Lattice QCD and flavour physics (II):

Impact of lattice on the Unitarity Triangle Analysis

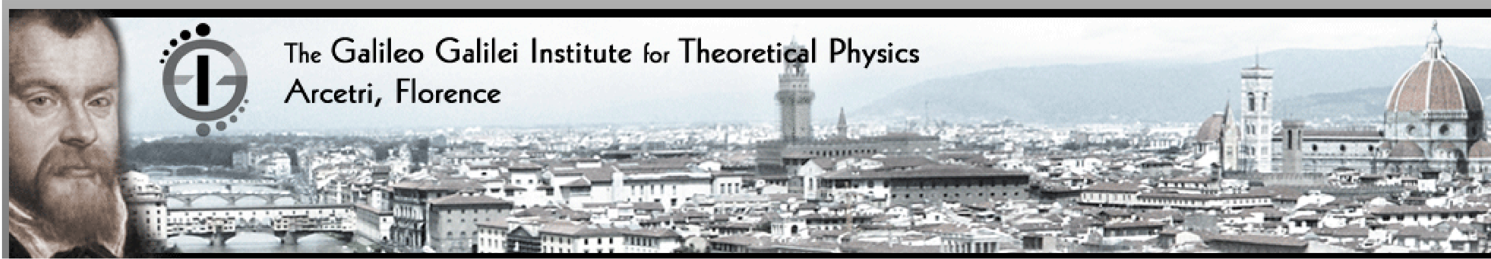
UNIVERSITÀ DEGLI STUDI ROMA TRE

Vittorio Lubicz

OUTLINE:

1. Role of lattice QCD in the UT Fit: the UT-lattice analysis
2. UT-lattice vs. UT-angles: comparison and role of V_{ub}
3. "Experimental" determination of lattice parameters

ApeNEXT workshop, Arcetri, February 8-10, 2007



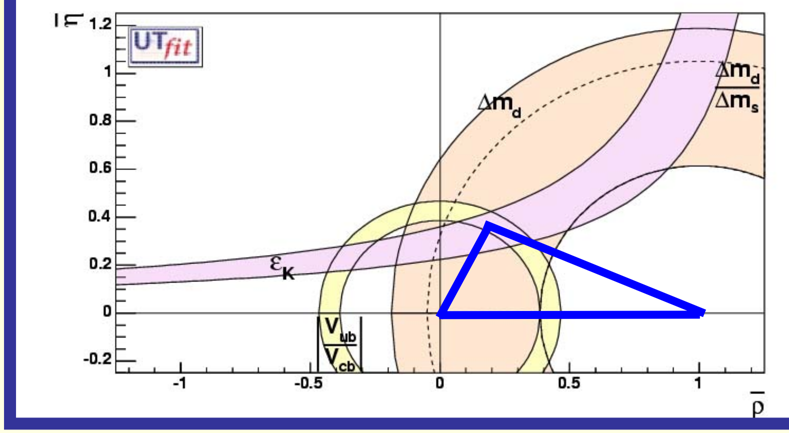
European Twisted Mass Collaboration

THE "UT-LATTICE" ANALYSIS:

UTA IN THE PRE-B FACTORIES ERA:

CP-conserving sizes + ε_K

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



Hadronic matrix elements from **LATTICE QCD**

$(b\to u)/(b\to c)$	$\bar\rho^2 + \bar\eta^2$	$f_+, F(1), \ldots$
Δm_d	$(1-\bar\rho)^2 + \bar\eta^2$	$f^2_{B_d} B_{B_d}$
$\Delta m_d / \Delta m_s$	$(1-\bar\rho)^2 + \bar\eta^2$	ξ
ε_K	$\bar\eta\,[(1-\bar\rho) + P]$	B_K

4 CONSTRAINTS

2 PARAMETERS

Already before the starting of the B factories

3 IMPORTANT RESULTS FOR FLAVOUR PHYSICS

1) Confirmation of the CKM origin of ~~CP~~ in K-$\bar{K}$ mixing

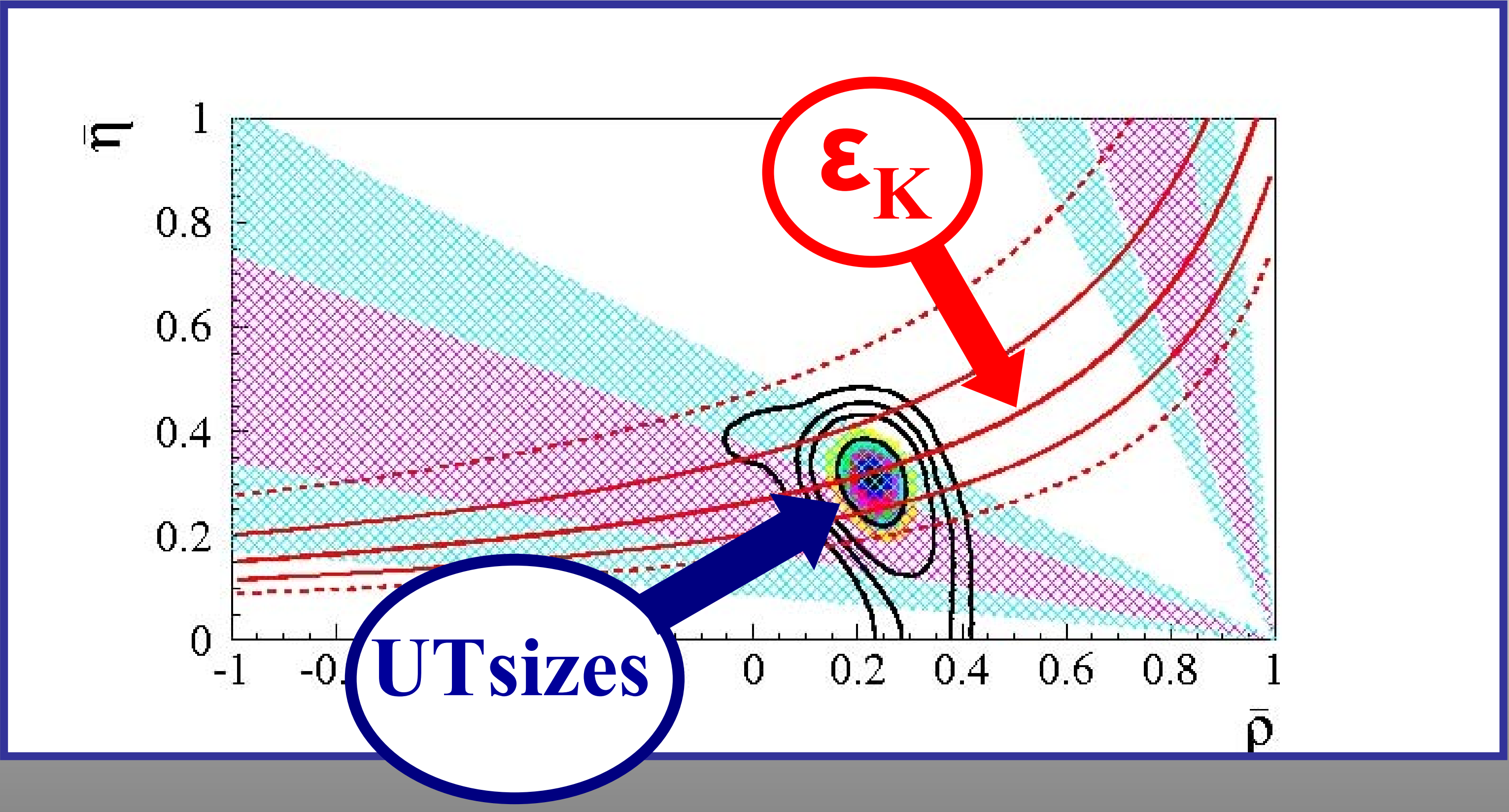
2) Prediction of sin2β

3) Prediction of Δm_s

A great success of (quenched) Lattice QCD calculations !!

1) INDIRECT EVIDENCE OF CP

Ciuchini et al. ("pre-UTFit" paper),2000



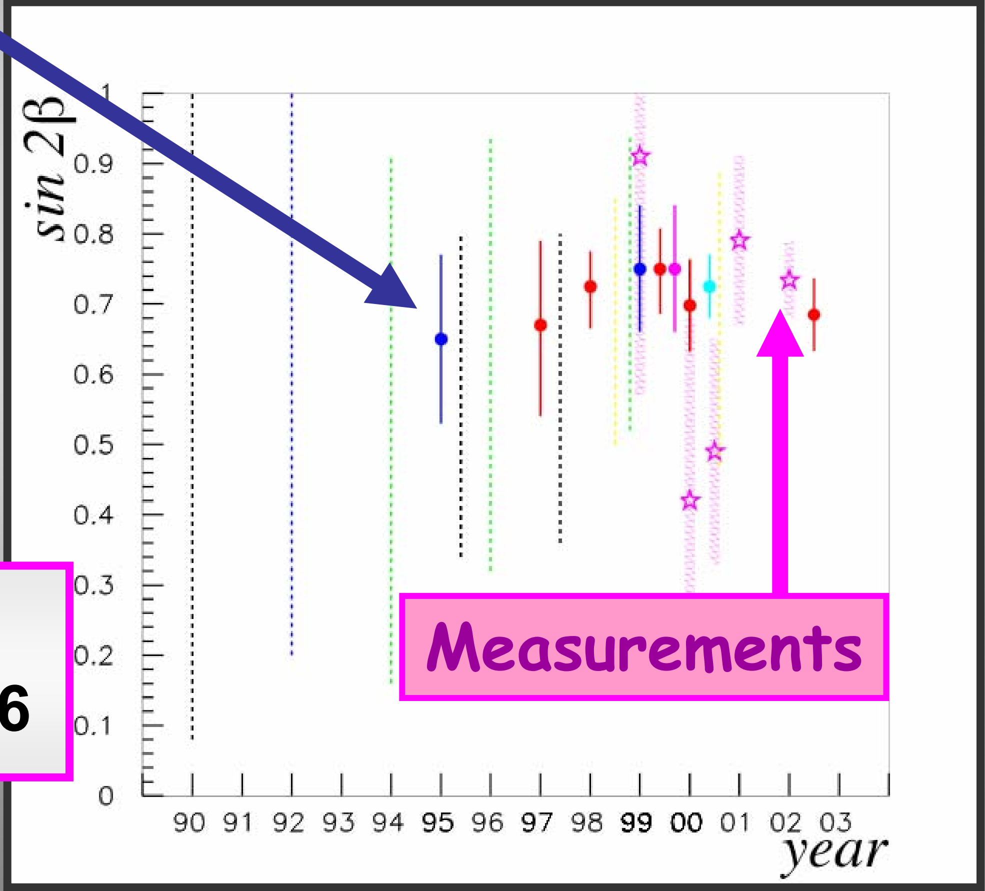
2) PREDICTION OF Sin2β

Predictions exist since 1995

Ciuchini et al.,1995:
$\sin 2\beta_{UTA} = 0.65 \pm 0.12$

Ciuchini et al.,2000:
$\sin 2\beta_{UTA} = 0.698 \pm 0.066$

ICHEP 2006:
$\sin 2\beta_{J/\psi\ K0} = 0.675 \pm 0.026$



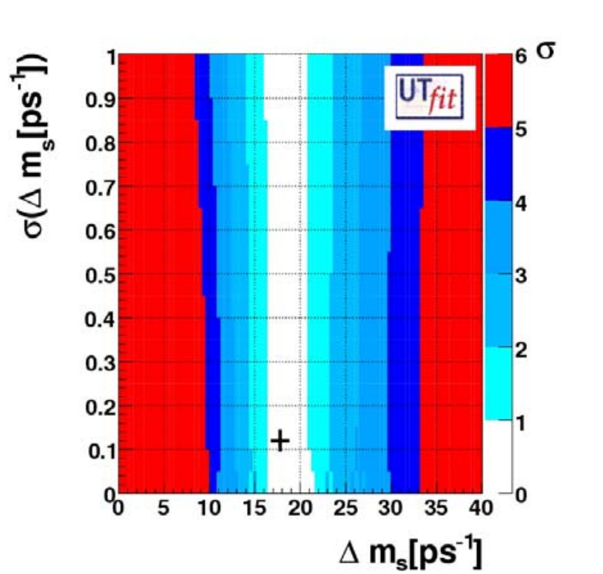
3) PREDICTION OF Δm_s

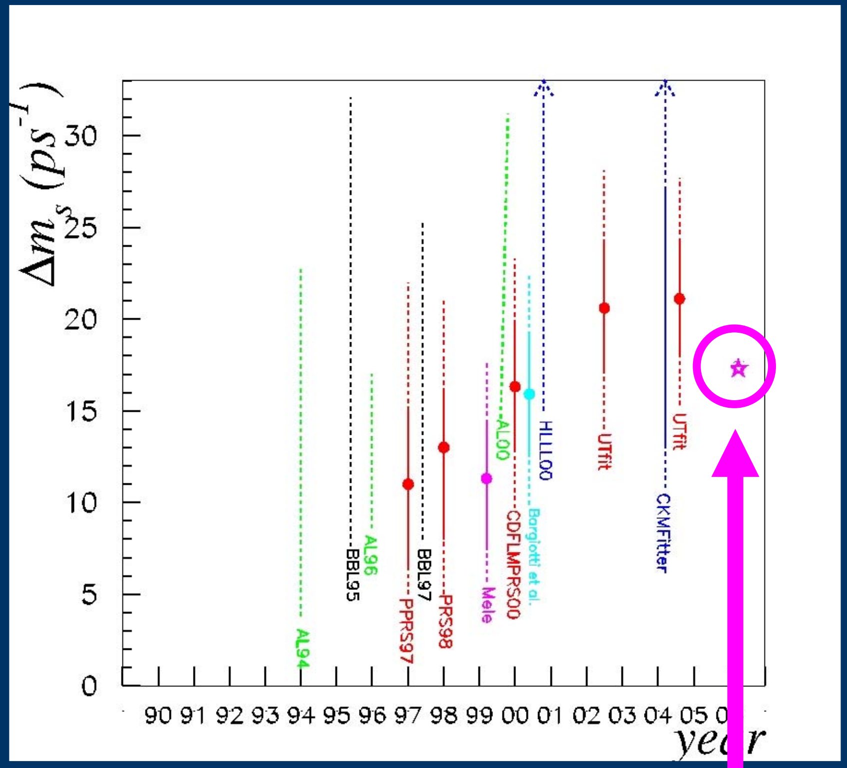
Ciuchini et al.,2000:

$\Delta m_s = (16.3 \pm 3.4)\ ps^{-1}$

UTFit Coll.,2006:

$\Delta m_s = (18.4 \pm 2.4)\ ps^{-1}$

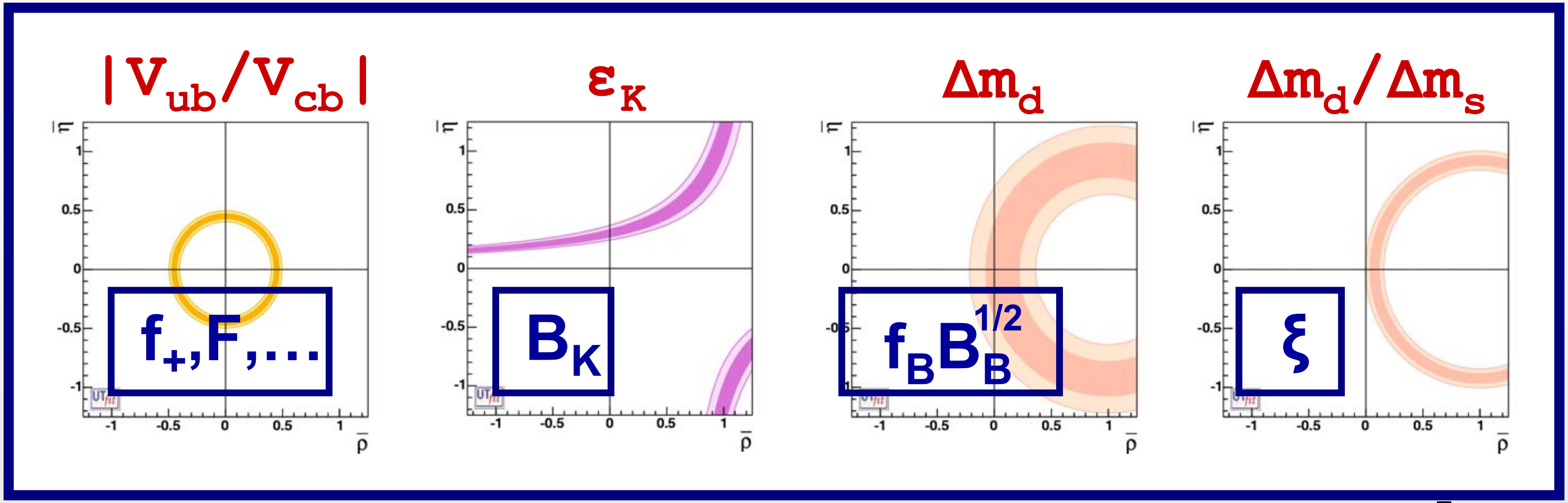




CDF, 2006:

$\Delta m_s = (17.77 \pm 0.10 \pm 0.07)\ ps^{-1}$

THE LATTICE INPUT PARAMETERS



$B_{d,s}$ mixing: f_{Bs}/f_B and ξ

f_B and therefore the ratio f_{Bs}/f_B are affected by the "potentially large" **effect of chiral logarithms**:

Recent history of ξ

"Old" estimates (<2002):

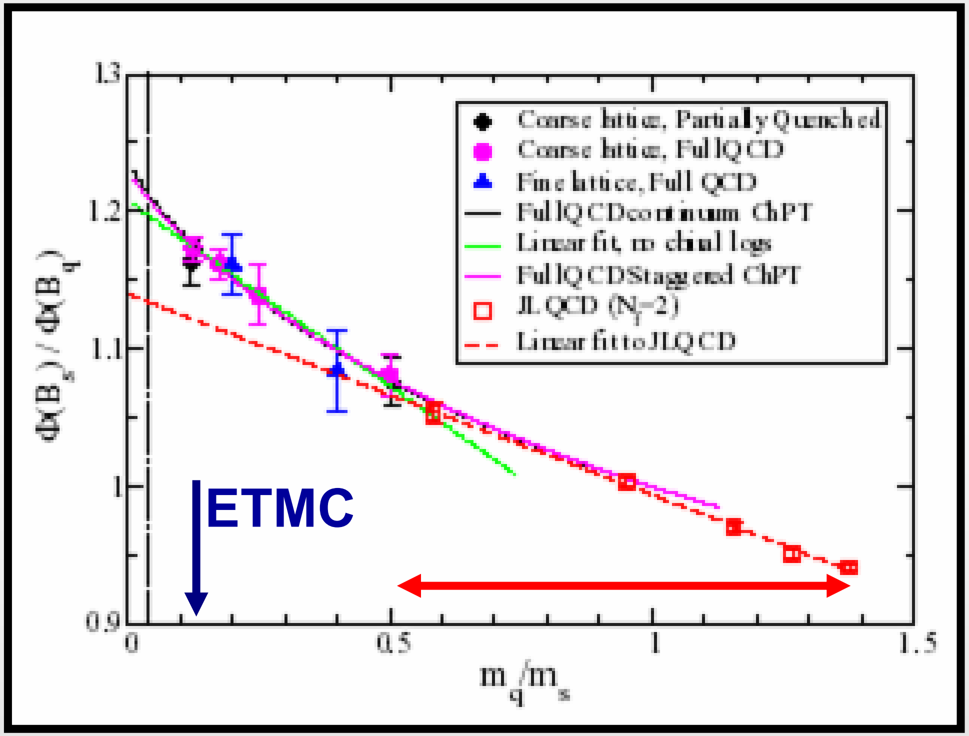
$f_{Bs}/f_B \approx 1.14 - 1.18$

Kronfeld and Ryan (2002)

$f_{Bs}/f_B = 1.32 \pm 0.10$

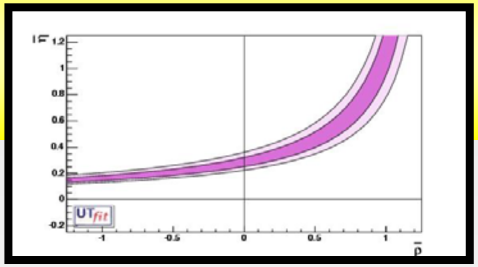
HPQCD (2005)

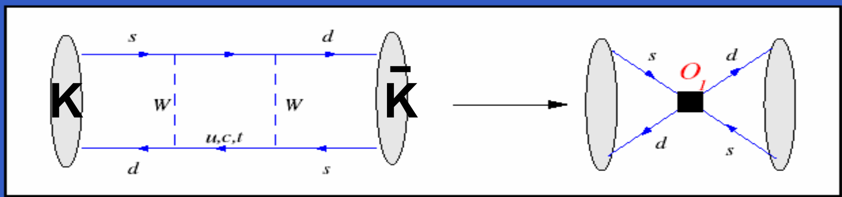
$f_{Bs}/f_B = 1.20 \pm 0.03$



But the present estimate still relies on a single calculation. Further determinations at low quark masses are required.

K–$\bar{K}$ mixing: ε_K and B_K





$$\langle \bar{K}^0 | Q(\mu) | K^0 \rangle = \frac{8}{3} f_K^2 m_K^2 B_K(\mu)$$

QUENCHED ERROR

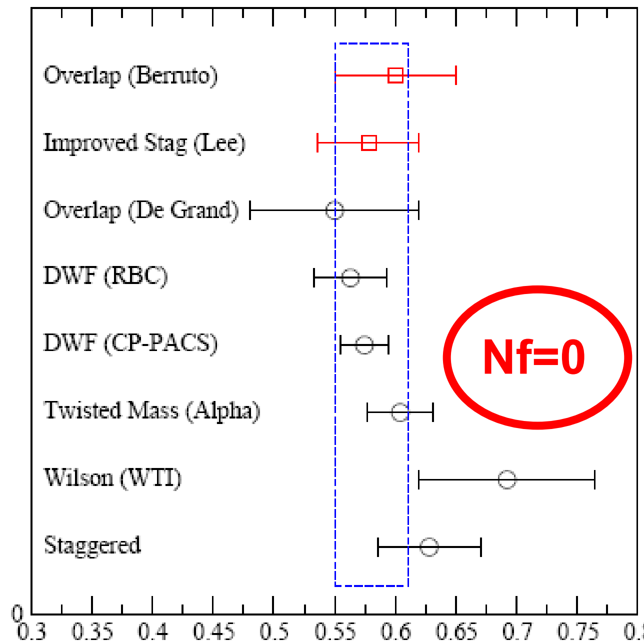
$B_K = 0.58 \pm 0.03 \pm 0.06$

$\hat{B}_K = 0.79 \pm 0.04 \pm 0.09$

C.Dawson@Latt'05

$\hat{B}_K = 0.90 \pm 0.20$ (Gavela et al.) **1987**

C.Dawson@Latt'05



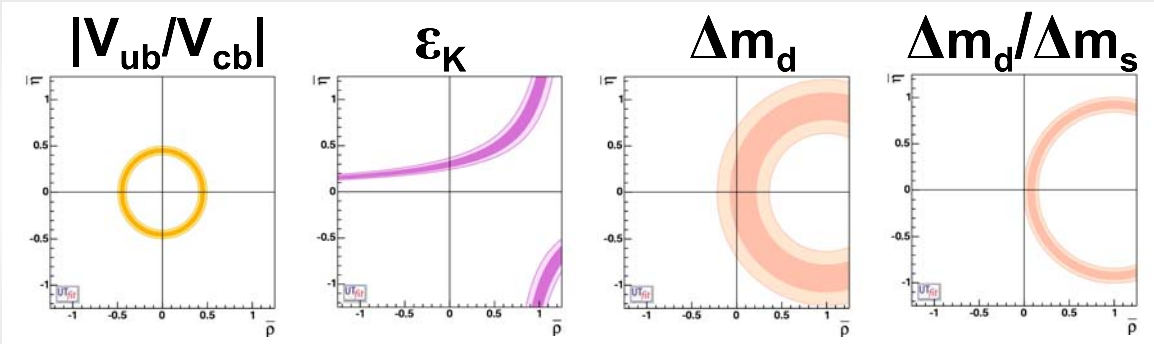
Nf=0

$B_K = 0.50 \pm 0.02 \pm ??$ Nf=2, RBC

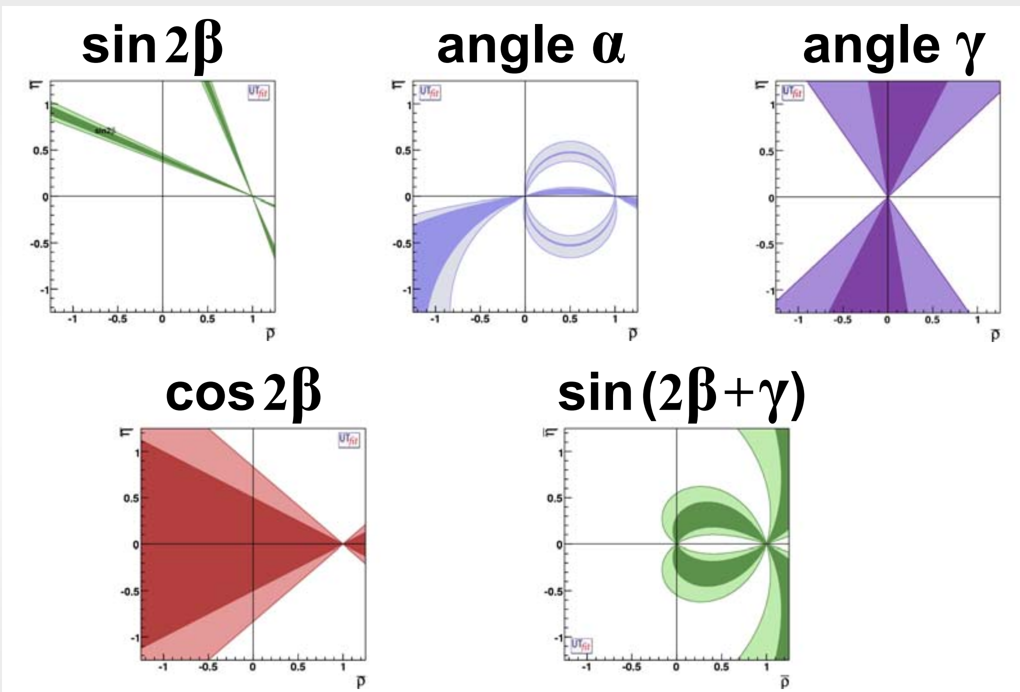
$B_K = 0.62 \pm 0.14$ (Stat.) Nf=2+1 HPQCD & UKQCD

ETMC, Nf=2: work in progress

UTA IN THE B FACTORIES ERA:



UT-LATTICE



UT-ANGLES

Direct determinations of the UT angles are now available from non-leptonic B decays

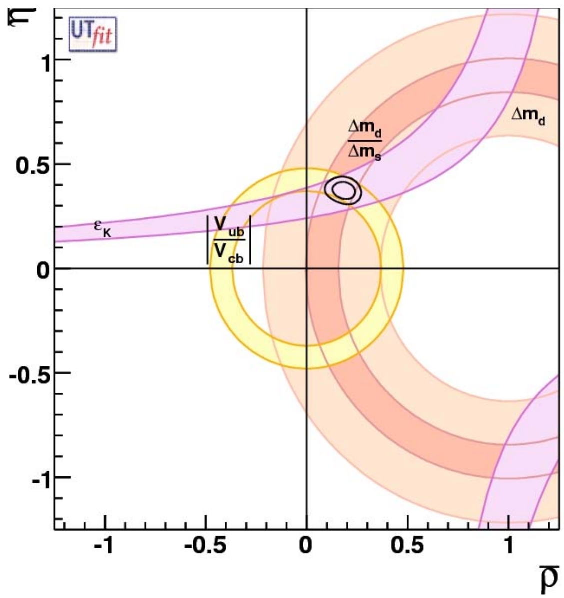
UTfit Collaboration

M.Bona, M.Ciuchini, E.Franco, V.L., G.Martinelli, F.Parodi, M.Pierini, P.Roudeau, C.Schiavi, L.Silvestrini, V.Sordini, A.Stocchi, V.Vagnoni

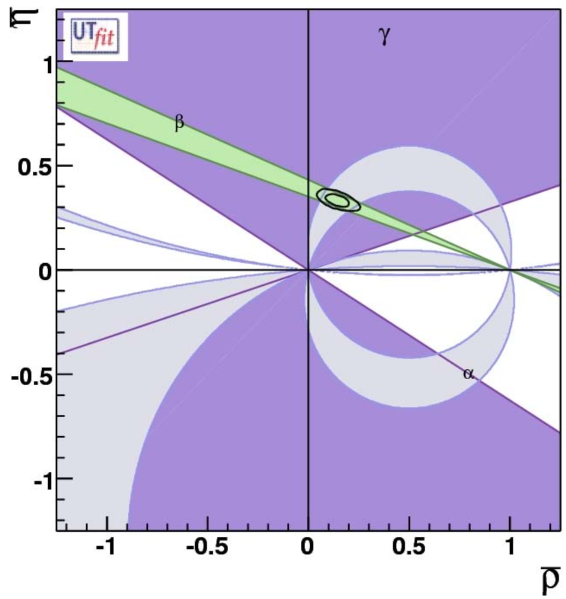
Annecy, Roma, Genova, CERN, Orsay, Bologna

www.utfit.org

UT-lattice



UT-angles



$\bar{\rho} = 0.188 \pm 0.036$

$\bar{\eta} = 0.371 \pm 0.027$

$\bar{\rho} = 0.134 \pm 0.039$

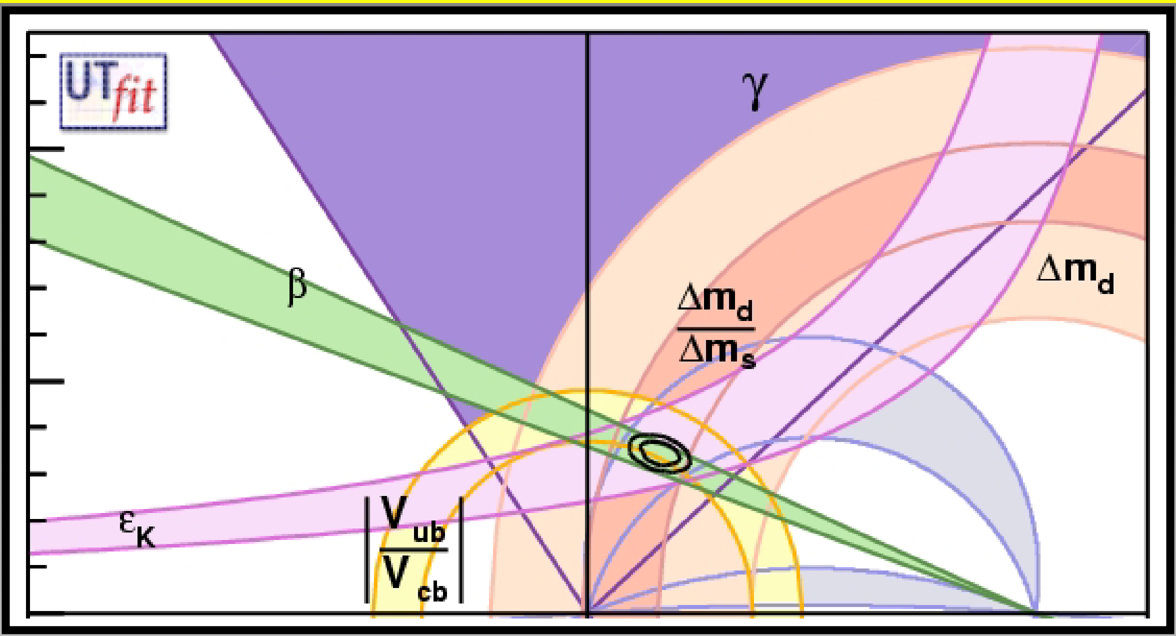
$\bar{\eta} = 0.335 \pm 0.020$

The errors have comparable sizes

The UT-angles fit does not depend on theoretical calculations (the treatment of theoretical errors is <u>not</u> an issue)

b->u decays and the V_{ub} puzzle

There is some tension in the fit, particularly between sin2β and V_{ub}

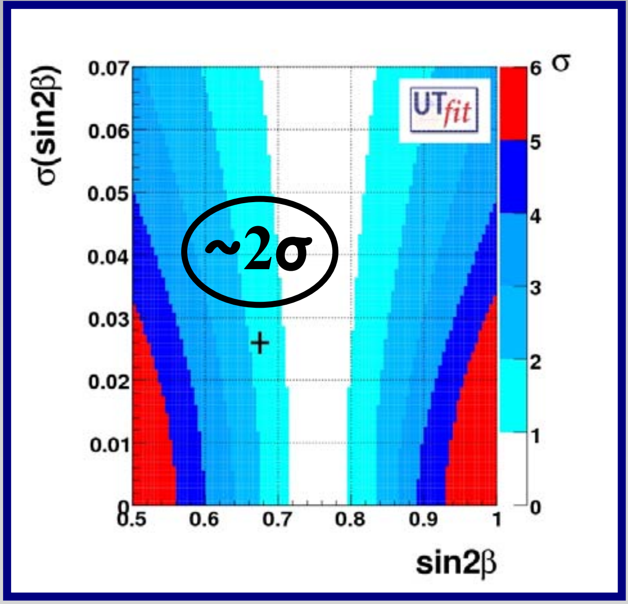


$\sin 2\beta = 0.675 \pm 0.026$

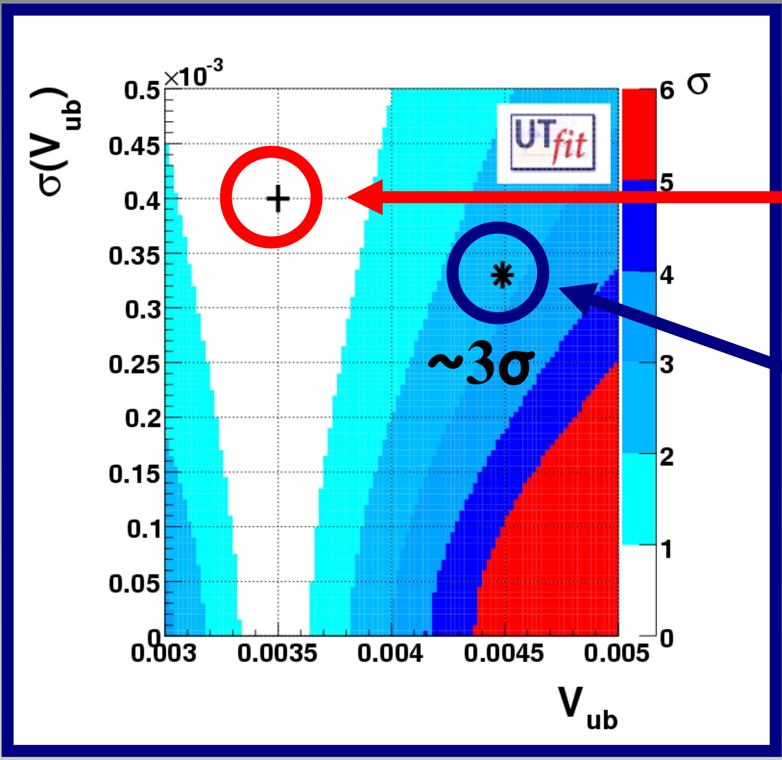
from the direct measurement

$\sin 2\beta = 0.755 \pm 0.040$

from the rest of the fit



The tension is between the inclusive V_{ub} and the rest of the fit



EXCLUSIVE

$V_{ub}^{excl.} = (35.0 \pm 4.0)\ 10^{-4}$

Form factors from LQCD and QCDSR

INCLUSIVE

$V_{ub}^{incl.} = (44.9 \pm 3.3)\ 10^{-4}$

Model dependent (BLNP, DGE,..)
Non perturbative parameters most not from LQCD (fitted from experiments)

AVERAGE

$V_{ub} = (40.9 \pm 2.5)\ 10^{-4}$

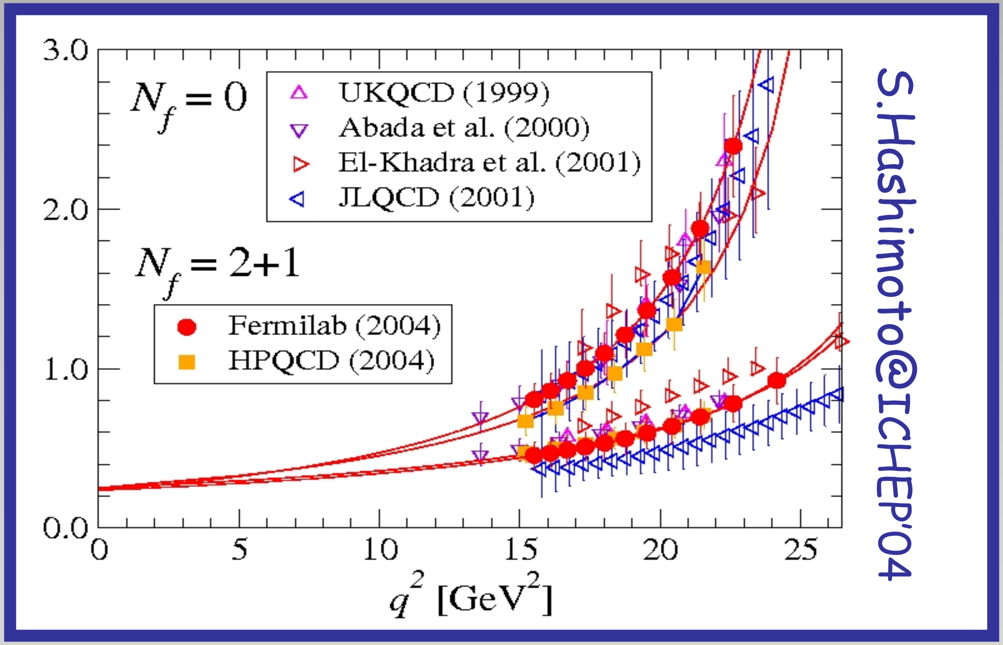
The discrepancy for V_{ub} inclusive is almost at the 3σ level

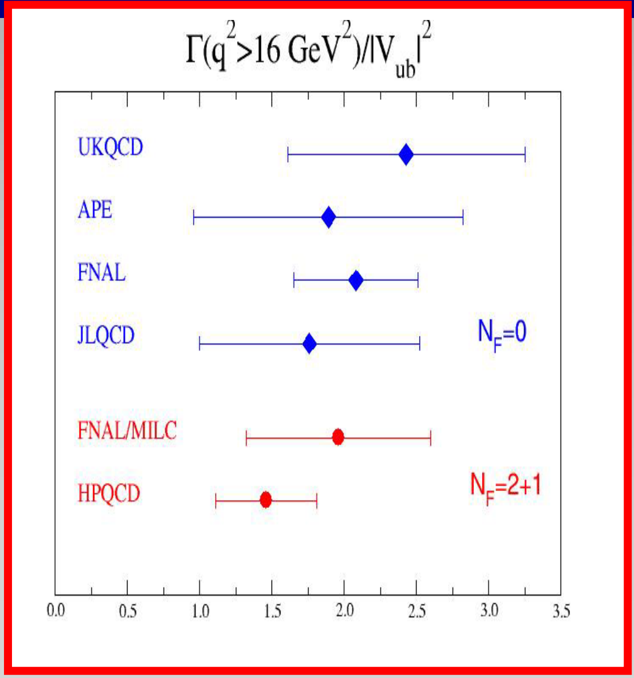
A New Physics effect is unlikely in this tree-level process

i) Statistical fluctuation

ii) Problem with the theoretical calculations and/or the estimate of the uncertainties

LATTICE QCD: improve V_{ub} exclusive to solve the tension





“EXPERIMENTAL” DETERMINATION OF THE LATTICE PARAMETERS

“EXPERIMENTAL” DETERMINATION OF LATTICE PARAMETERS

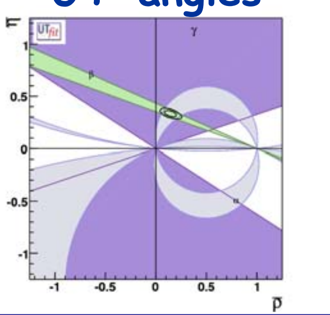
The new measurements of Δm_s and $BR(B\to\tau\nu_\tau)$ allows a simultaneous fit of the hadronic parameters:

$$|\varepsilon_K| = C_\varepsilon A^2\lambda^6\,\bar{\eta}\left[-\eta_1 S(x_c)+\eta_2 S(x_t)\left(A^2\lambda^4(1-\bar{\rho})\right)+\eta_3 S(x_c,x_t)\right]\hat{B}_K$$

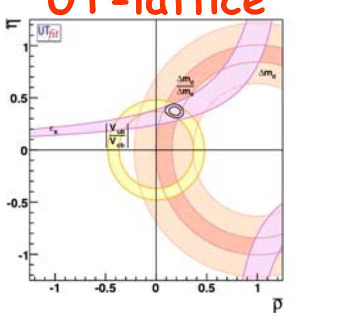
$$\Delta m_q = \frac{G_F^2}{6\pi^2} m_{B_q} M_W^2\,\eta_B S_0(x_t)\,|V_{tq}|^2\,\hat{B}_{B_q} f_{B_q}^2$$

$$BR(B^-\to\tau^-\bar{\nu}_\tau) = f_B^2|V_{ub}|^2\,\frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1-\frac{m_\tau^2}{m_B^2}\right)^2\tau_B$$

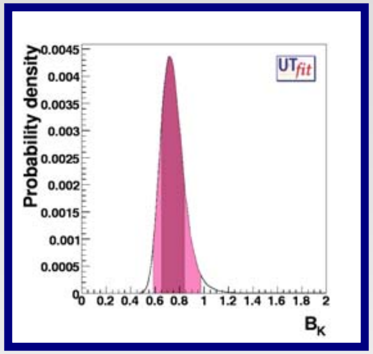
UT-angles



UT-lattice



Take the angles from experiments and extract $f_{B_s}\sqrt{B_{B_s}}$, $f_B\sqrt{B_{B_d}}$ or ξ and f_B

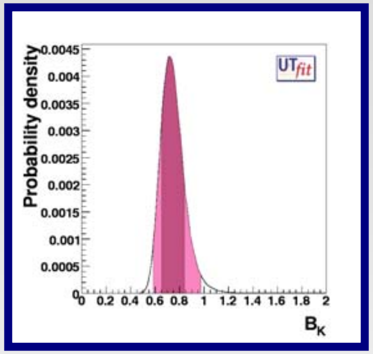


$\hat{B}_K = 0.75 \pm 0.09$

UTA

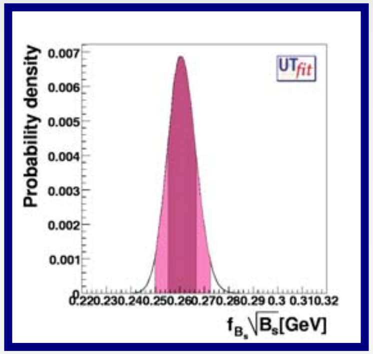
$\hat{B}_K = 0.79 \pm 0.04 \pm 0.08$

Lattice
[Dawson]



$\hat{B}_K = 0.75 \pm 0.09$ — UTA

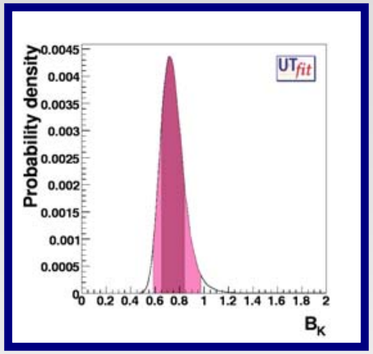
$\hat{B}_K = 0.79 \pm 0.04 \pm 0.08$ — Lattice [Dawson]



2% !

$f_{Bs}\sqrt{B_{Bs}} = 261 \pm 6$ MeV — UTA

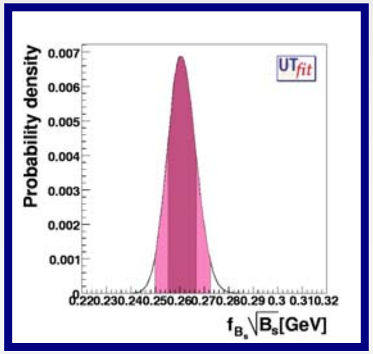
$f_{Bs}\sqrt{B_{Bs}} = 262 \pm 35$ MeV — Lattice [Hashimoto]



$\hat{B}_K = 0.75 \pm 0.09$ — UTA

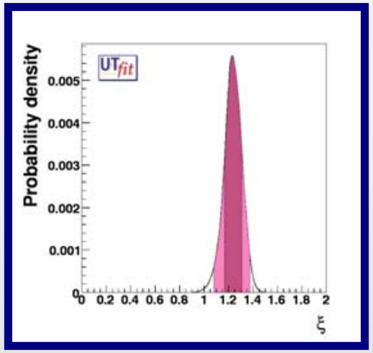
$\hat{B}_K = 0.79 \pm 0.04 \pm 0.08$ — Lattice [Dawson]

2% !



$f_{Bs}\sqrt{B_{Bs}} = 261 \pm 6$ MeV — UTA

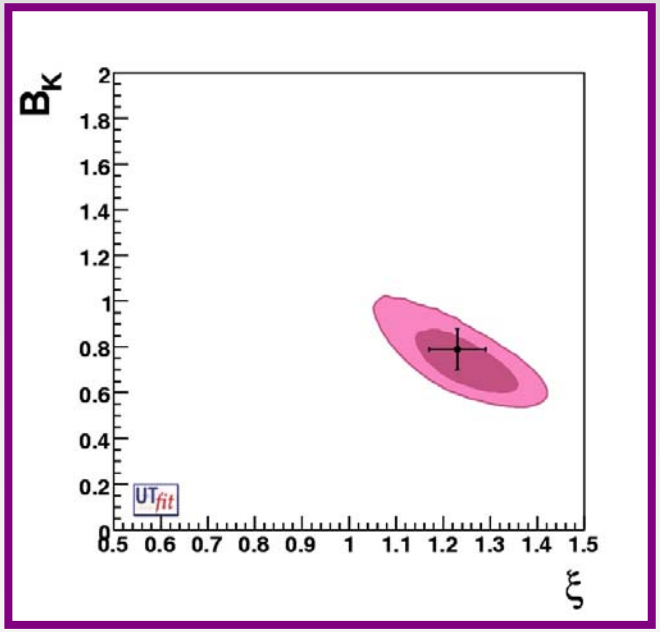
$f_{Bs}\sqrt{B_{Bs}} = 262 \pm 35$ MeV — Lattice [Hashimoto]

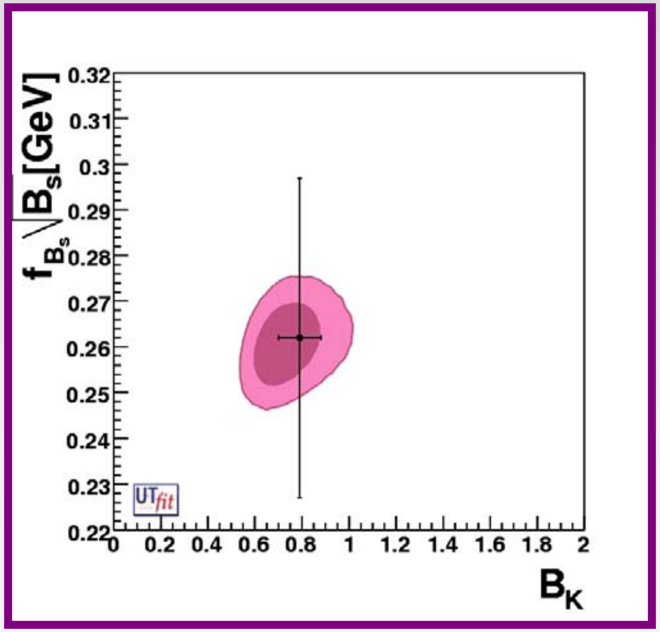


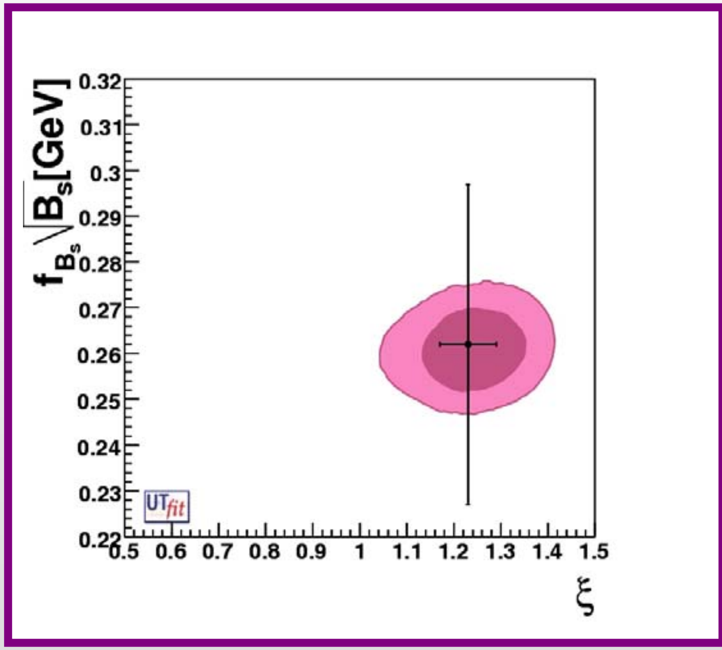
$\xi = 1.24 \pm 0.08$ — UTA

$\xi = 1.23 \pm 0.06$ — Lattice [Hashimoto]

The agreement is spectacular!







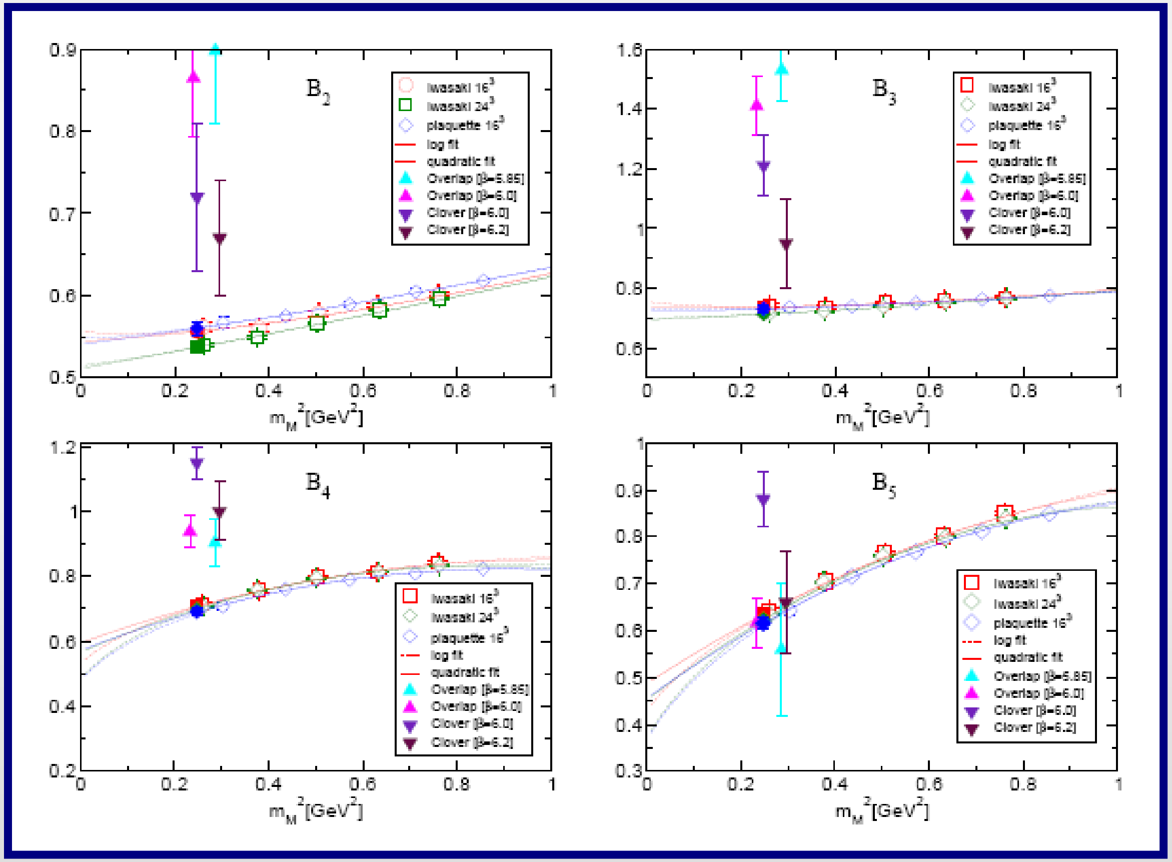
Note: the scale is 6 times larger!!

You may have got the impression that Lattice QCD calculations are becoming irrelevant for the UTA. But this is not true…

They are crucial to perform the UTA when looking for signature of New Physics

K-$\bar{K}$ MIXING IN NP MODELS

$$\mathcal{O}_1 = \bar{s}^a \gamma_\mu (1-\gamma_5) d^a \bar{s}^b \gamma_\mu (1-\gamma_5) d^b,$$
$$\mathcal{O}_2 = \bar{s}^a (1-\gamma_5) d^a \bar{s}^b (1-\gamma_5) d^b,$$
$$\mathcal{O}_3 = \bar{s}^a (1-\gamma_5) d^b \bar{s}^b (1-\gamma_5) d^a,$$
$$\mathcal{O}_4 = \bar{s}^a (1-\gamma_5) d^a \bar{s}^b (1+\gamma_5) d^b,$$
$$\mathcal{O}_5 = \bar{s}^a (1-\gamma_5) d^b \bar{s}^b (1+\gamma_5) d^a$$



Clover

APE 1999

Overlap

Babich et al. 2006

Domain wall

CP-PACS 2006

CONSTRAINTS ON THE MSSM

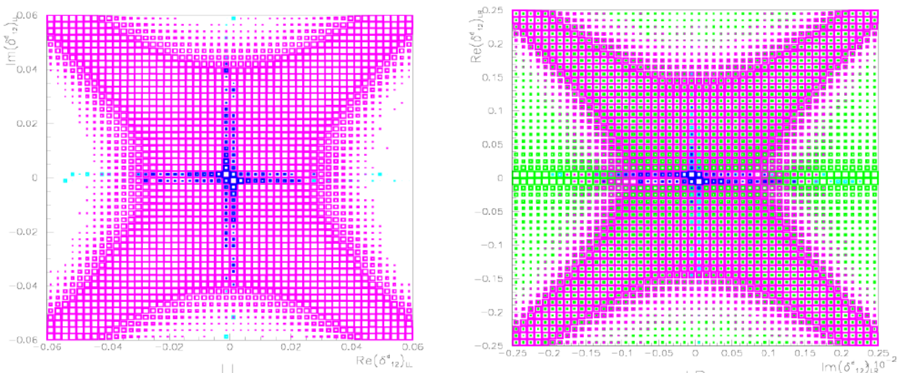
M.Ciuchini, E.Franco, D.Guadagnoli, V.L., V.Porretti, L.Silvestrini (in preparation)

Super-CKM basis: all gauge interactions governed by the CKM matrix. **Additional sources of flavour violation in squark masses.**

$$(M_{\tilde{U}}^2)_{LL} = \begin{pmatrix} (m_{\tilde{U}1}^2)_{LL} & (\Delta_{\tilde{U}}^{12})_{LL} & (\Delta_{\tilde{U}}^{13})_{LL} \\ (\Delta_{\tilde{U}}^{21})_{LL} & (m_{\tilde{U}2}^2)_{LL} & (\Delta_{\tilde{U}}^{23})_{LL} \\ (\Delta_{\tilde{U}}^{31})_{LL} & (\Delta_{\tilde{U}}^{32})_{LL} & (m_{\tilde{U}3}^2)_{LL} \end{pmatrix}$$

$$(\delta_{\tilde{U}}^{IJ})_{LR} = \frac{(\Delta_{\tilde{U}}^{IJ})_{LR}}{(m_{UI})_{LL}\,(m_{UJ})_{RR}}$$

Re $(\delta^d_{12})_{LL,RR}$ vs Im $(\delta^d_{12})_{LL,RR}$ Re $(\delta^d_{12})_{LR}$ vs Im $(\delta^d_{12})_{LR}$



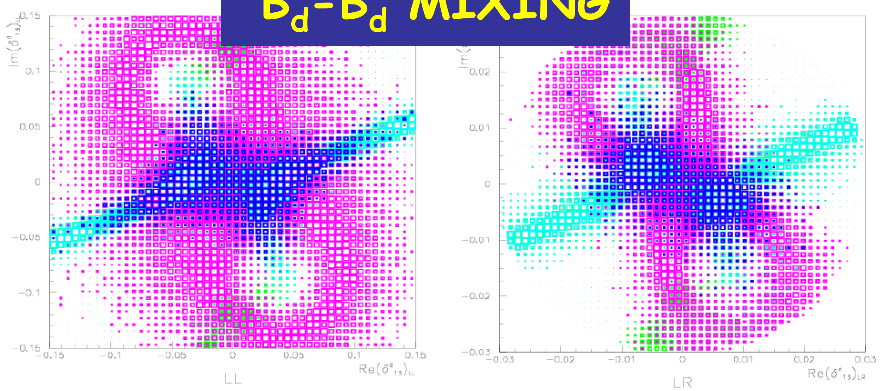
Δm_K only ε'/ε only

ε_K only

Δm_K and ε_K $m_{sq}=m_{gl}$=350 GeV

K-$\bar{K}$ MIXING

B_d-$\bar{B}_d$ MIXING



Re $(\delta^d_{13})_{LL,RR}$ vs Im $(\delta^d_{13})_{LL,RR}$ Re $(\delta^d_{13})_{LR,RL}$ vs Im $(\delta^d_{13})_{LR,RL}$

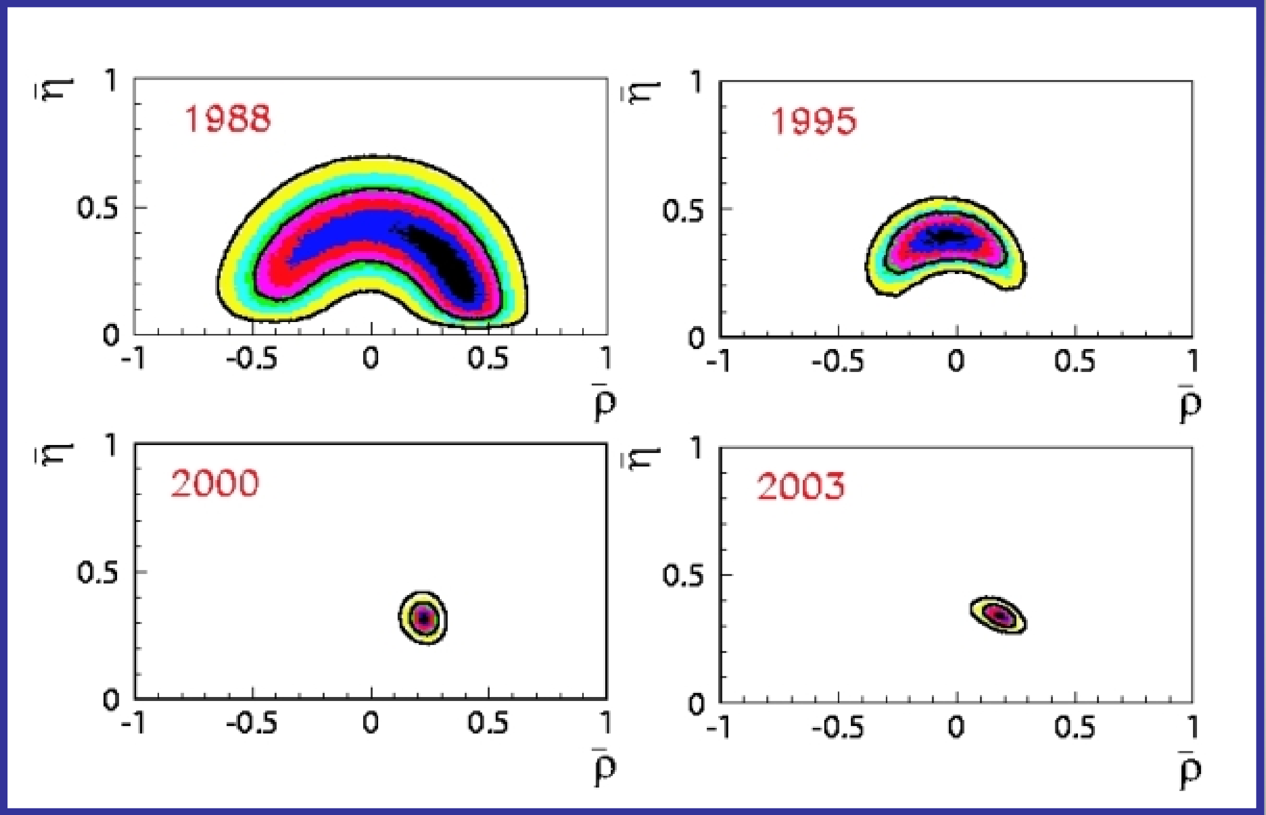
Δm_B only

sin 2β only

sin 2β and cos 2β

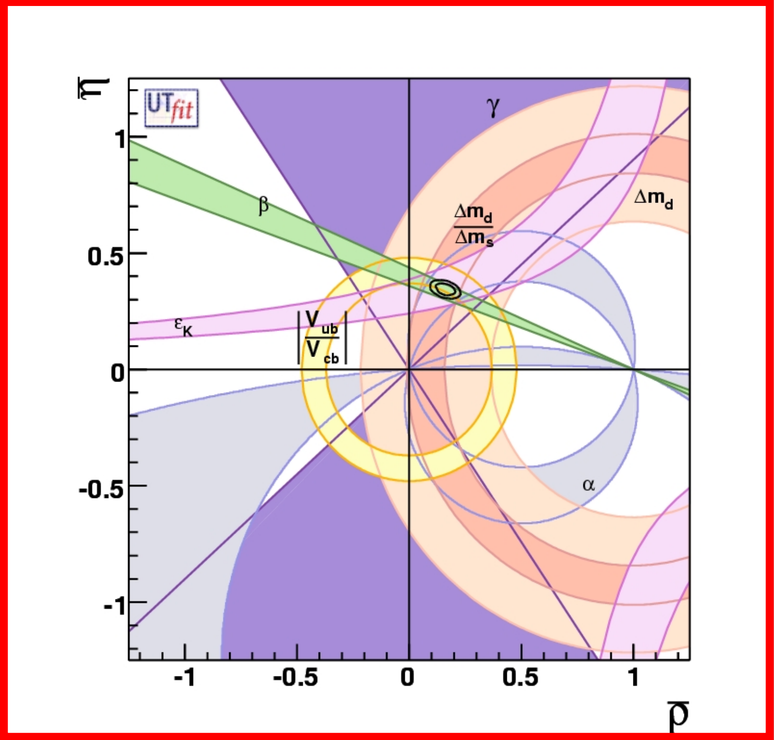
All constraints

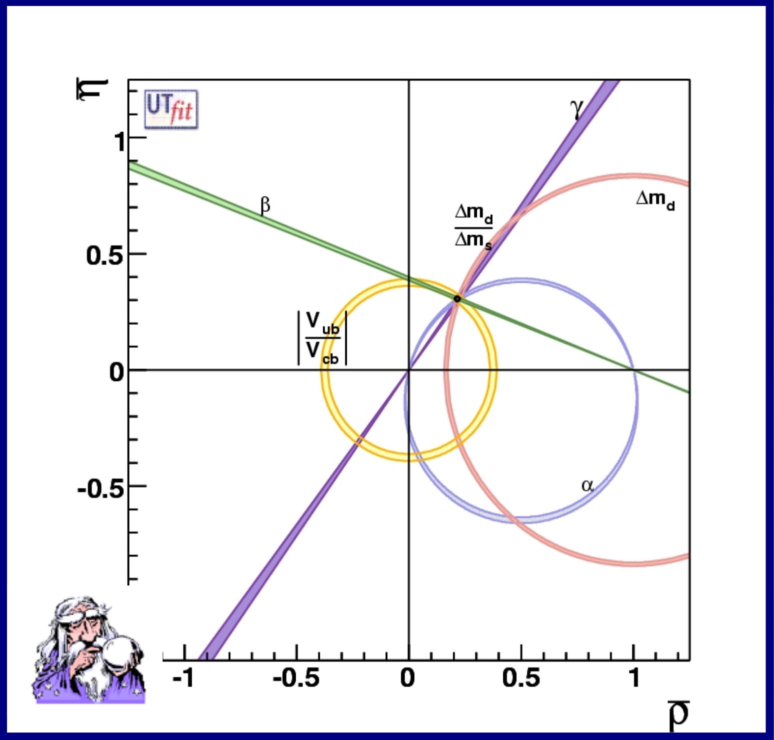
15 YEARS OF ($\bar{\rho}$-$\bar{\eta}$) DETERMINATIONS



The result of a remarkable experimental and theoretical progress

UT fit at a Super B factory: 2006 vs. 2015





$\bar{\rho} = 0.163 \pm 0.028$

$\bar{\eta} = 0.344 \pm 0.016$

$\bar{\rho} = 0.2226 \pm 0.0028$

$\bar{\eta} = 0.3052 \pm 0.0024$