4% on ξ-1)
$\mathcal{F}_{B\to D/D^*l\nu}$	4% (40% on 1-$\mathcal{F}$)	1.2% (13% on 1-$\mathcal{F}$)	0.5% (5% on 1-$\mathcal{F}$)
$f_+^{B\pi}, \ldots$	11%	4 - 5%	2 – 3%
$T_1^{B\to K^*/\rho}$	13%	----	3 – 4%

S.Sharpe @ Lattice QCD: Present and Future, Orsay, 2004
and report of the U.S. Lattice QCD Executive Committee