CKM fits and new physics in B–$\bar{B}$ mixing

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based mainly on: R. Fleisher, G. I., J. Matias *hep−ph/0302229*
G. D'Ambrosio & G. I. *Phys. Lett. B 530 (2002) 108*

- Introduction
- The Unitarity Triangle with a non–standard B–$\bar{B}$ mixing
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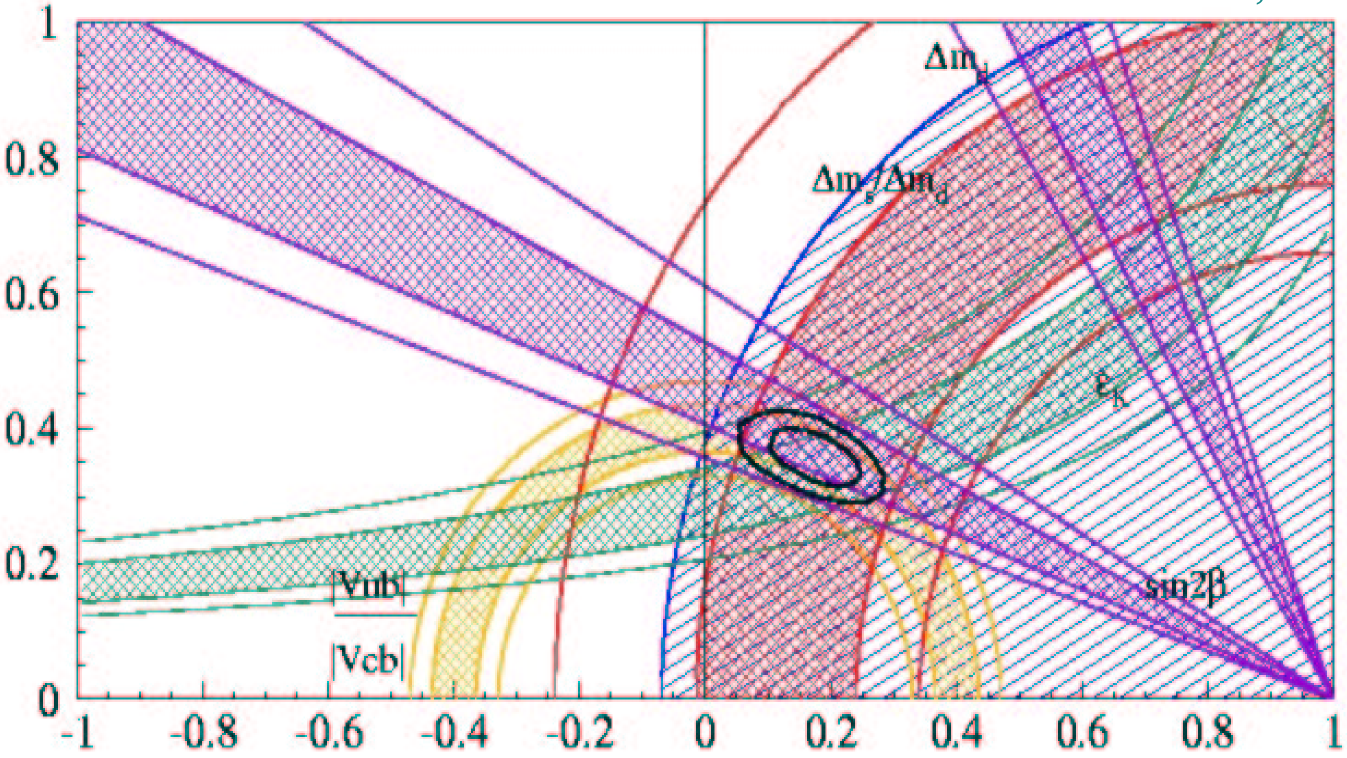
Introduction

Recent precise measurements of flavour–changing transitions (especially in the *B* sector) show a good consistency with the expectations of the CKM mechanism:



A. Stocchi, ’03

⇐ *Standard UT fits* shows that large new–physics contributions are not *needed* to explain the data...

...however this is not the complete answer to the following question:

Is there still room for possible large new−physics contributions in flavour dynamics?

To answer this question we shall first address the following points:

- Which are the observables in the flavour sector most sensitive to NP?
- Can we determine the CKM structure ignoring these obs.?
- Are we using all the available exp. data in the *standard UT fits*?
- How large is the parameter space then left for NP effects?

To answer this question we shall first address the following points:

Which are the observables in the flavour sector most sensitive to NP?	B–$\bar{B}$ mix. and, more in general, $\Delta F=2$ ampl. are the most natural candidates
Can we determine the CKM structure ignoring these obs.?	Yes: it is possible, but with less precision
Are we using all the available exp. data in the *standard UT fits*?	No: *rare decays* and charmless non−leptonic B decays are usually ignored
How large is the parameter space then left for NP effects?	It is quite small, but it has a rather interesting structure...

The Unitarity Triangle with a non–standard B–$\bar{B}$ mixing

If we allow generic $O(1)$ new contributions to B–$\bar{B}$ mixing...

$$A(B \to \bar{B}) \propto \Delta M_{B_d}\, e^{-i\phi_d} \propto (V_{td})^2 + \Delta$$

contrib. of a generic $(\bar{b}d)^2$ operator

SM term

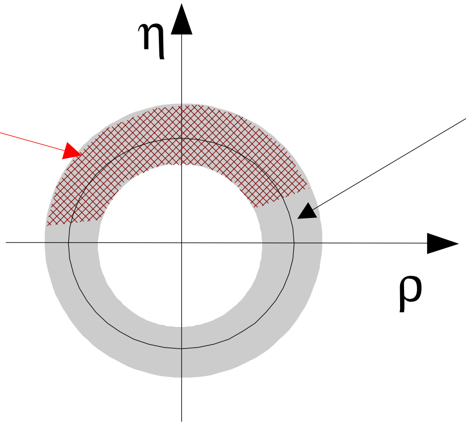
...we loose the UT constraints *both* from ΔM_{B_d} and from $A_{CP}(B \to \psi K_S)$

$$\Delta M_{B_d} \propto \left| (V_{td})^2 + \Delta \right|$$

$$A_{CP}(B \to \psi K_S) \overset{\text{def}}{=} -\sin(\phi_d) = -\sin(2\beta + \phi_N)$$

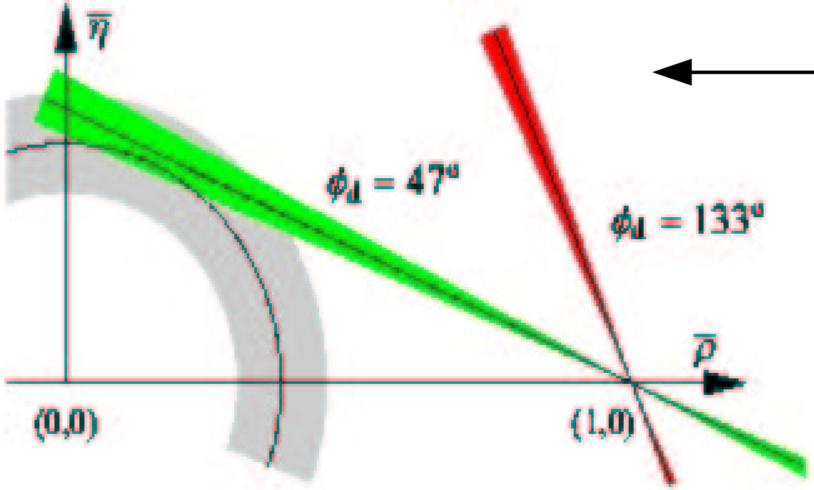
There is a large range of values for Re(Δ) and Im(Δ) which satisfy these two (experimental) conditions

region favored by the SM interpretation of ϵ_K



constraint from $b \to u$ semileptonic decays [tree–level SM amplitude]: very stable with respect to NP

N.B.: The experimental measurement of $A_{CP}(B \rightarrow \psi K_S)$ let us to fix the $\Delta B=2$ mixing phase (ϕ_d) up to a twofold ambiguity: $(\phi_d)^{\text{exp}} \approx 47^{\text{o}}$ or 133^{o}



The *standard* interpretation [$\phi_d=2\beta$] of the second solution is clearly inconsistent with the $|V_{ub}|$ circle

This solution make sense only in presence of NP, when $\phi_d=2\beta+\phi_N$

but if $\phi_N \neq 0$ we cannot translate the measurement of ϕ_d into a constraint for β

The *standard* plot of the ≈ 133^{o} solution is totally misleading!

If we wish to put some additional bound on the NP phase ϕ_{N} we need extra constraints (independent from B–$\bar{B}$ mixing) on the angles of the UT

Several strategies have been proposed in the literature, but most of them are not particularly useful at the moment, e.g.:

- determination of γ by means of $\Gamma(B \to K\pi)$
  good exp. data, but large th. uncertainties
- determination of γ by means of $A_{CP}(B \to D+X)$
  th. clean, but very difficult from the exp. side

In the following I shall concentrate on two (very different) class of observabels:

- time–dependent CP asymmetries in $B \to \pi^+\pi^-$
  precise data expected soon, partial th. control of the *penguin pollution* by means of $B \to K\pi$ [Fleischer & Matias, ’02]
- the rate of the rare decay $K^+ \to \pi^+\nu\nu$
  th. very clean, slow but significant exp. progress in 2002

New–physics in B–$\bar{B}$ mixing vs. new–physics in ΔF=1 transitions

Both $K\to\pi\nu\nu$ and $B\to\pi\pi$ transitions are not (pure) tree–level decays:

to which extent can we use their SM expressions to determine the CKM structure if we assume large NP effects in ΔB=2 (ΔF=2) amplitudes?

NP effects in ΔF=1 FCNC amplitudes turn out to be very suppressed −with respect to the SM term − under two very <u>general</u> and <u>natural</u> conditions:

- *the effective NP scale is substantially higher that the e.w. scale*
- *the new effective flavour–changing coupling ruling ΔF=2 transitions can be expressed as the square of two ΔF=1 couplings*

$$Q^{NP}_{\Delta B=2}=\frac{\delta^2_{bd}}{\Lambda^2_{eff}}(\bar{b}\,\Gamma\,d)^2 \qquad Q^{NP}_{\Delta B=1}=\frac{\delta_{bd}}{\Lambda^2_{eff}}(\bar{b}\,\Gamma\,d)\,\bar{f}\,\Gamma\,f$$

normaliz. of the operators such that →

$$Q^{SM}_{\Delta B=2}=\frac{(V^*_{tb}V_{td})^2}{M^2_W}(\bar{b}\,\Gamma\,d)^2 \qquad Q^{SM}_{\Delta B=1}=C\,\frac{(V^*_{tb}V_{td})}{M^2_W}(\bar{b}\,\Gamma\,d)\,\bar{f}\,\Gamma\,f$$

$\Lambda_{eff}\gg M_W$

→ $C\gg1$ for QCD penguins

These conditions, which are satisfied in several specific frameworks,

low–energy SUSY with large LL and/or RR mixing terms and small LR terms
models with a new flavour−changing Z'
models with vector−like quarks
⋮

leads to the following general dimensional argument:

$$\boxed{\frac{\left\langle Q^{NP}_{\Delta B=2}\right\rangle}{\left\langle Q^{SM}_{\Delta B=2}\right\rangle} \sim 1 \quad \Rightarrow \quad \frac{\left\langle Q^{NP}_{\Delta B=1}\right\rangle}{\left\langle Q^{SM}_{\Delta B=1}\right\rangle} \sim \frac{1}{C}\,\frac{M_W}{\Lambda_{eff}} \ll 1}$$

This generic inequality can be evaded under specific circumstances

[fine−tuning cancellations of different terms, large hierarchies of matrix elements,...]

but it is clearly the most natural possibility:

the generic scenario with $O(1)$ modifications in $\Delta B=2$ amplitudes and negligible ($<$ 10%) effects in $\Delta F=1$ amplitudes is certainly worth to be investigate in detail

The role of $B \to \pi^+\pi^-$ CP asymmetries

Neglecting $\Delta B=1$
NP contributions: $A(B \to \pi^+\pi^-) \propto e^{i\gamma} - d e^{i\theta}$

QCD *penguin pollution*
[θ=strong phase]

tree−level $b \to u \bar{u} d$
amplitude

$d=0$

$$A_{CP}(B \to \pi^+\pi^-)^{\mathrm{mix}} = \sin(\phi_d+2\gamma) \overset{\mathrm{SM}}{=} -\sin(2\alpha) \qquad A_{CP}(B \to \pi^+\pi^-)^{\mathrm{dir}} = 0$$

using the (exp.) value of ϕ_d from $A_{CP}(B\to\psi K_S)^{\mathrm{mix}}$ we extract an info on γ independent of possible NP in $\Delta B=2$

different from zero only if $\theta \neq 0$
[model−independent constraint
on θ in terms of γ and d]

In the general case ($d \neq 0$) we can extract γ if we complement the two asymmetries with a theoretical estimate of d

→

A phenomenological estimate of d can be obtained by means of SU(3) relations from $B \to K^{\pm}\pi^{\mp}$ rates

[Fleischer & Matias, ’02]

If $B \to \pi^+\pi^-$ CP asymmetries turn out to be large, this procedure is very stable with respect to possible th. errors [much better than bounds on γ based on $B \to K\pi$ rates only] and preliminary results by Babar and Belle certainly do not exclude this possibility:

naïve average of Babar & Belle:

$$\boxed{\begin{aligned} A_{CP}(B \to \pi^+\pi^-)^{\text{mix}} &= +0.49 \pm 0.27 \\ A_{CP}(B \to \pi^+\pi^-)^{\text{dir}} &= -0.51 \pm 0.19 \end{aligned}}$$

not to be taken seriously
[bad consistency]...

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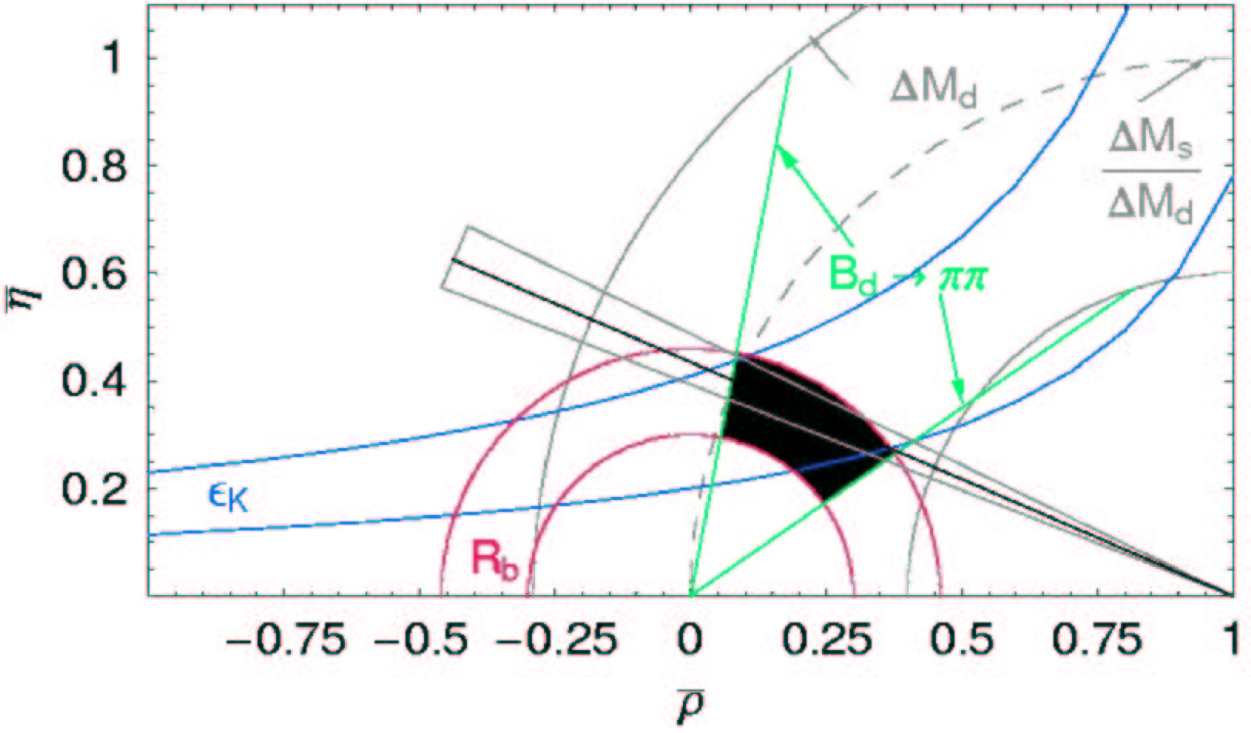
...but too nice to be completely ignored!

1−σ bounds on γ for the standard solution $\phi_d \approx 47^{\mathrm{o}}$

[consitency of the SM case]



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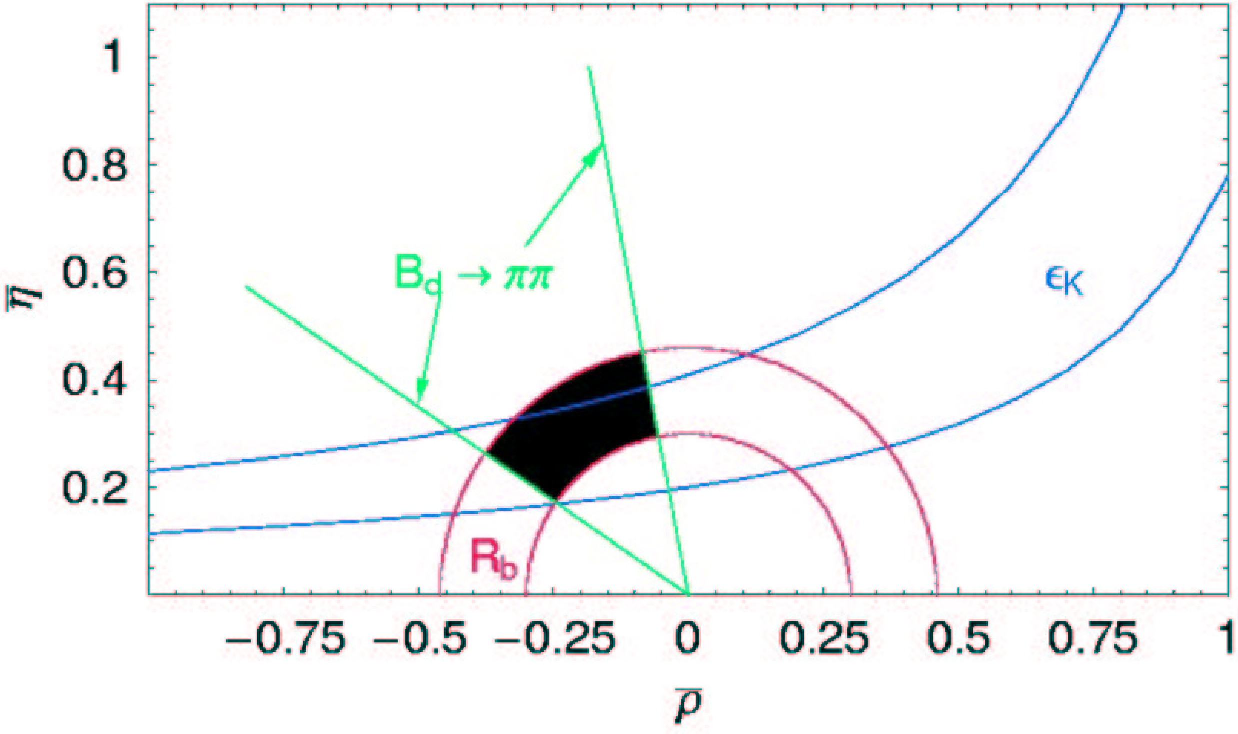
[Fleischer, G.I., Matias, ’03]

1–σ bounds on γ
for the non–standard
solution $\phi_d \approx 133^o$

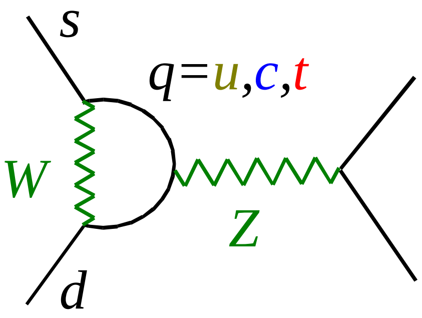
[without further inputs,
the consistency of this
solution is completely
equivalent to the one of
the standard case]



Implications for rare decays

Rare transitions of the type $s,b \to d + \nu\nu(ll)$ are ideal probes to measure $|V_{td}|$

$\Rightarrow$ most clean observables: $BR(K^+ \to \pi^+\nu\nu)$ & $BR(B_d \to \mu^+\mu^-)$



$$+\ box \Rightarrow A_q \sim m_q^2 \underbrace{V_{qs}^* V_{qd}}_{\lambda_q} \sim \left[\begin{array}{ll} \Lambda_{QCD}^2 \lambda & (u) \\ m_c^2 \lambda + i\, m_c^2 \lambda^5 & (c) \\ m_t^2 \lambda^5 + i\, m_t^2 \lambda^5 & (t) \end{array} \right.$$

$[\lambda = \sin\theta_c]$

- genuine $O(G_F^2)$ transition dominated by short–distances
- hadronic matrix element determined by K_{l3} data

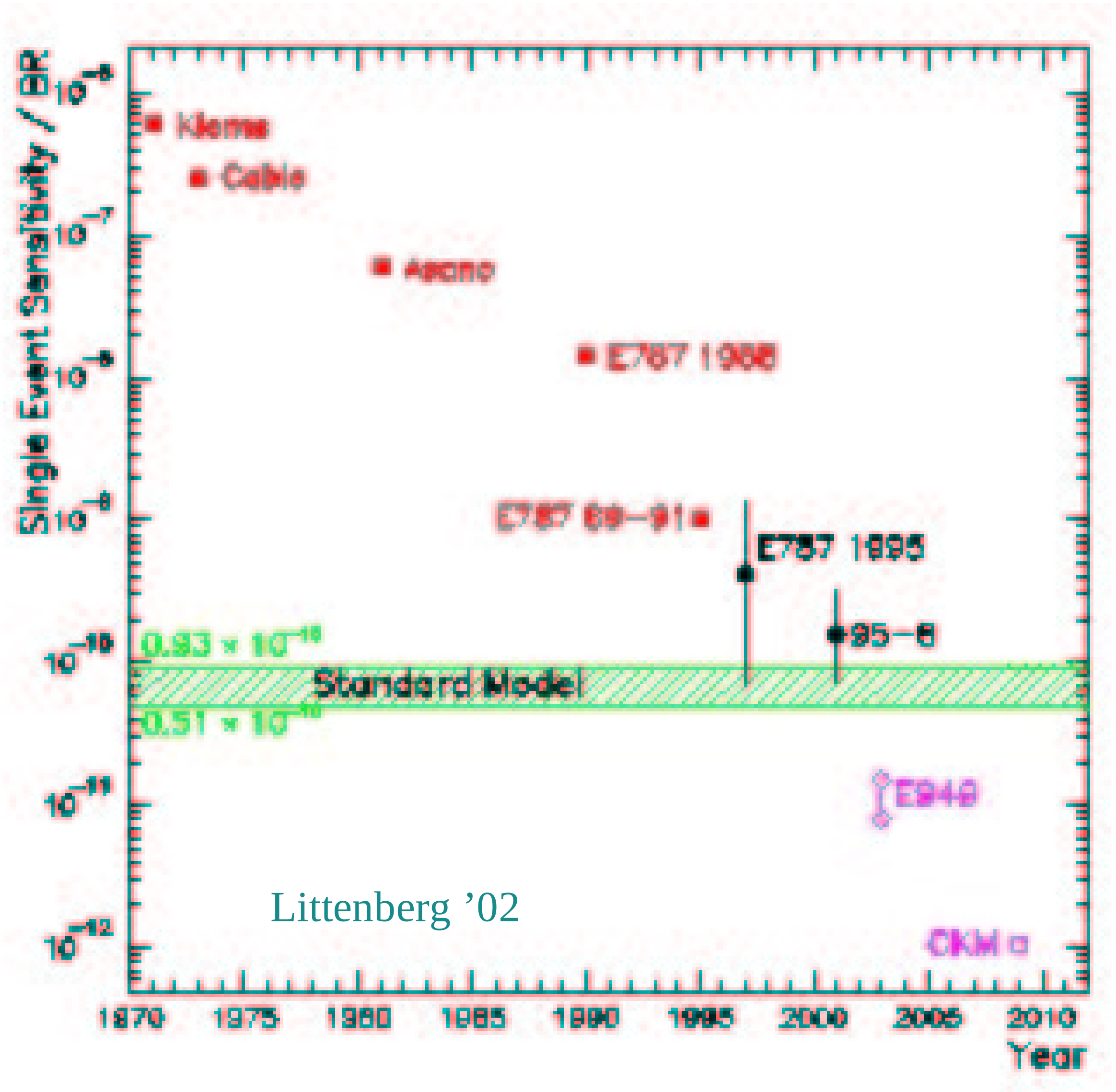
$$\boxed{BR(K^+)^{(SM)} = C\, |V_{cb}|^4 \,[(\bar{\rho} - \rho_c)^2 + (\sigma \bar{\eta})^2] = (7.2 \pm 2.0) \times 10^{-11}}$$

Irreducible th. error due to the charm contribution δ(B.R.) ~ 8%

$\rho_c = 1.40 \pm 0.06$

present range determined by present uncertainty on CKM parameters

Status & future prospects of the *BR*($K^+ \to \pi^+ \nu\nu$) measurement:



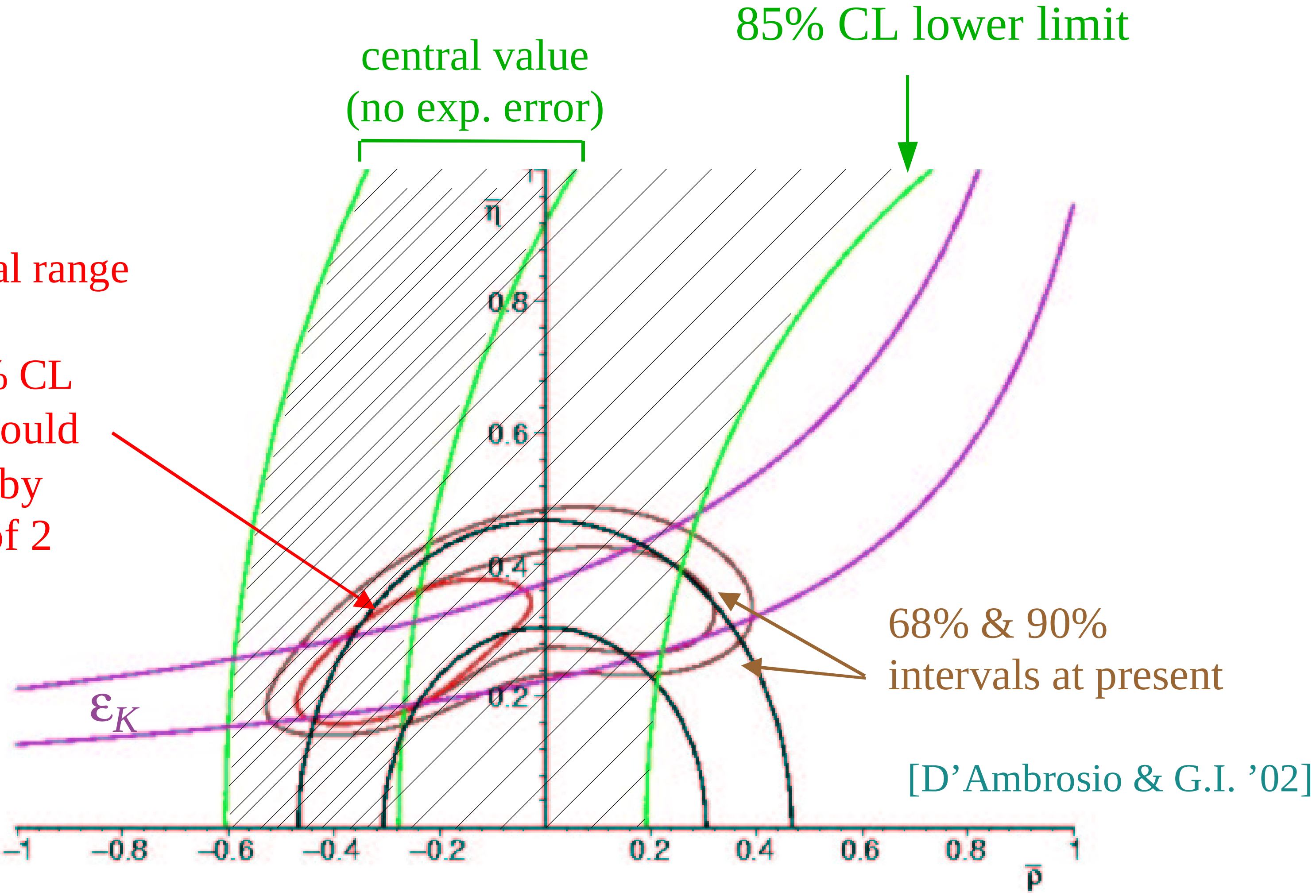
Littenberg '02

$$BR(K^+ \to \pi^+ \nu \bar{\nu}) = \left(1.57 \,{}^{+1.75}_{-0.82}\right) \times 10^{-10}$$

- 2 events observed at BNL–E787 (0.15 bkg)
- central value 2×SM !
- Experimental apparatus upgraded to increase the sensitivity (E949: 10–20 events in 2 yrs)...

...but no running time scheduled in 2003.

Impact of $BR(K^+ \to \pi^+ \nu\nu)$ on the UT [fit without ΔB=2 constraints]:



[D'Ambrosio & G.I. '02]

The statistical significance in favour of the non−standard solution is still not very high, but it is enough to conclude that we should not disregard it yet...!

Conclusions

- *Standard CKM fits* provide a useful tool to check the consistency of the SM, but they are not the best tool to investigate non–standard scenarios
  ⇒ underestimate of the NP parameter space

- B–$\bar{B}$ mixing has a *dark–side* [the $\phi_d \approx 133^o$ solution] which need to be further investigated [this is still the most natural place to look large NP effects !]
  ⇒ better data on $A_{CP}(B \to \pi^+\pi^-)$ and a direct measurement of $\cos(\phi_d)$
  would be very useful in this respect

- The information on flavour mixing obtained from $BR(K^+ \to \pi^+ \nu\nu)$ is so clean and important that it would be a big pity not to continue/plan dedicated experiment to improve it