# Enrico, the Unitarity Triangle Analysis and New Physics in ΔF=2

# Introduction

- Enrico has accompanied and guided me from my first steps in 1993, we wrote more than 100 papers together
- His contribution was fundamental in all those papers, and I used to clear up all my doubts discussing with him, taking advantage of his clean logical attitude and of his sense of humour
- In the following I will quickly review some of his most important contributions in UTfit and in the study of $\Delta F=2$ processes beyond the SM

# Flavour Physics and the UTA

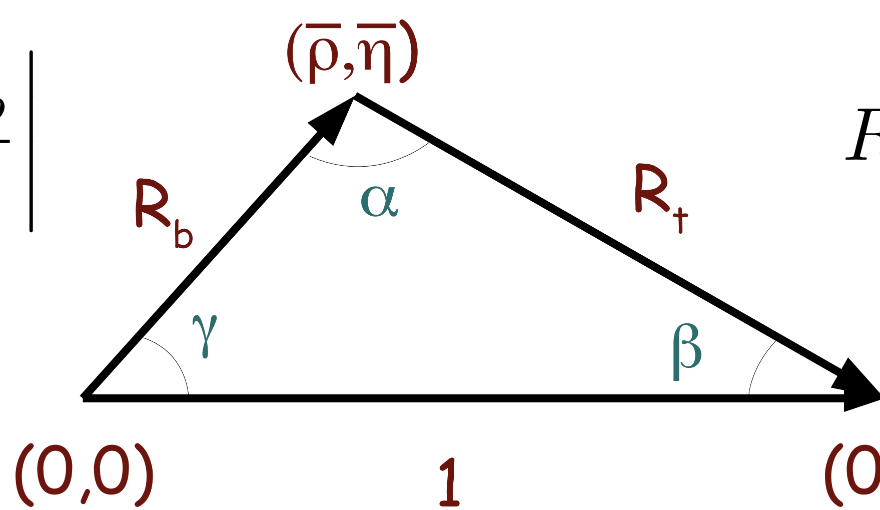
- All flavour and CP violation in the SM governed by the Unitary Cabibbo-Kobayashi-Maskawa matrix V
- No tree-level Flavour Changing Neutral Current, and GIM suppression of loop contributions
- FCNC ideal place to test the SM and look for NP

# SM UTA

- CKM unitarity implies triangular relations:

$(V^\dagger V)_{bd} = 0 = V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^*$

$$R_b = \left|\frac{V_{ud}V_{ub}}{V_{cd}V_{cb}}\right| \qquad R_t = \left|\frac{V_{td}V_{tb}}{V_{cd}V_{cb}}\right|$$




$$\alpha = \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right) \quad \beta = \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right) \quad \gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

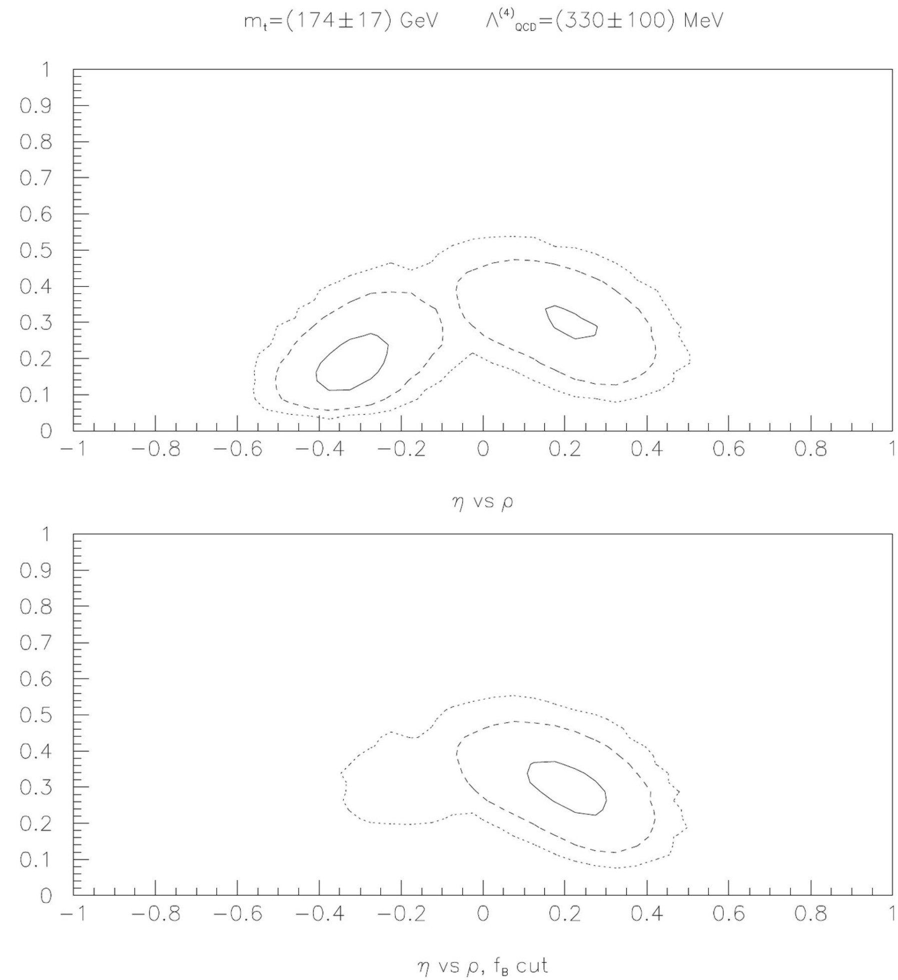
# The Prehistory of the UTA

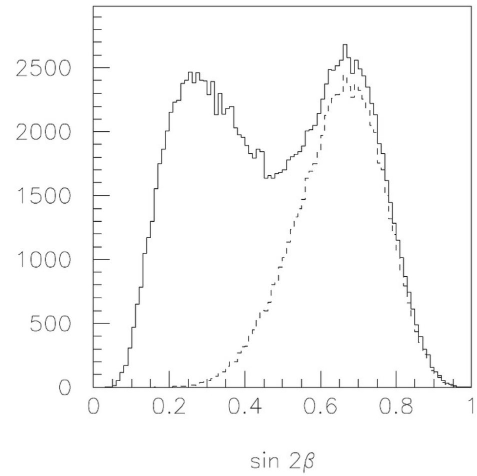
**An upgraded analysis of $\varepsilon'/\varepsilon$ at the next-to-leading order**

M. Ciuchini[1], E. Franco[2], G. Martinelli[3,★], L. Reina[4], L. Silvestrini[5]

1995

- Bayesian analysis of the UTA, with Gaussian likelihoods for experimental measurements and flat priors for theory parameters
- Lattice estimate of $f_B B_B^{\frac{1}{2}}$ breaks the degeneracy of $\varepsilon_K$ and allows to **predict sin2β**



# The Birth of UTfit

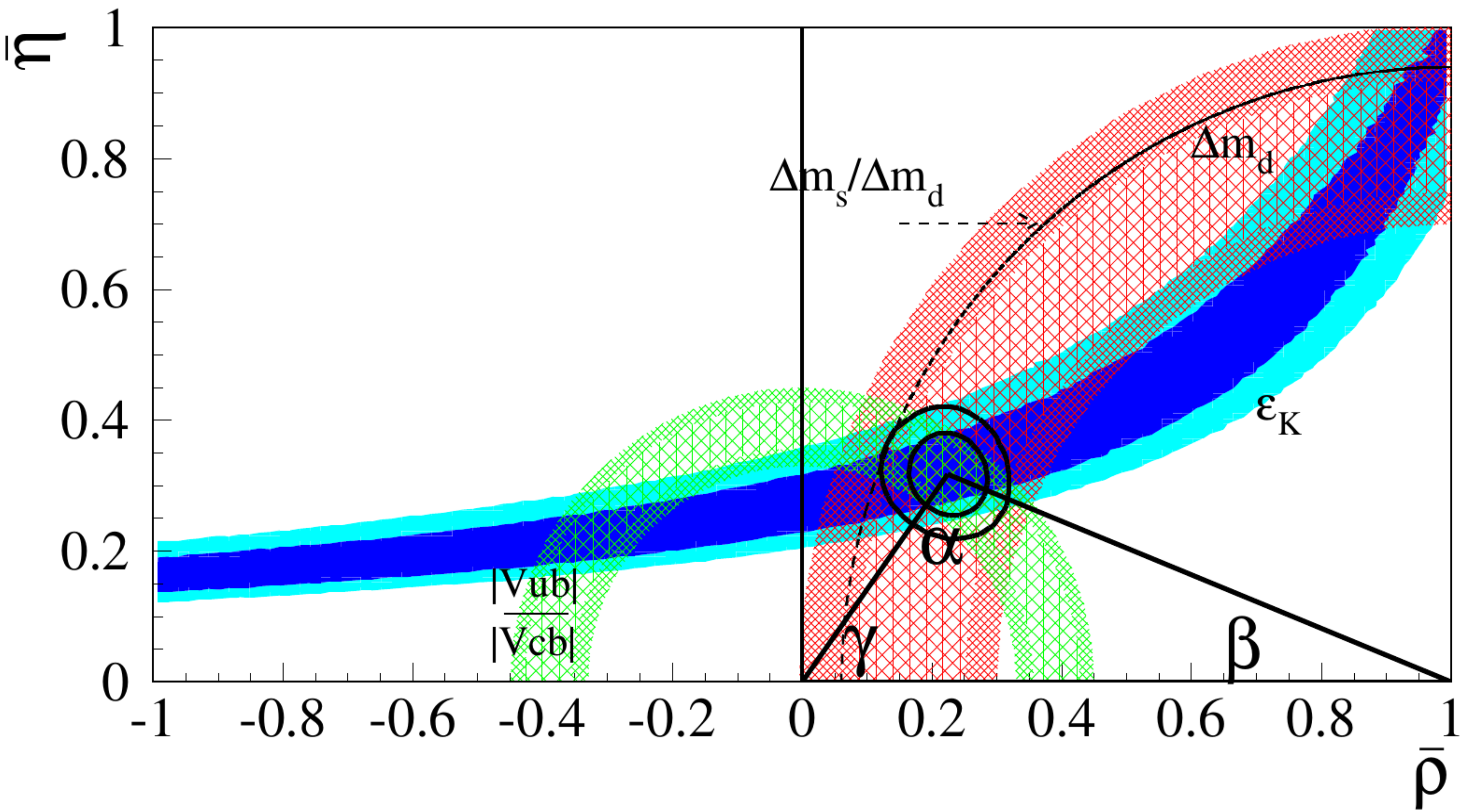
- B physics was clearly playing a very important role in the UTA
- LEP experiments were producing very interesting B-physics data
- Lattice QCD was needed to take advantage of B physics measurements
- B factories were in preparation, and BaBar "official" ideas on how to combine theory and experiment in a global fit were very primitive
- Put together a "dream team" of experts in perturbative calculations, Lattice QCD, LEP experiments and Bayesian statistics:

  M. Ciuchini[(a)], G. D'Agostini[(b)], E. Franco[(b)], V. Lubicz[(a)], G. Martinelli[(b)], F. Parodi[(c)], P. Roudeau[(d)] and A. Stocchi[(d)]

  and produce a classic paper containing the fundamental ingredients of all future work: a careful combination of experimental results and a critical review of lattice and other theoretical inputs

# 2000 CKM-TRIANGLE ANALYSIS

## A Critical Review with Updated Experimental Inputs and Theoretical Parameters



# Narrow-minded frequentists strike back

- Desperately seeking ways to criticize UTfit, a competing group published a paper with the only goal of showing inconsistencies in the UTfit Bayesian analysis
- They focused on the extraction of the angle $\alpha$, which mathematically has degeneracies, and pointed out that those degeneracies were broken in the UTfit results
- Enrico took the lead in understanding the origin of the degeneracy breaking, with several very interesting implications that led to subsequent developments:
  - the extraction of $\alpha$ beyond the Standard Model
  - how to improve $\alpha$ with $B_s \to KK$ decays and SU(3)

# Enrico having fun with α

From Enrico Franco <Enrico.Franco@roma1.infn.it>
Reply | Reply All | Forward | Archive | Junk | Delete | More

To Vittorio Lubicz <lubicz@fis.uniroma3.it>, Marco Ciuchini <marco.ciuchini@roma3.infn.it>, Me <Luca.Silvestrini@roma1.infn.it> 03/10/06, 13:29

Subject **Giochi Alfici**

```
Cari amici,
ho fatto un montecarlino in c dove ho messo lo jacobiano per passare dai
parametri sperimentali ai parametri adronici. L'espressione e' curiosamente
molto meno incasinata di quel che temevo.
A questo punti possiamo provare tutte le nostre sparate praticamente in tempo
reale, visto che poche migliaia di eventi sono piu che sufficenti.

Ho fatto un programmino math che e' l'interfaccia per quello in c.

Vi mando il file c e il nb.
Se ci volete giocare un poco dovete
1) compilare il file c (ovviamente con -lm)
2) modificare la variabile exedir nel notebook, mettendoci il path
dell'eseguibile.

Buon divertimento!!!

Ciao ciao, enrico.
```

2 attachments 1.0 MB Save All

# Improved Determination of the CKM Angle $\alpha$ from $B \to \pi\pi$ decays

**UT***fit* Collaboration
**M. Bona**[a], **M. Ciuchini**[b], **E. Franco**[c], **V. Lubicz**[b],
**G. Martinelli**[c], **F. Parodi**[d], **M. Pierini**[e], **P. Roudeau**[f],
**C. Schiavi**[d], **L. Silvestrini**[c], **V. Sordini**[f], **A. Stocchi**[f] **and V. Vagnoni**[g]

2007

Motivated by the criticisms recently appeared in ref. [1], we present a new analysis of the CKM angle $\alpha$ from $B \to \pi\pi$ decays based on the Bayesian statistical approach. The main results are the following:

- we show that the differences between the frequentist and the Bayesian approaches are *NOT* due to the difference in the two methods but to the difference in the physical assumptions on the weak amplitudes, contrary to the claims of ref. [1];
- although we expect an eightfold ambiguity for $\alpha$ using as "a priori" knowledge only isospin symmetry and the experimental measurements of the relevant branching fractions and CP asymmetries, *this degeneracy can be reduced in the presence of further information on the hadronic amplitudes*. We will discuss and use this information which can already be extracted from the data;
- among the information that we do have on the amplitudes, the existence of a scale of strong interactions and the use of the experimental values of related decays allow to limit the size of the hadronic matrix elements and to eliminate the *unphysical* region of values corresponding to $\alpha$ close to zero;
- within our approach, we obtain consistent results at a meaningful probability value irrespective of the parametrisation used for the hadronic amplitudes.

# The importance of being skeptic

- $|V_{cb}|$ and $|V_{ub}|$ can be extracted from semileptonic B decays. Two approaches: exclusive and inclusive decays, with long-standing tension between the two determinations at the level of ~3$\sigma$. Need to combine incompatible data with some recipe, for example the PDG one
- Since 2015, LHCb measures $|V_{ub}|/|V_{cb}|$ from exclusive decays, introducing correlation between the two. Not clear how to extend the PDG method to 2D: scale the whole covariance matrix? Or else?
- Use D'Agostini's skeptical combination!

# Skeptic discussions...

From Enrico Franco <enrico.franco@roma1.infn.it>

Reply | Reply All | Forward | Archive | Junk | Delete | More

To Guido Martinelli <guido.martinelli@roma1.infn.it>

15/06/16, 14:54

Cc Me <Luca.Silvestrini@roma1.infn.it>, Marco Ciuchini <marco.ciuchini@roma3.infn.it>

Subject **Re: ci possiamo sentire su vub etc.**

---

Ne parliamo poi al telefono ma ti anticipo 2 obiezioni al tuo approccio

1) osservazione tecnica.
La funzione dago che hai scritto assume implicitamente una prior piatta per la grandezza misurata, ergo
non puoi trattare Vub/Vcb in questo modo assieme a Vub e Vcb, perché vorrebbe dire prior piatta per Vub, Vcb e Vcb/Vub che ovviamente è impossibile

2) osservazione filosofica. Combinazione scettica e richiedere che il valore medio sia invariato non ha molto senso.
Se sei scettico vuol dire che sei pronto ad accettare che qualche esperimento ha toppato la stima dell'errore
e i dati suggeriscono che è piu probabile che Vub inclusivo Vcb esclusivo abbiano sottostimato l'errore. In questo caso non vi è alcun
motivo per richiedere che il valore medio rimanga invariato rispetto la combinazione non-scettica

ciao, enrico.

From Enrico Franco <enrico.franco@roma1.infn.it>

Reply | Reply All | Forward | Archive | Junk | Delete | More

To Guido Martinelli <guido.martinelli@roma1.infn.it>, Me <Luca.Silvestrini@roma1.infn.it>, Marco Ciuchini <marco.ciuchini@roma3.infn.it>

15/06/16, 12:52

Subject **Re: ci possiamo sentire su vub etc.**

---

Per me ok alle 17:30

Per vostra curiosità allego un paio di immagini con le seguenti combinazioni
(i colori non hanno alcun significato probabilistico)

1) scettica d'agostiana (viene un po' bimodale su Vcb, ma visti i dati è inevitabile)

2) scettica modificata (il valore medio di r = sigma_vero/sigma_exp ha valore medio >1 perché non ammetto r<1).
In questo caso Vcb non è bimodale, ma ovviamente è un po asimmetrica

Ciao, Enrico

# Skeptic discussions...

From Enrico Franco <enrico.franco@roma1.infn.it>
To Guido Martinelli <guido.martinelli@roma1.infn.it>
Cc Me <Luca.Silvestrini@roma1.infn.it>, Marco Ciuchini <marco.ciuchini@roma3.infn.it>
Subject **Re: ci possiamo sentire su vub etc.**

Reply | Reply All | Forward | Archive | Junk | Delete | More

15/06/16, 14:54

Ne parliamo poi al telefono ma ti anticipo 2 obiezioni al tuo approccio

1) osservazione tecnica.
La funzione dago che hai scritto assume implicitamente una prior piatta per la grandezza misurata, ergo
non puoi trattare Vub/Vcb in questo modo assieme a Vub e Vcb, perché vorrebbe dire prior piatta per Vub, Vcb e Vcb/Vub che ovviamente è impossibile

2) osservazione filosofica. Combinazione scettica e richiedere che il valore medio sia invariato non ha molto senso.
Se sei scettico vuol dire che sei pronto ad accettare che qualche esperimento ha toppato la stima dell'errore
e i dati suggeriscono che è piu probabile che Vub inclusivo Vcb esclusivo abbiano sottostimato l'errore. In questo caso non vi è alcun
motivo per richiedere che il valore medio rimanga invariato rispetto la combinazione non-scettica

ciao, enrico.

From Enrico Franco <enrico.franco@roma1.infn.it>
To Guido Martinelli <guido.martinelli@roma1.infn.it>, Me <Luca.Silvestrini@roma1.infn.it>, Marco Ciuchini <marco.ciuchini@roma3.infn.it>
Subject **Re: ci possiamo sentire su vub etc.**

Reply | Reply All | Forward | Archive | Junk | Delete | More

15/06/16, 12:52

Per me ok alle 17:30

Per vostra curiosità allego un paio di immagini con le seguenti combinazioni
(i colori non hanno alcun significato probabilistico)

1) scettica d'agostiana (viene un po' bimodale su Vcb, ma visti i dati è inevitabile)

From Enrico Franco <enrico.franco@roma1.infn.it>
To Guido Martinelli <guido.martinelli@roma1.infn.it>
Cc Me <Luca.Silvestrini@roma1.infn.it>, Marco Ciuchini <marco.ciuchini@roma3.infn.it>
Subject **Re: ci possiamo sentire su vub etc.**

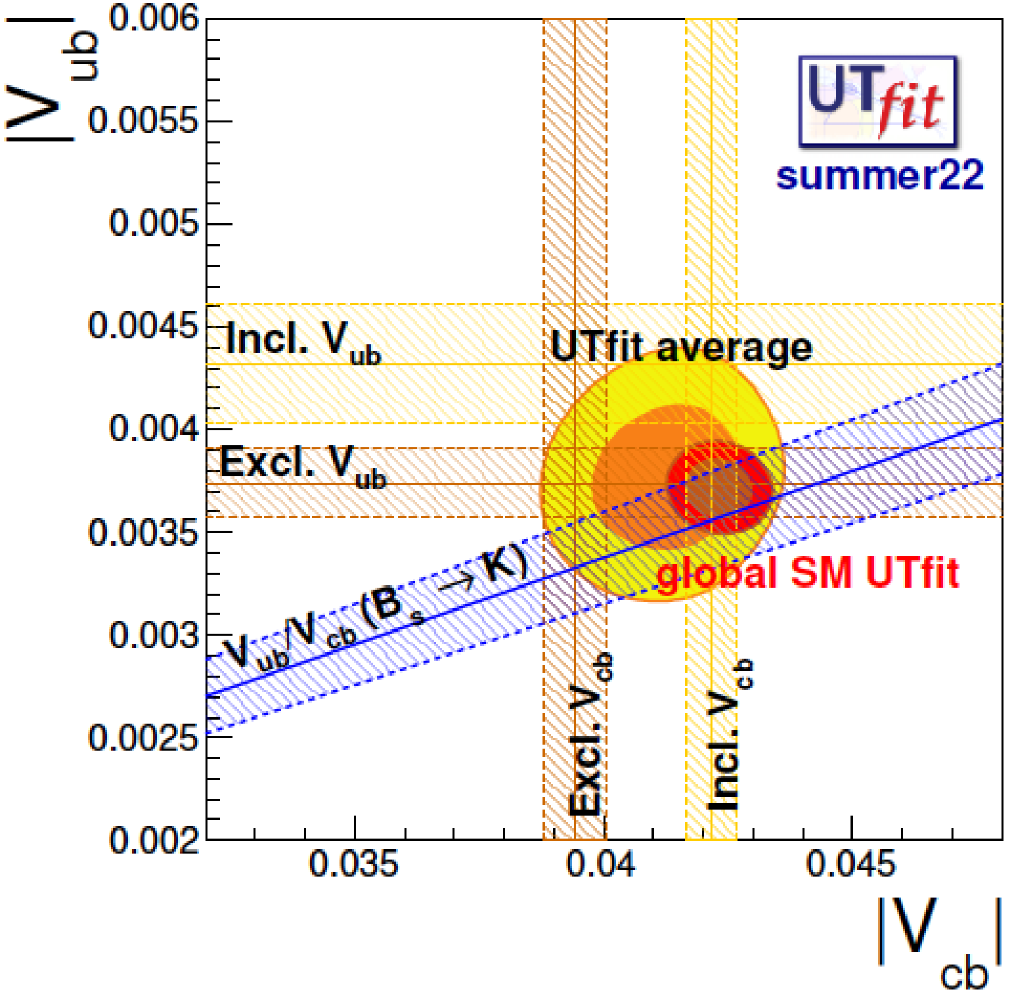
Reply | Reply All | Forward | Archive | Junk | Delete | More

15/06/16, 17:45

Io devo scappare e quindi salto l'incontro!
alla prossima.

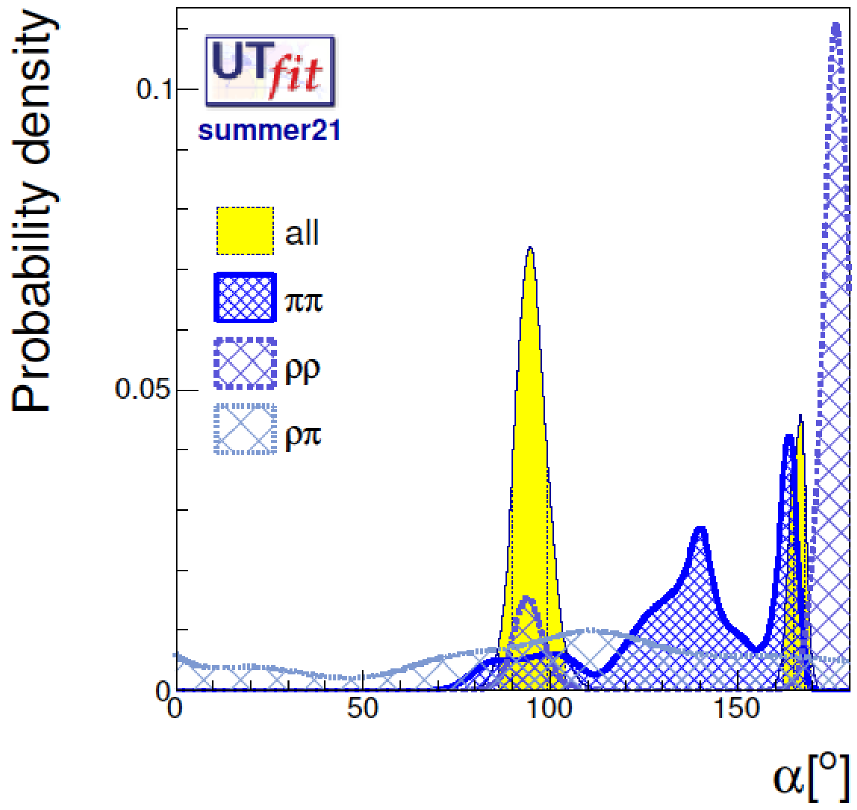
Ciao, enrico

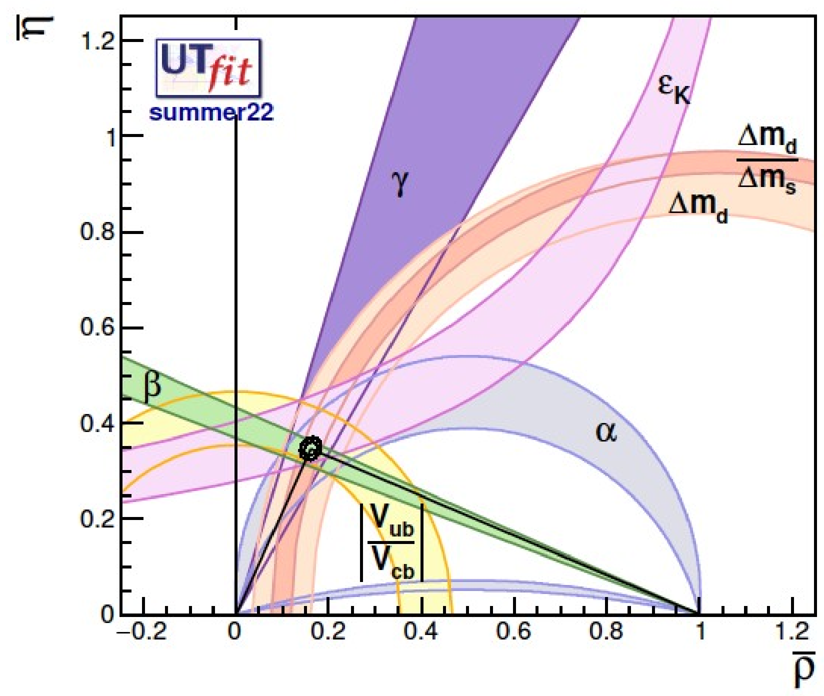
# ...and finally...



UTfit
summer22
Incl. $V_{ub}$
UTfit average
Excl. $V_{ub}$
global SM UTfit
$V_{ub}/V_{cb}$ ($B_s \to K$)
Excl. $V_{cb}$
Incl. $V_{cb}$
$|V_{ub}|$
$|V_{cb}|$
0.002
0.0025
0.003
0.0035
0.004
0.0045
0.005
0.0055
0.006
0.035
0.04
0.045

# α and the UTA Today



# Enrico and NP in $\Delta F=2$

- $\Delta F=2$ ideal place to look for NP
- Very stringent bounds on Supersymmetric models, where new operators present
- In the 90's we had all the tools to compute QCD corrections to the full operator basis at NLO
- In 1997, Bagger et al point out the importance of QCD corrections at the LO
- We start computing the necessary ingredients for a full NLO analysis in SUSY (actually, Enrico had worked on SUSY models in the 80's)

# Enrico and NP in $\Delta F=2$

- We computed the NLO anomalous dimension already in 1997
- Lattice values for the matrix elements of the NP basis were quickly computed by the Rome group, and phenomenological SUSY analyses of $\Delta S=2$ (1998) and of $\Delta B=2$ (2001) were performed
- Finally, the last missing piece, the NLO corrections to the SUSY matching, were completed in 2006

# New Physics in $\Delta F=2$ and the UTA

- Generalize the UTA allowing for NP in loop-mediated processes:
  - $V_{us}$, $V_{cb}$, $V_{ub}$, $\gamma$ from trees and $\alpha$ unaffected (provided no huge NP effect in EWP)
  - NP allowed in $\Delta F=2$ processes
- Extract both CKM parameters and NP contributions

# NP Contributions to ΔF=2

- Phenomenological parameterization:

$$C_{B_q} e^{2i\phi_{B_q}} = \frac{\langle B_q | H_{\rm eff}^{\rm full} | \bar{B}_q \rangle}{\langle B_q | H_{\rm eff}^{\rm SM} | \bar{B}_q \rangle} = 1 + \frac{A_q^{\rm NP}}{A_q^{\rm SM}} e^{2i\phi_q^{\rm NP}}$$

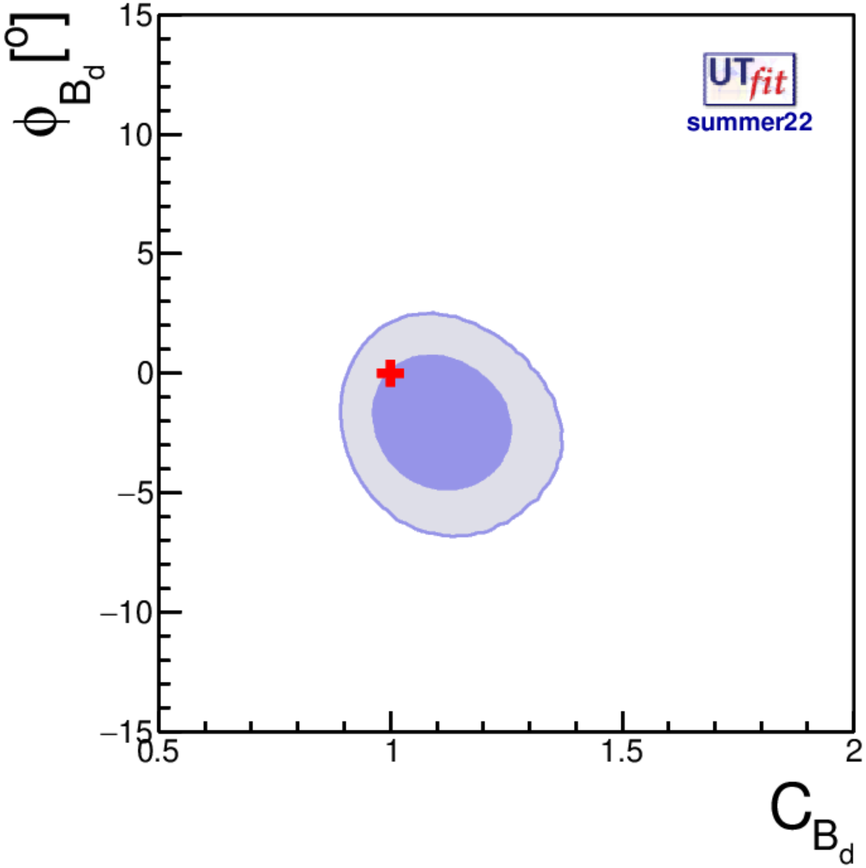
$$\Delta m_{d,s}^{\rm exp} = C_{B_{d,s}} \Delta m_{d,s}^{\rm SM}$$

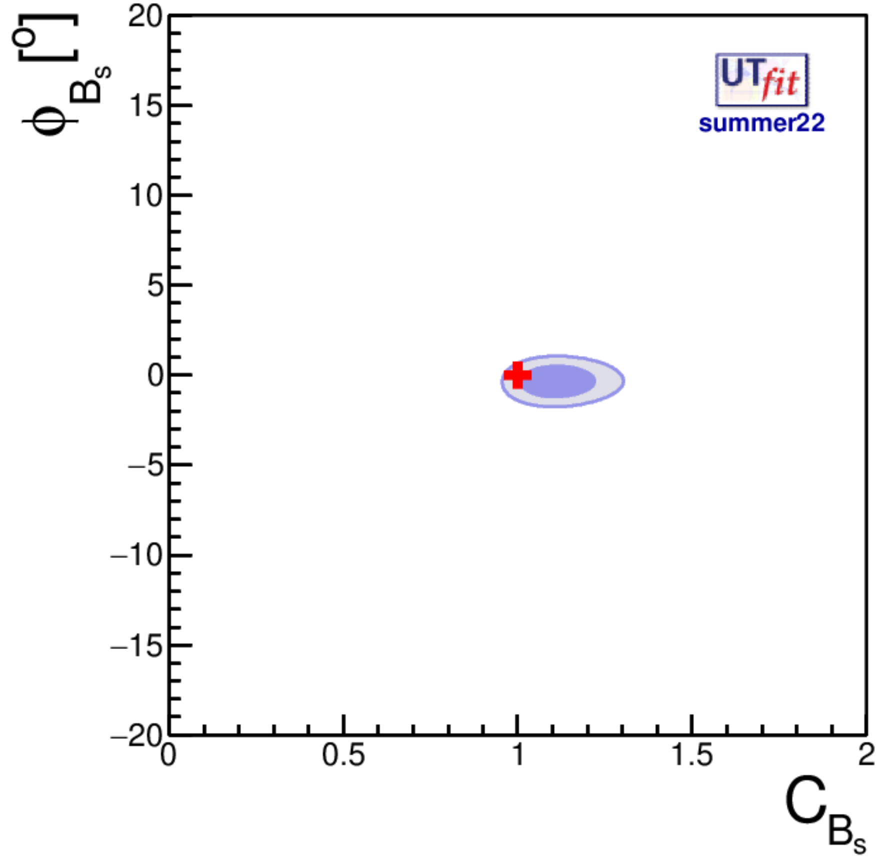
$$\sin 2\beta^{\rm exp} = \sin(2\beta + 2\phi_{B_d}) \qquad \phi_s^{\rm exp} = \beta_s - \phi_{B_s}$$

$$A_{\rm SL}^{d,s;\rm exp} = {\rm Im}\left(\frac{\Gamma_{12}^{\rm SM}}{M_{12}^{\rm SM}}\right) \frac{\cos 2\phi_{B_{d,s}}}{C_{B_{d,s}}} - {\rm Re}\left(\frac{\Gamma_{12}^{\rm SM}}{M_{12}^{\rm SM}}\right) \frac{\sin 2\phi_{B_{d,s}}}{C_{B_{d,s}}}$$

$$C_{\varepsilon_K} = \frac{\varepsilon_K^{exp}}{\varepsilon_K^{\rm SM}} = \frac{{\rm Im}\langle K^0 | \mathcal{H}_{\rm eff}^{\rm full} | \bar{K}^0 \rangle}{{\rm Im}\langle K^0 | \mathcal{H}_{\rm eff}^{\rm SM} | \bar{K}^0 \rangle} \qquad C_{\Delta m_K} = \frac{\Delta m_K^{exp}}{\Delta m_K^{\rm SM}} = \frac{{\rm Re}\langle K^0 | \mathcal{H}_{\rm eff}^{\rm full} | \bar{K}^0 \rangle}{{\rm Re}\langle K^0 | \mathcal{H}_{\rm eff}^{\rm SM} | \bar{K}^0 \rangle}$$

# Results on NP Parameters

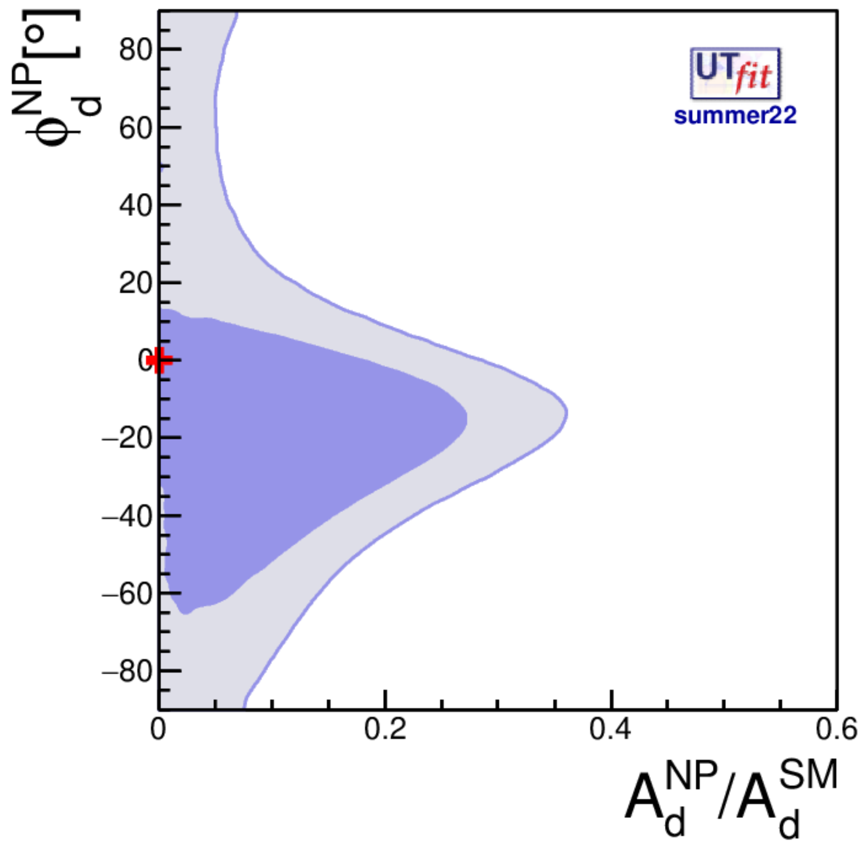


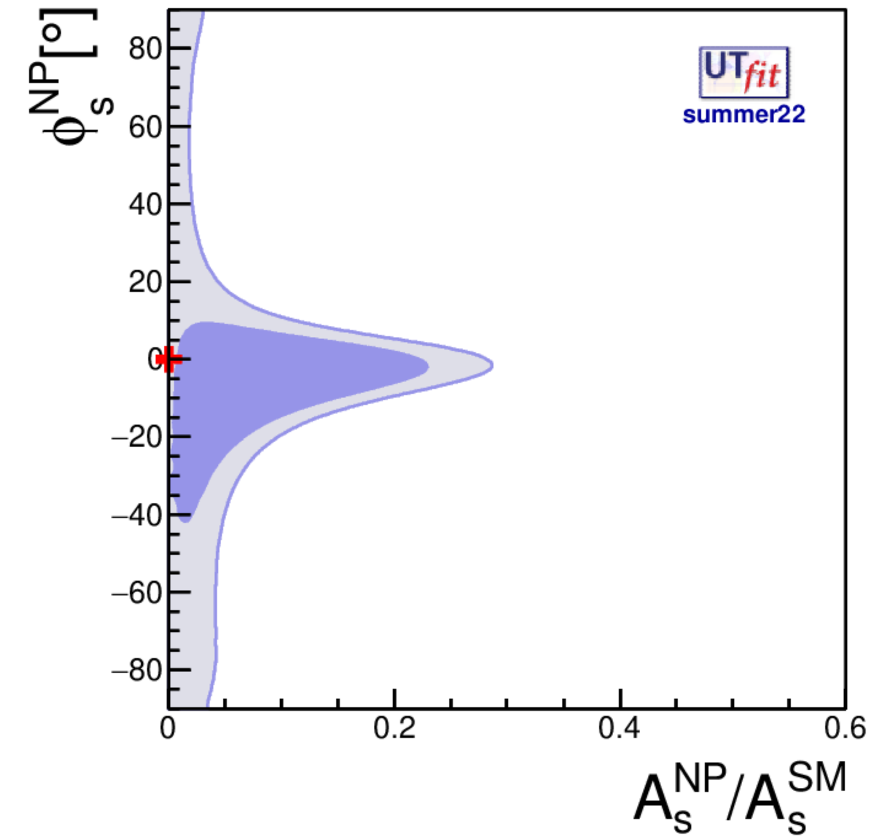




$C_{Bd}$ = 1.14 ± 0.11, $\phi_{Bd}$ = (-3.4 ± 2.0)°, $C_{Bs}$ = 1.14 ± 0.08, $\phi_{Bs}$ = (-0.3 ± 0.6)°

$C_{\varepsilon K}$ = 1.12 ± 0.12

# Results on NP Parameters

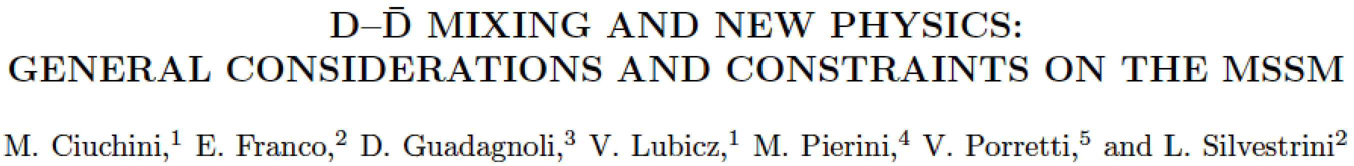



Marginalizing on the phase: $A_{NP}{}^{d}/A_{SM}{}^{d} < 35\%$ and $A_{NP}{}^{s}/A_{SM}{}^{s} < 30\%$ at 95% probability

# $D$-$\bar{D}$ Mixing

- D mixing is not calculable in the SM, but nevertheless strongly constrains NP, since CP violation in the SM is expected to be very small


D–D̄ MIXING AND NEW PHYSICS:
GENERAL CONSIDERATIONS AND CONSTRAINTS ON THE MSSM

M. Ciuchini,[1] E. Franco,[2] D. Guadagnoli,[3] V. Lubicz,[1] M. Pierini,[4] V. Porretti,[5] and L. Silvestrini[2]

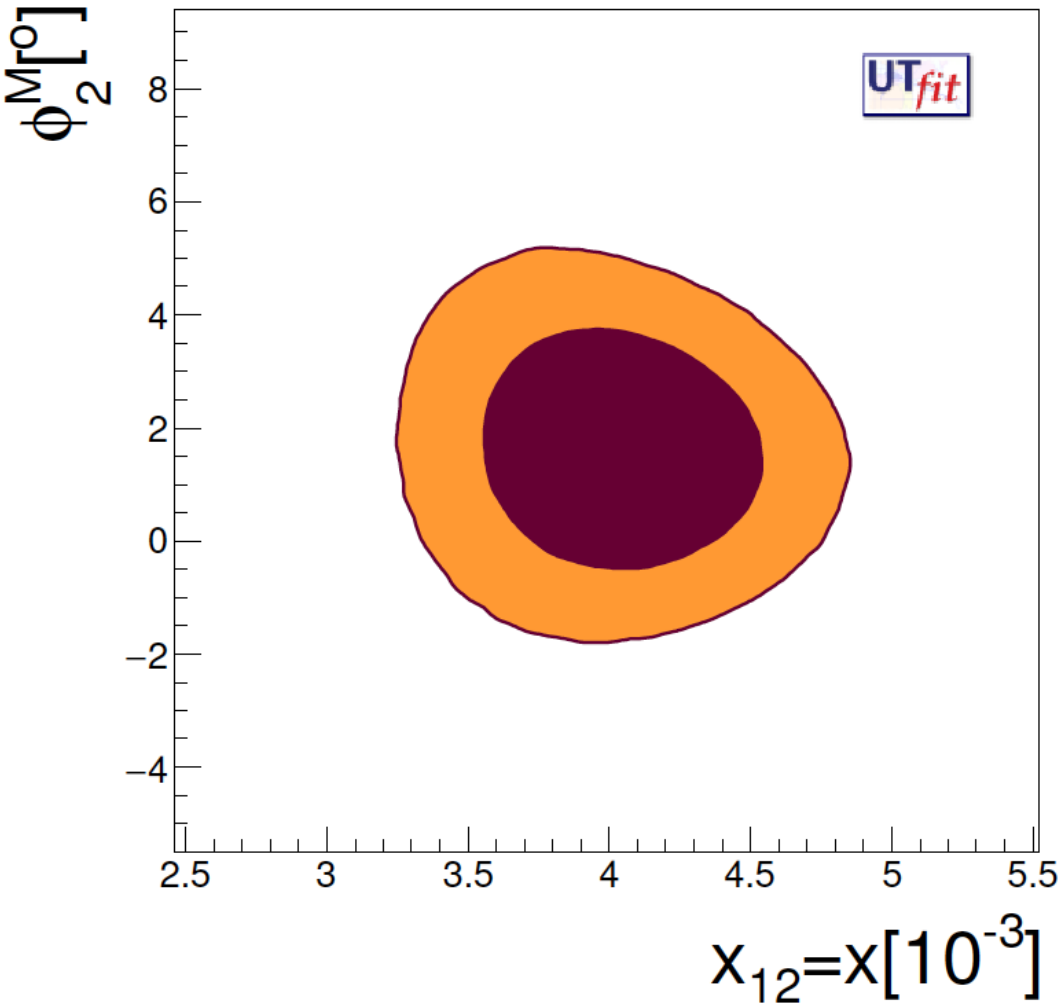
2007

- the first of a series of papers on the combination of exp data on D mixing in the SM and beyond

# “REAL SM” APPROXIMATION

- In the SM, imaginary parts suppressed by tiny CKM factor $r=6.5\ 10^{-4}$
- Given present experimental errors, it is perfectly adequate to assume that SM contributions to $M_{12}$ and $\Gamma_{12}$ are real
- All decay amplitudes relevant for D mixing can also be taken real
- NP could generate a nonvanishing phase for $M_{12}$

# D Mixing Today



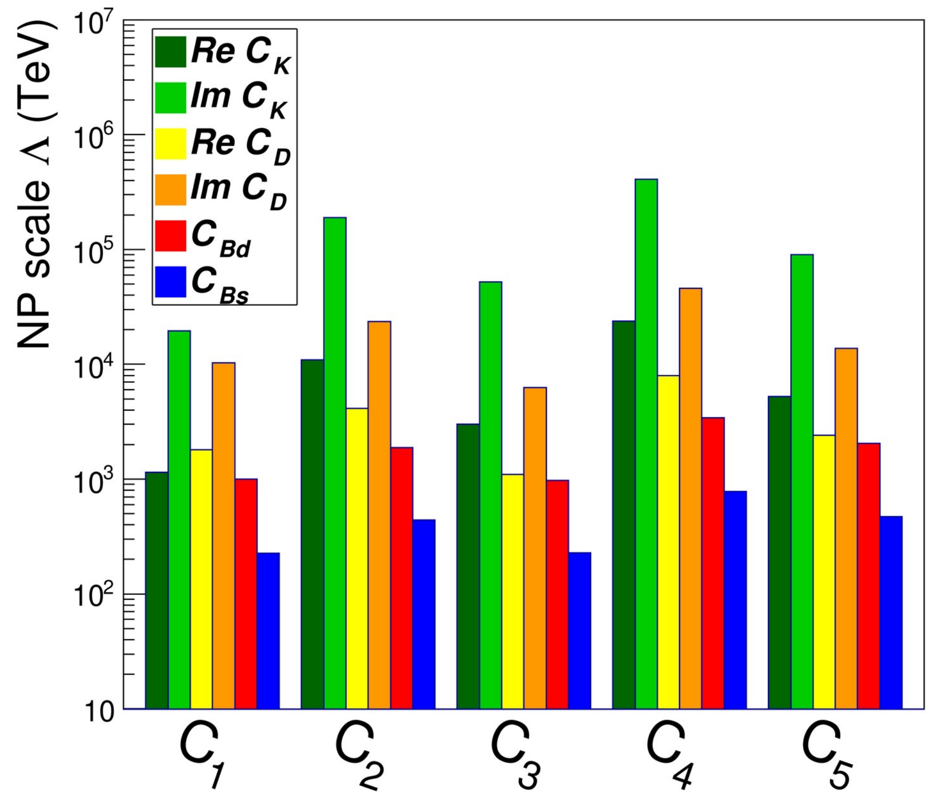

From R. Di Palma's thesis

# FROM ΔF=2 TO THE NP SCALE

- $H_{eff}^{\Delta F=2} = \sum_{i=1}^{5} C_i\, O_i + \sum_{i=1}^{3} C_i'\, O_i'$
- In the SM only $O_1$ (V-A)
- Operators with i>1 are RG- and chirally-enhanced
- In general, $C_i \sim F_i L_i / \Lambda^2$
- Take $L_i$=1 and $F_i$ = 1 (generic) or $F_i \sim F_1^{SM}$ (next-to-minimal flavour violation)

# GENERIC STRONGLY-INTERACTING NP

- Best bound from $\varepsilon_K$, dominated by CKM error
- CPV in charm mixing follows, exp error dominant
- $B_d$ and $B_s$ behind, error from both CKM and B-params
- Non-perturbative NP:
  - $L > 4\ 10^5$ TeV
- Weakly interacting:
  - $L > 10^4$ TeV



# Conclusions

- Enrico gave crucial contributions to the development of the UTA and to the study of NP in $\Delta F=2$ processes
- Collaborating with him (on those and on several other topics) was a big privilege and an even bigger pleasure for me
- I sorely miss discussing physics at the blackboard and writing code with Enrico, as much as I miss the conversations at lunch and at the coffee machine, when Enrico with his universal culture would kindly explain to me how things worked in any field