B Physics at Super-High Luminosity
A New Physics Story

Marco Ciuchini
INFN Roma III

1 Flavour new physics story just began

2 Present and future (!) bounds on NP

3 What kind of NP do present bounds point to?

  a Minimal Flavour Violation

  b New Flavour and CPV in 3 $\rightarrow$ 2 transitions

   - The SUSY case
   - The SUSY-GUT case

thanks to M. Pierini
and L. Silvestrini

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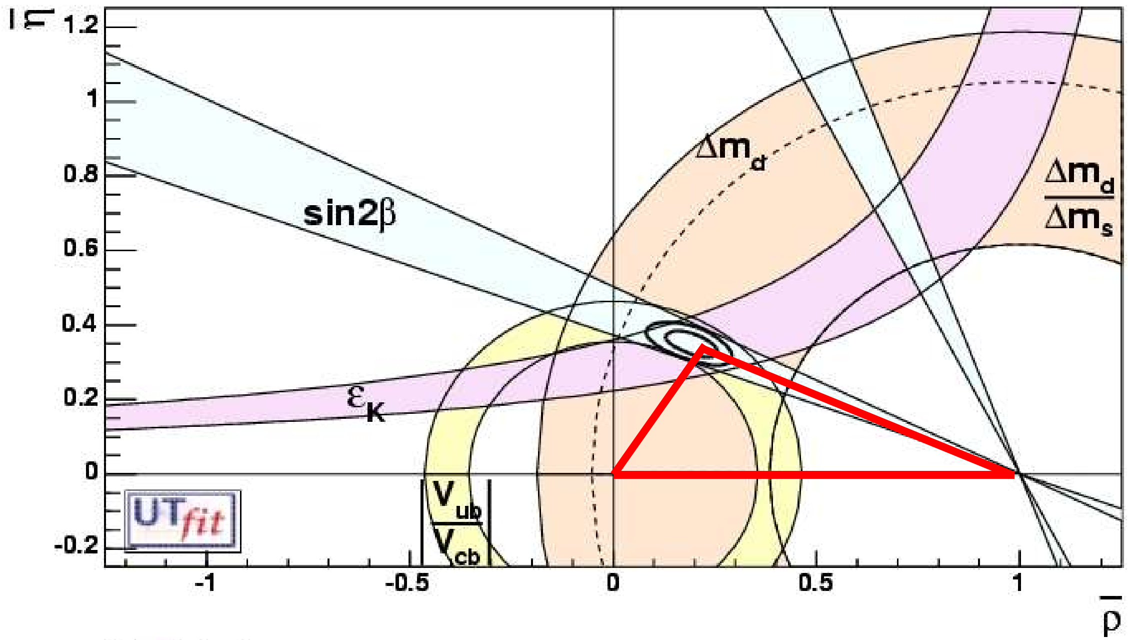
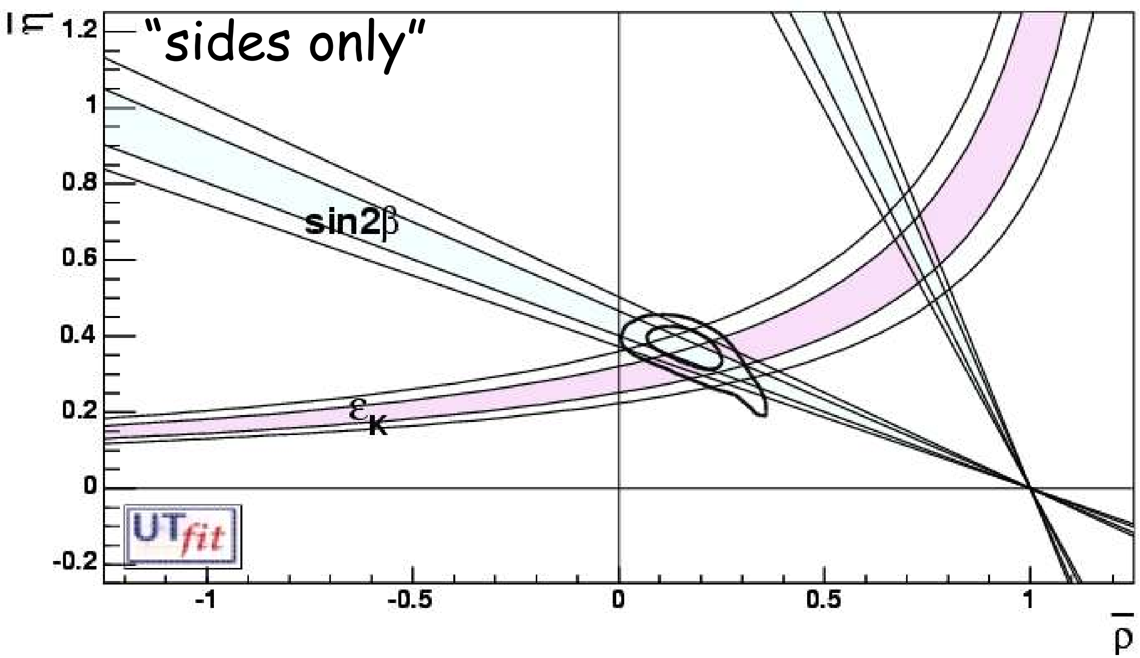
The old story ended...

$$\bar{\rho} = 0.190 \pm 0.044$$
$$[0.100,\ 0.271] @ 95\%$$

$$\bar{\eta} = 0.349 \pm 0.024$$
$$[0.303,\ 0.396] @ 95\%$$

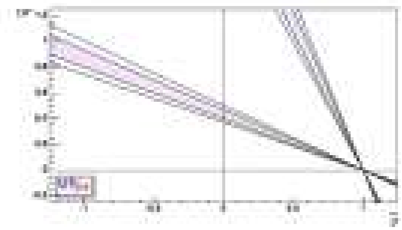
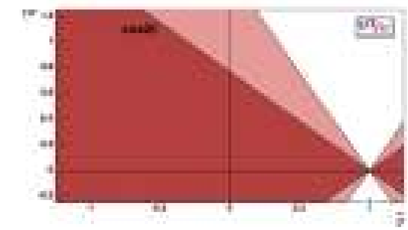
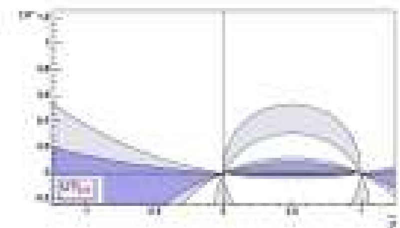
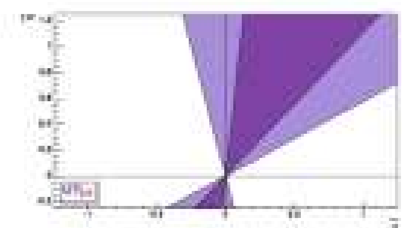
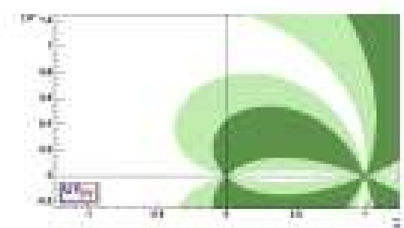
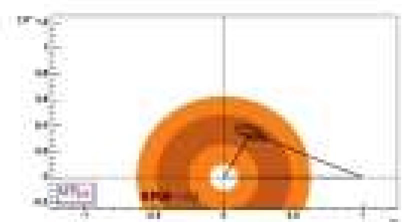
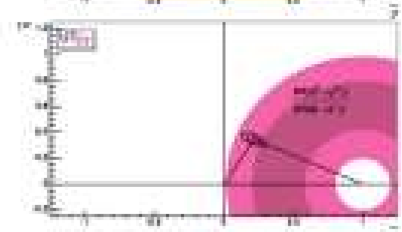




- Spectacular agreement between direct and indirect measurements

$$(\sin 2\beta)_{\text{sides}} = 0.732 \pm 0.044$$
$$(\sin 2\beta)_{\text{ind}} = 0.729 \pm 0.042$$
$$(\sin 2\beta)_{\text{dir}} = 0.725 \pm 0.037$$
$$\sin 2\beta = 0.728 \pm 0.028$$

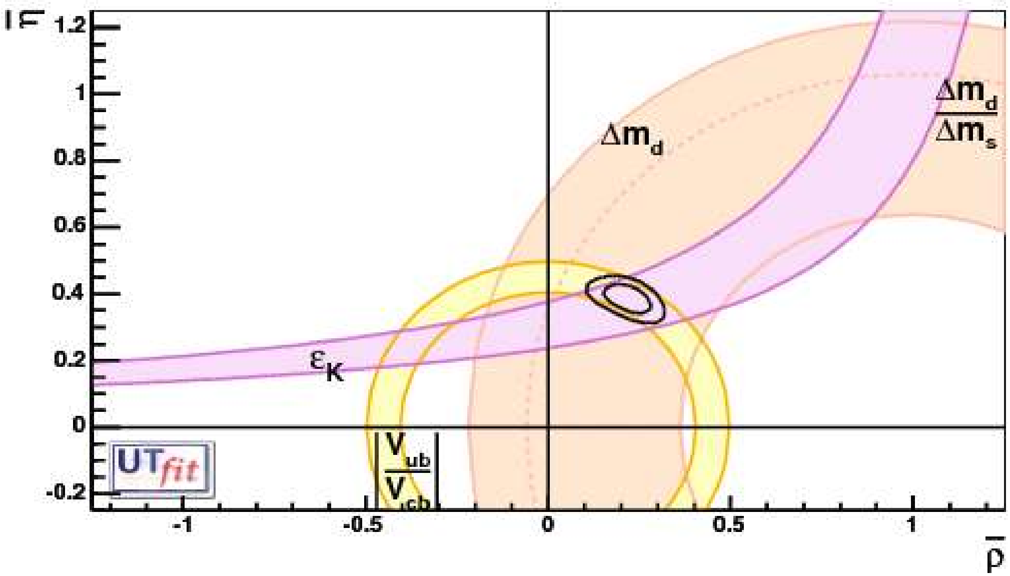
The UT in the late B-factory era

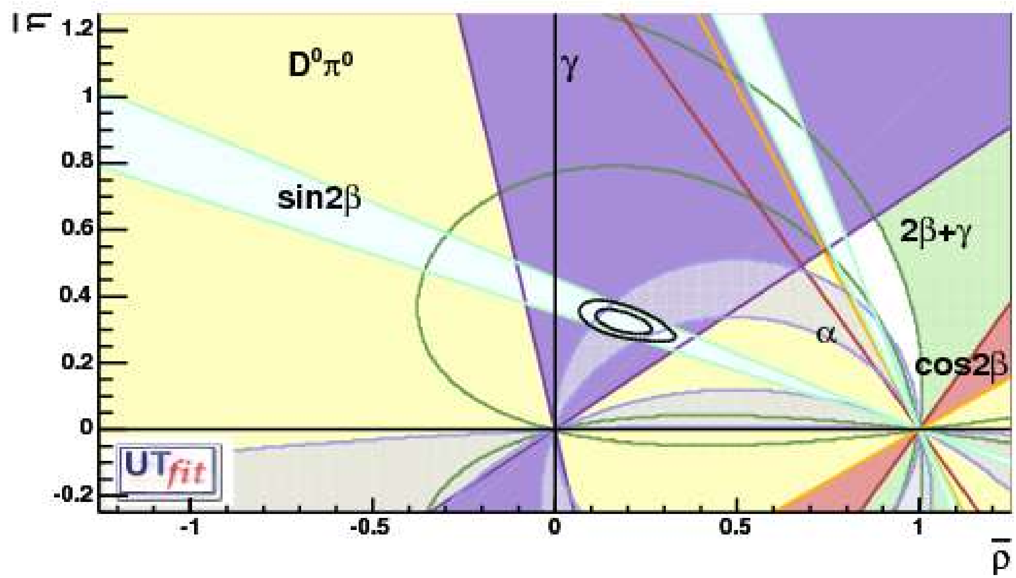
$A_{CP}(b\to c\bar{c}s)$ $(J/\psi\ K, \ldots)$	$\sin 2\beta$, $\cos 2\beta$	 
$A_{CP}(b\to s\bar{s}s,\ d\bar{d}s)$ $(\phi\ K, \pi K, \ldots)$	$\sin 2\beta$	
$A_{CP}(b\to d\bar{d}d,\ u\bar{u}d)$ $(\pi\pi, \rho\rho, \ldots)$	$\sin 2\alpha$	
$BR(b\to c\bar{u}d,\ c\bar{u}s)$ $(DK, \ldots)$	γ, $\sin(2\beta+\gamma)$	 
$BR(B\to\tau\nu)$	$\lvert V_{ub}\rvert$	
$BR(B\to\rho\gamma)/BR(B\to K^*\gamma)$	$\lvert V_{td}\rvert$	

2005: A new story begins

No angles:
$|V_{ub}/V_{cb}|$, Δm_d, ΔM_s, ε_K

Angles only:
$\sin 2\beta$, $\cos 2\beta$, $\sin 2\alpha$, γ





the parameter determination era ends

the precision test/new physics era begins

redundant constraints on the triangle and **test of new physics**

The New Physics Genome Project

The SM is an effective theory valid up to some scale Λ

$$\mathcal{L} = \mathcal{L}_{SM} + \Sigma_{k=1} C \cdot Q^{(k+4)}/\Lambda^k$$

- Gauge hierarchy problem: $\Lambda \sim 1$ TeV
- Flavour physics: $\Lambda \sim 100\text{-}1000$ TeV

"Tension" between new physics scales

The bright side

1. **New particles produced at the LHC cannot have "generic" flavour properties**

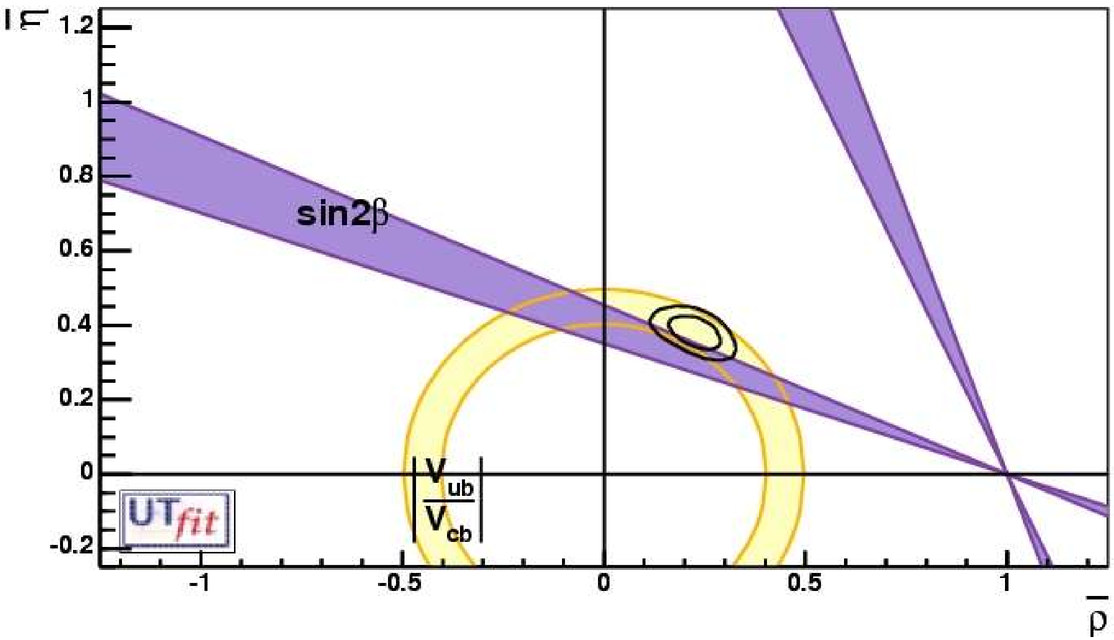
In a given NP framework, flavour- and CP-violating observables provide insights on the structure of NP (for ex.: Soft SUSY-breaking terms in the MSSM)

Complementary to NP searches at hadron colliders

2. **Large effects from NP in loops are possible and "generically" expected in untested sectors**

Flavour physics has a big potential for the indirect search of NP

Is the NP test already interesting?



Slight tension

between $|V_{ub}/V_{cb}|$ and sin2β

with the new measurements

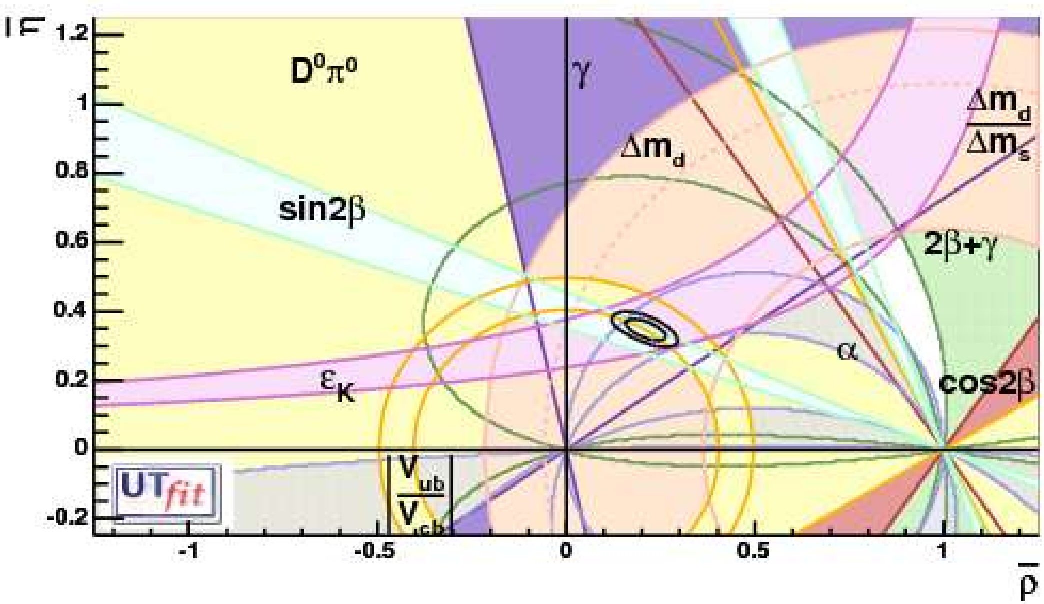
SM fluctuation or NP?

Need (much) more statistics

and

a careful assessment of

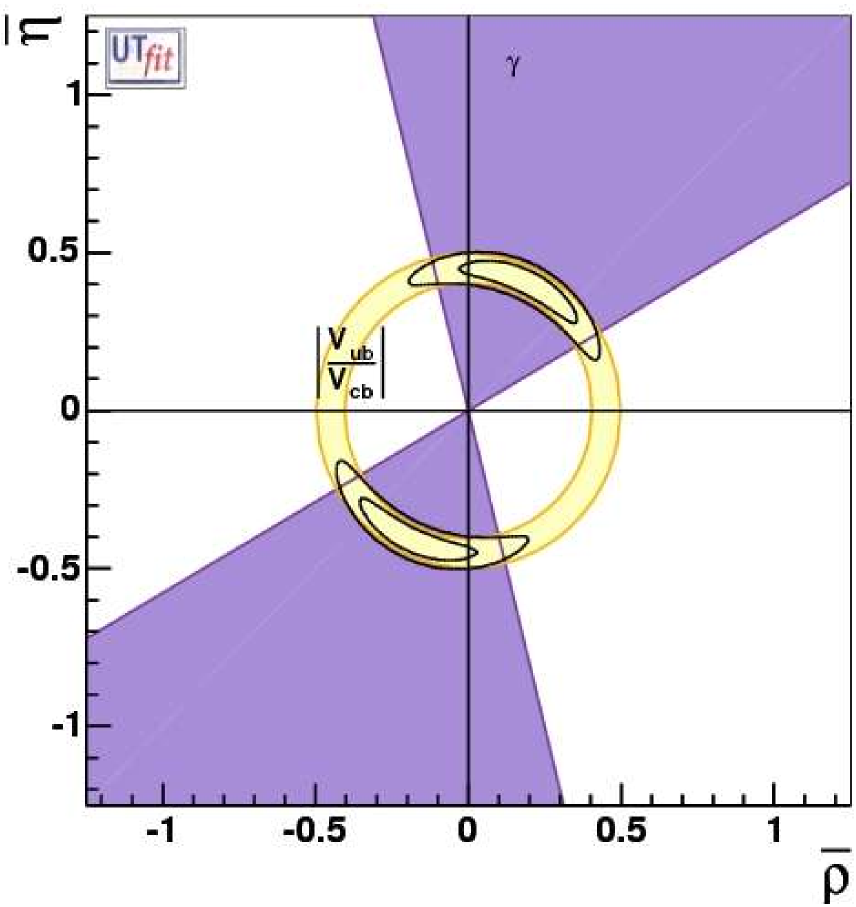
the uncertainties



Checking the Unitarity Clock now

Assumptions: (1) 3-generations unitarity
(2) no new physics in tree-level processes

Using only tree-level: γ and $|V_{ub}/V_{cb}|$. Results:



$\bar{\rho} = \pm 0.18 \pm 0.12$

$\bar{\eta} = \pm 0.41 \pm 0.05$

$\sin 2\beta = 0.782 \pm 0.065$
-0.641 ± 0.087

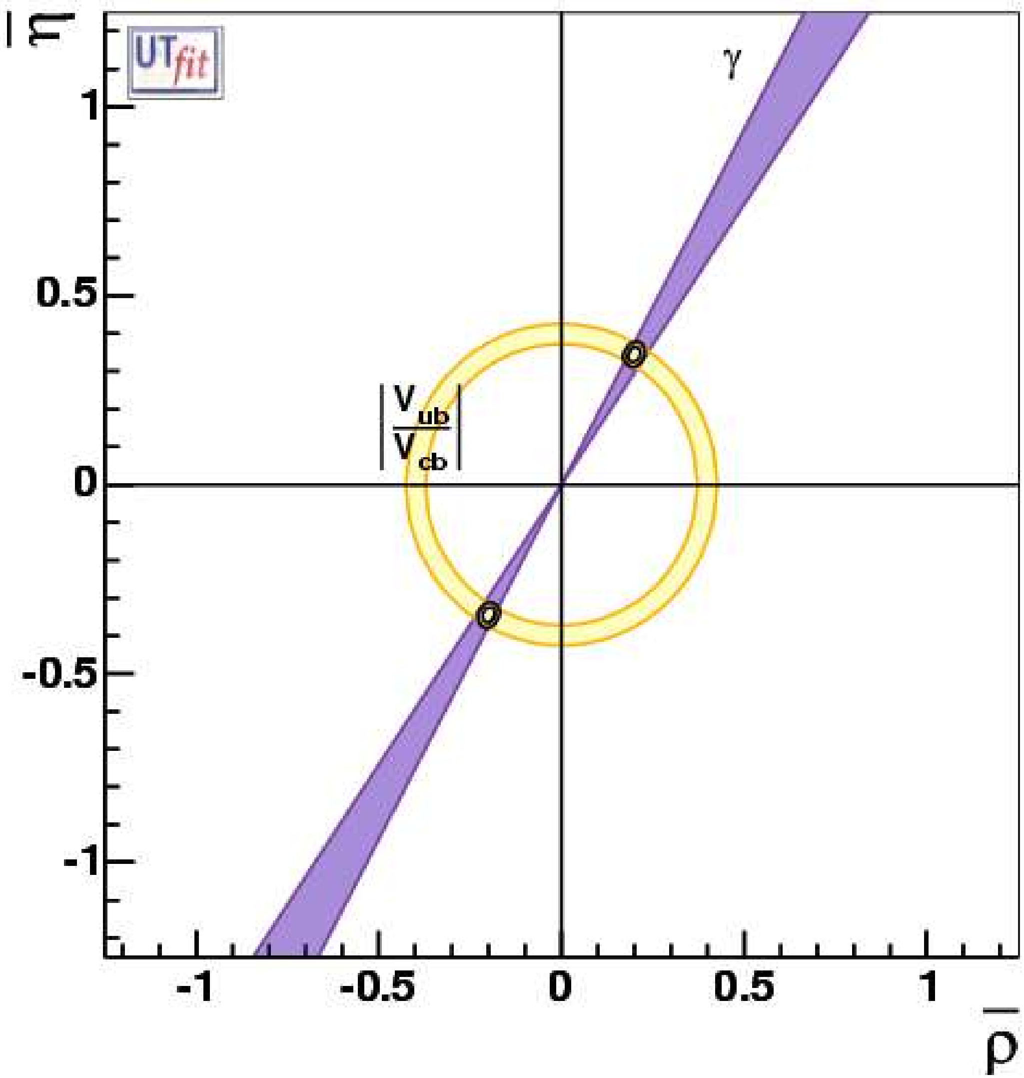
$\gamma = (65\pm18)^\circ \cup (-115\pm18)^\circ$

$\alpha = (87\pm15)^\circ \cup (-46\pm15)^\circ$

Any model of new physics must satisfy these constraints

UTfit coll., hep-ph/0501199;
Botella et al., hep-ph/0502133

Rechecking the Unitarity Clock in 10 years from now



$\gamma = (60.0 \pm 1.5)^\circ$

$|V_{cb}| = (41.7 \pm 0.4) \times 10^{-3}$

$|V_{ub}| = (3.74 \pm 0.12) \times 10^{-3}$

$\bar{\rho} = \pm 0.199 \pm 0.012$

$\bar{\eta} = \pm 0.345 \pm 0.013$

Amazing accuracy but clocks have always two hands

extrapolated experimental errors
from hep-ph/0503261
or naïve scaling

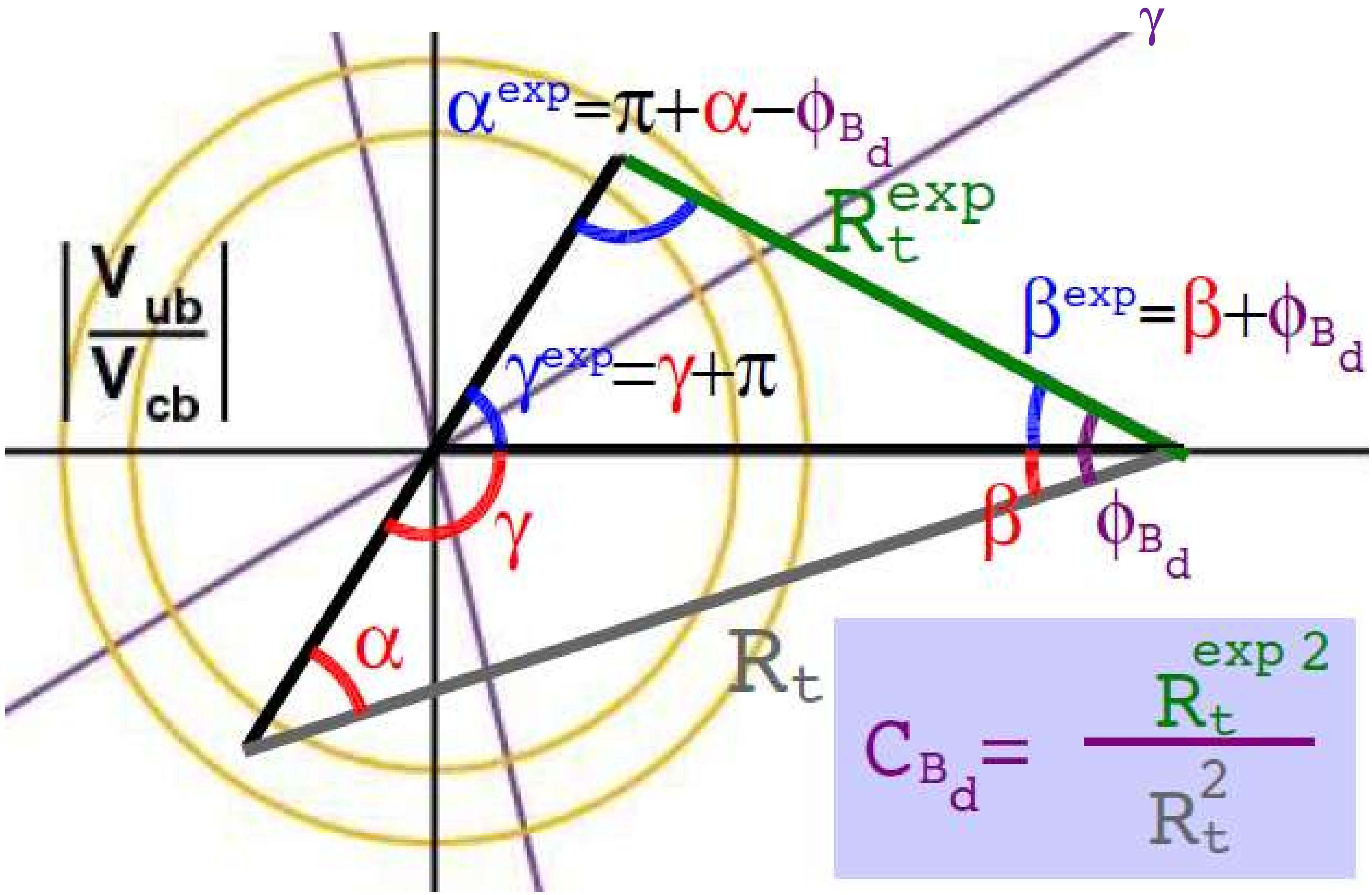
NP in the UT: The “Brute Force” Strategy

1. Add most general NP to all sectors
2. Use all available info
3. Constrain simultaneously ρ, η and the NP parameters

Only possible thanks to the new measurements of CKM angles!!!

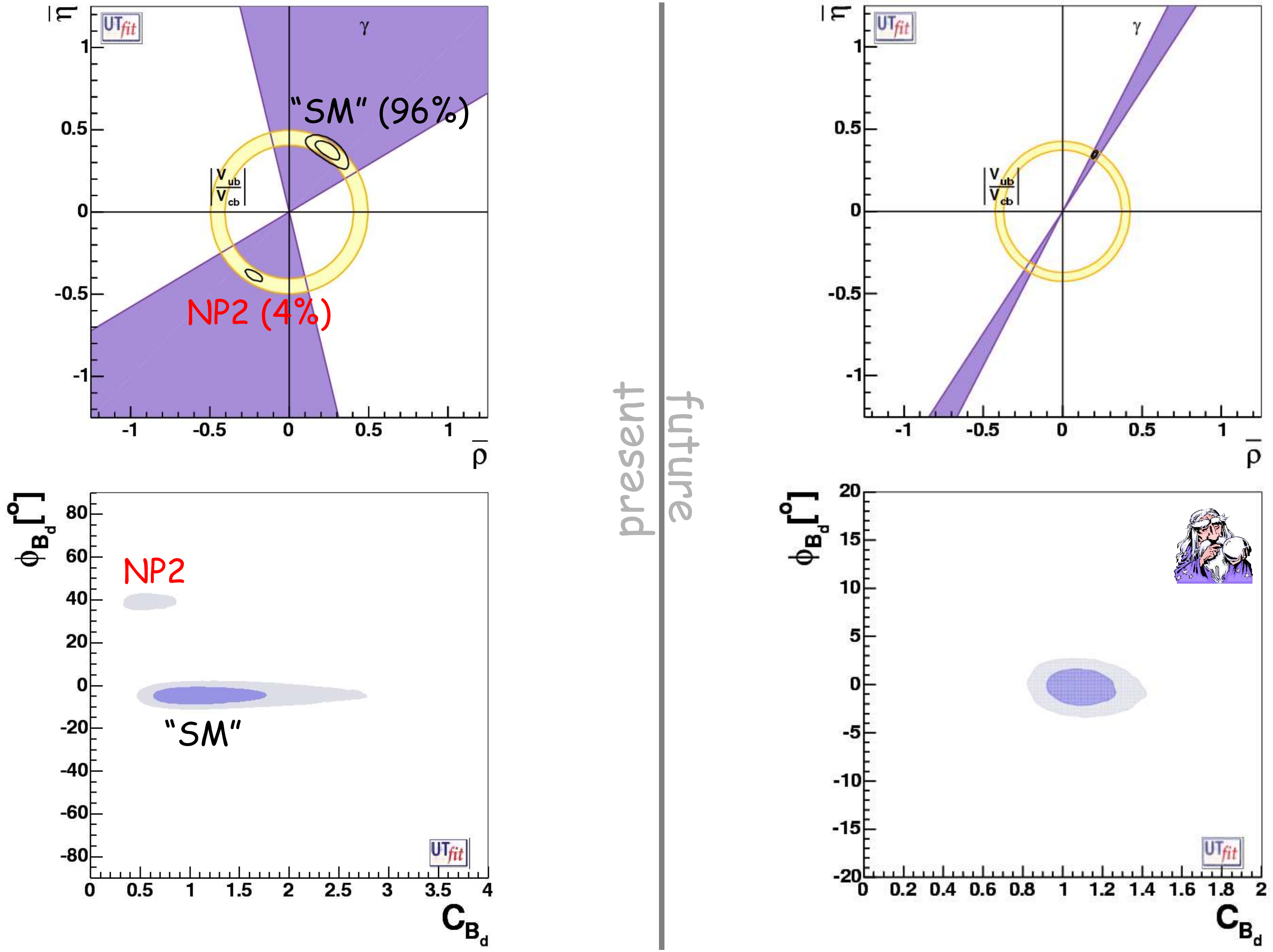
Botella et al., hep-ph/0502133; Agashe et al., hep-ph/0509117; UTfit coll., hep-ph/0509219.
Previous attempts: Ciuchini et al., hep-ph/0307195; CKMfitter group, hep-ph/0406184;
Ligeti, hep-ph/0408267.

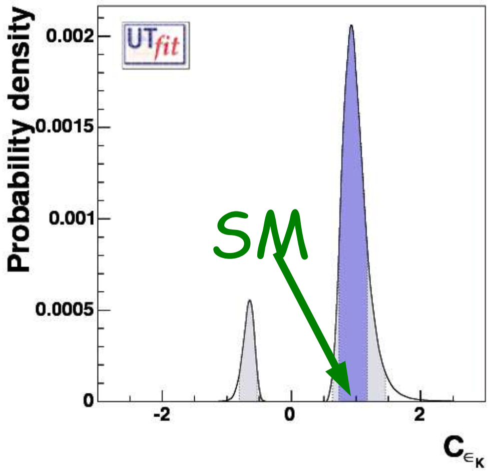
The UT with NP in b/s -> d transitions



$$C_{B_d} = \frac{R_t^{exp\,2}}{R_t^2}$$

Using: ε, Δm_d, $|V_{ub}/V_{cb}|$, $\sin 2\beta$, γ, α, β, A_{SL}

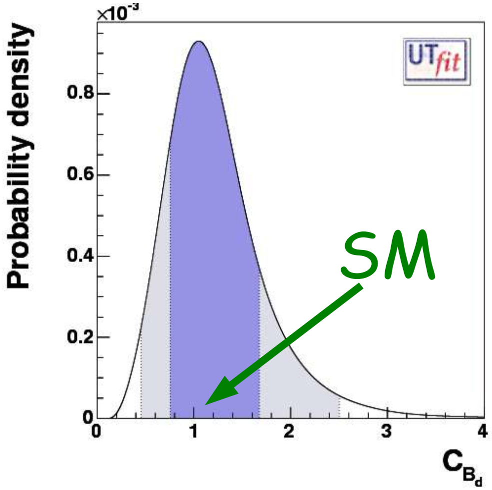




C_ε = 0.95±0.22

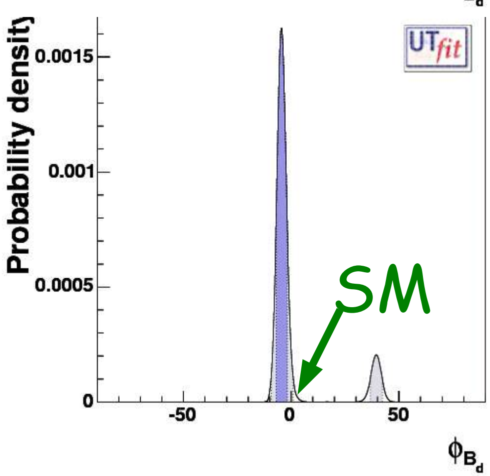
[-0.81,-0.53]

[0.64,1.45]



C_{Bd}= 1.21±0.46

[0.45,2.50]



ϕ_{Bd} [°]=-4.5±2.6

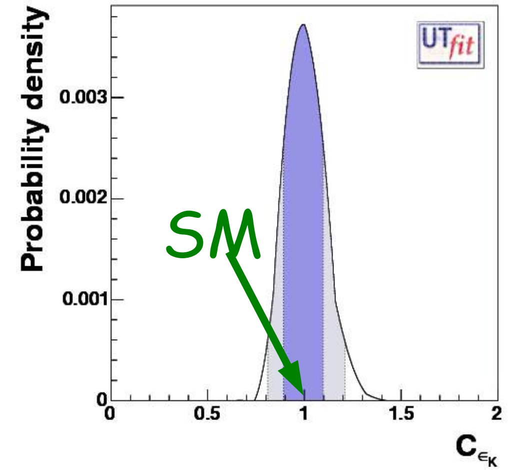
[-9.4,0.9]

[37,42]

present | future

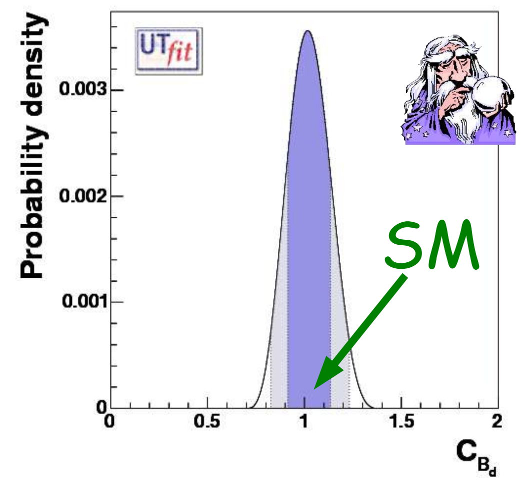
C_ε = 0.99±0.10

[0.81,1.21]



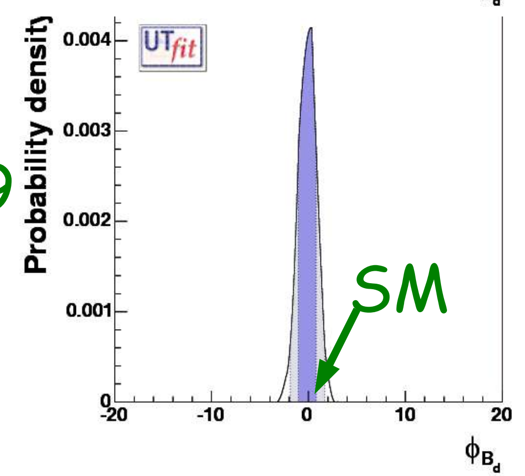
C_{Bd}= 1.02±0.11

[0.82,1.23]



ϕ_{Bd} [°]=-0.1±0.9

[-1.9,1.7]



Hints for Model Building

Two classes of NP models are suggested by the UT fit already at present:

1. Models with no new sources of flavour and CP violation
Minimal Flavour Violation (and variations)

2. Models with large new sources of flavour and CP violation confined to $b \to s$ transitions

1. Minimal Flavour Violation

Gabrielli, Giudice, NPB433
D'Ambrosio et al., NPB645

1) No new source of flavour and CP violation

NP contributions governed by SM Yukawa couplings

Ex.: Constrained MSSM (MSUGRA), Universal Extra Dim.

NP only modifies SM top contribution to FCNC & CPV

2a) One Higgs or small/moderate tanβ

No new operators

Full correlations among K and B decays

2b) Large tanβ

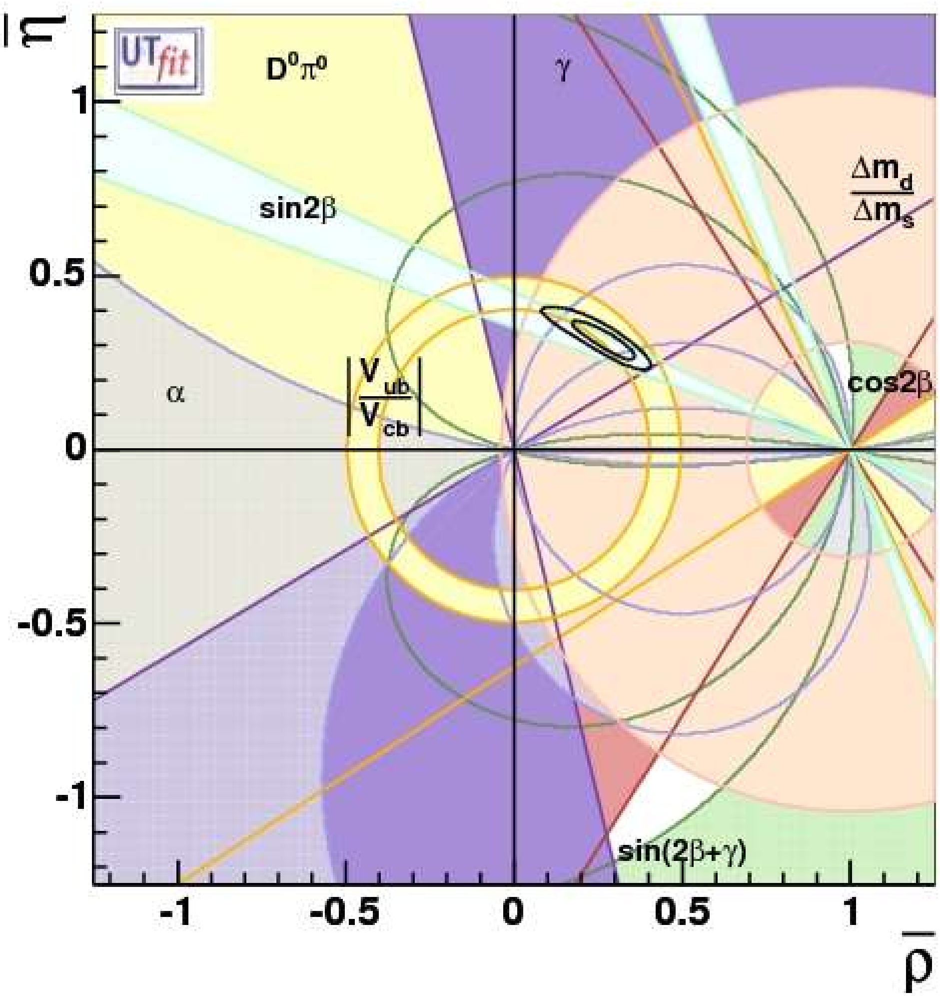
New operators

Less correlations among K and B decays

The Universal Unitarity Triangle today

Buras et al., PLB500

Angle measurements + $\Delta m_d/\Delta m_s$ unaffected by NP in MFV



$\bar{\rho}$	0.258 ± 0.066	$[0.107, 0.373]$
$\bar{\eta}$	0.319 ± 0.039	$[0.249, 0.398]$
$\sin 2\beta$	0.726 ± 0.028	$[0.668, 0.778]$
$\alpha[^\circ]$	105 ± 11	$[81, 123]$
$\gamma[^\circ]$	51 ± 10	$[34, 74]$
$(2\beta+\gamma)[^\circ]$	98 ± 12	$[78, 122]$

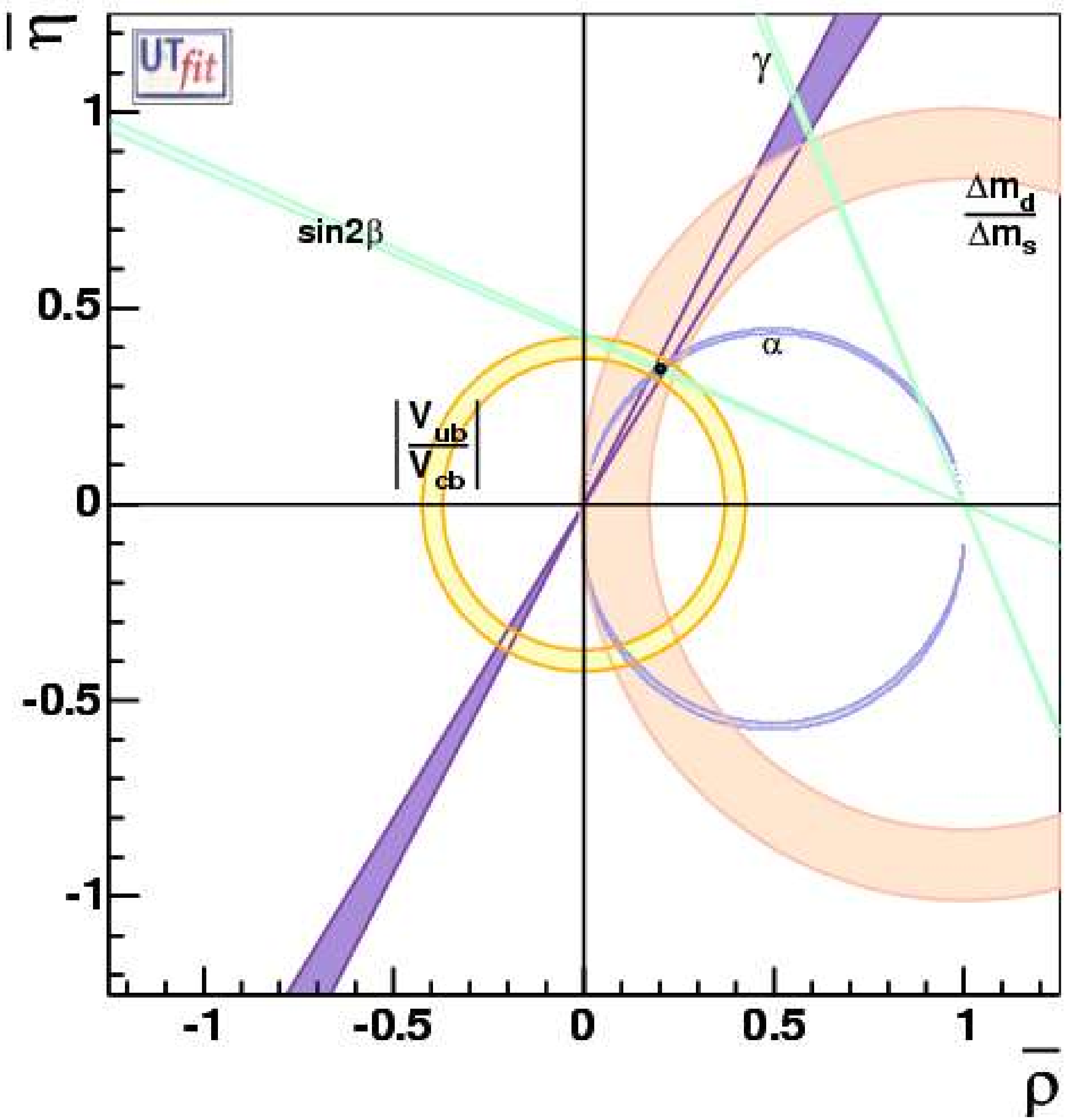
valid in any MFV model

for any value of tanβ

accuracy comparable to SM

UTfit Coll., hep-ph/0509219

The Universal Unitarity Triangle "tomorrow"



$\bar{\rho}$	0.200 ± 0.005	$[0.191, 0.209]$
$\bar{\eta}$	0.343 ± 0.003	$[0.338, 0.349]$
$\sin 2\beta$	0.725 ± 0.004	$[0.718, 0.733]$
$\alpha[^o]$	96.8 ± 0.7	$[95.5, 98.1]$
$\gamma[^o]$	59.7 ± 0.7	$[58.4, 61.0]$
$(2\beta+\gamma)[^o]$	105.5 ± 0.5	$[104.0, 107.0]$

Determination of the UUT at the percent level

2.Flavour and CPV NP in b -> s transitions

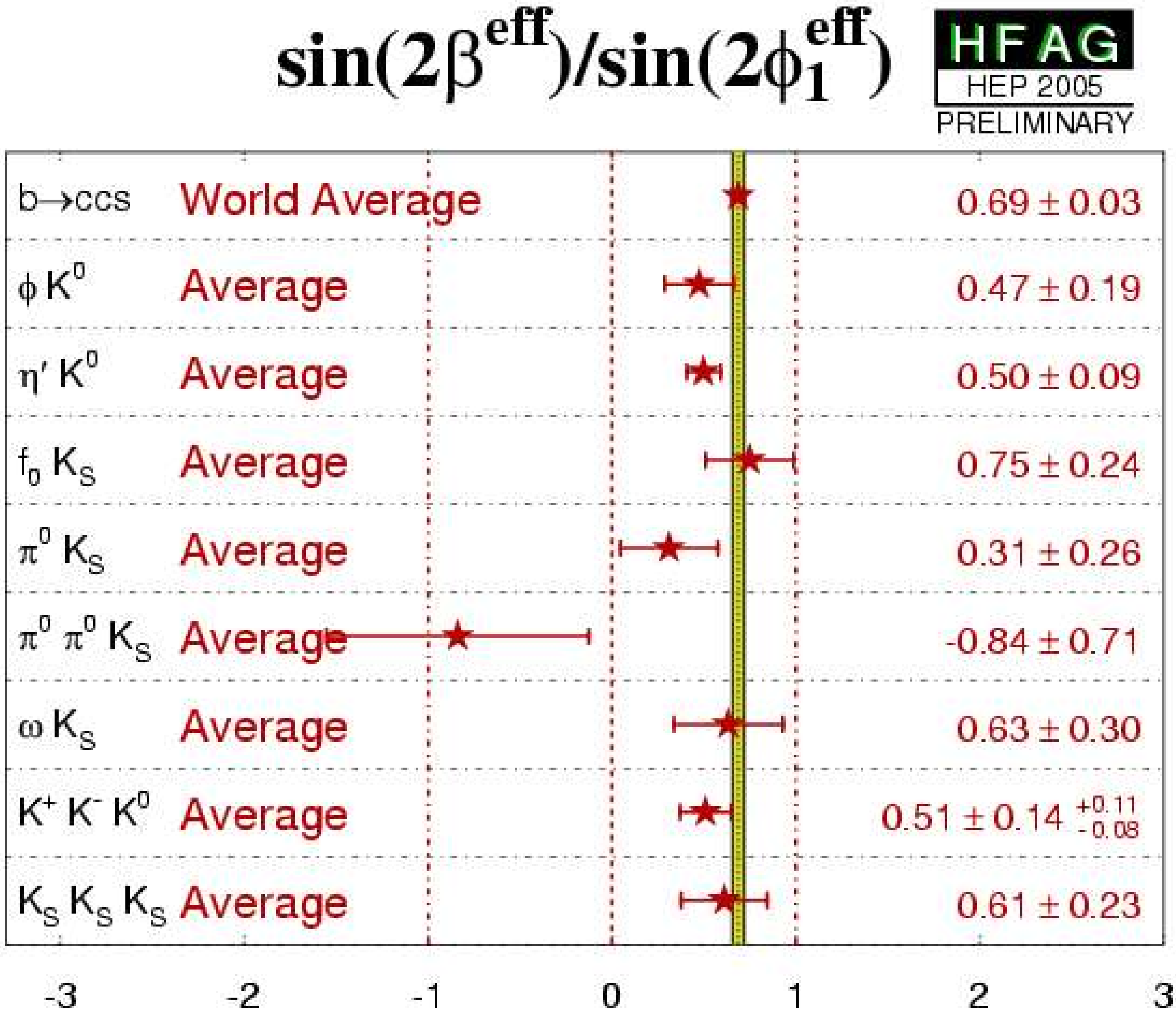
- **natural in any flavour models given the strong breaking of family SU(3)**
  Pomarol, Tommasini; Barbieri, Dvali, Hall; Barbieri, Hall; Barbieri, Hall, Romanino; Berezhiani, Rossi; Masiero, Piai, Romanino, Silvestrini; …

- **hinted at by ν's in SUSY-GUTs**
  Baek, Goto, Okada, Okumura; Moroi; Akama, Kiyo, Komine, Moroi; Chang, Masiero, Murayama; Hisano, Shimizu; Goto, Okada, Shimizu, Shindou, Tanaka; …

- **experimental hints (?) in the time-dependent CP asymmetries**

Let's consider the SUSY option

NP in b -> s modes



$\rightarrow \pm 0.05$

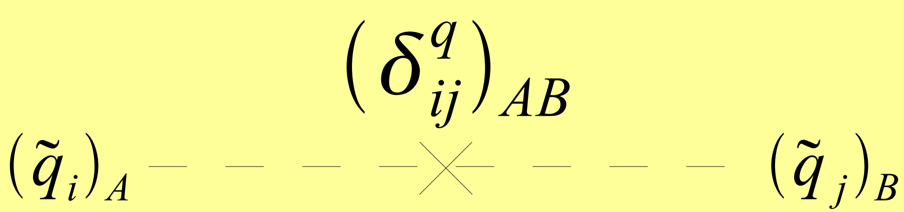
MSSM + generic soft SUSY-breaking terms

Useful tool: the mass-insertion approximation

SuperCKM basis + perturbative smass diagonalization

- expansion parameters: $(\delta_{ij}^{q})_{AB} \equiv \frac{(M_{ij}^{2})_{AB}^{q}}{\tilde{m}^{2}}$

All flavour-changing NP effects in the squark propagators



$q=\{u,d\}, \; (A,B)=\{L,R\}$

$(i,j)=\{1,2,3\}$

FCNC and CP violation impose model-independent bounds on the δ's

NB: only dominant gluino contributions are considered

Constraints on the δ's

- gluinos contribute to rare decays only through (chromo)magnetic penguins (electro)penguin operators are suppressed

Bertolini et al., NPB353; Gabbiani et al., NPB477; Buras, Romanino, L.S., NPB520

- strong constraints from the combination of $b \to s\,\gamma$ and $b \to s\, l^+ l^-$ (both dominated by C_7^{eff})

Ciuchini et al; Hiller, PRD69; Gambino, Haisch, Misiak, PRL94

Updated results for

$$m_{gl} = m_{sq} = -\mu = 350 \text{ GeV}, \tan\beta = 10$$

$$BR(B \to X_s \gamma, E_{\rm cut} = 1.8\,{\rm GeV}) = (3.51 \pm 0.43) \times 10^{-4}$$

$$a_{\rm CP}(B \to X_s \gamma) = 0.004 \pm 0.036$$

$$BR(B \to X_s l^+ l^-, {\rm low}) = (1.59 \pm 0.49) \times 10^{-6}$$

$$BR(B \to X_s l^+ l^-, {\rm high}) = (4.34 \pm 1.15) \times 10^{-7}$$

$$a_{\rm CP}(B \to X_s l^+ l^-) = -0.22 \pm 0.26$$

Today

$$BR(B \to X_s \gamma, E_{\rm cut} = 1.8\,{\rm GeV}) = (3.73 \pm 0.02) \times 10^{-4}$$

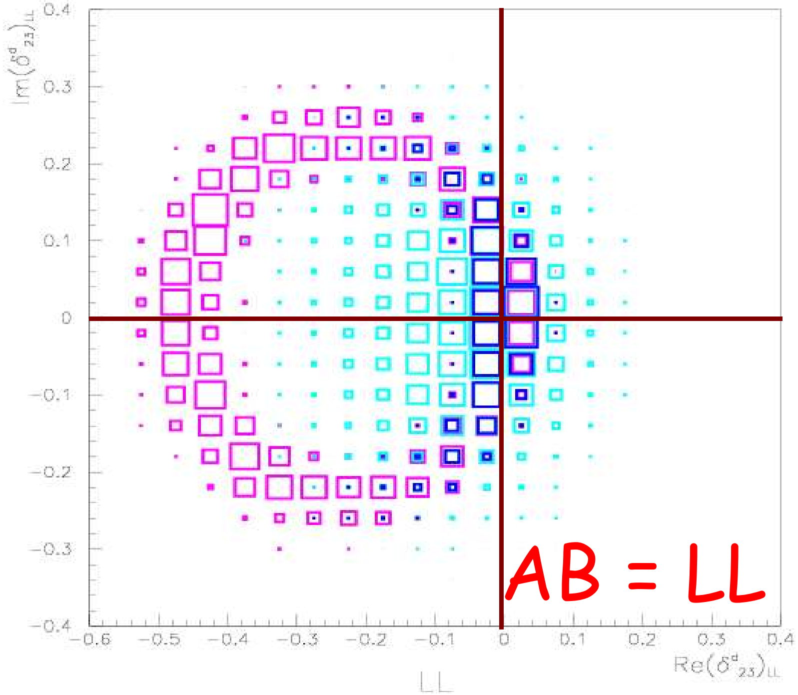
$$a_{\rm CP}(B \to X_s \gamma) = 0.000 \pm 0.005$$

$$BR(B \to X_s l^+ l^-, {\rm low}) = (2.40 \pm 0.04) \times 10^{-6}$$

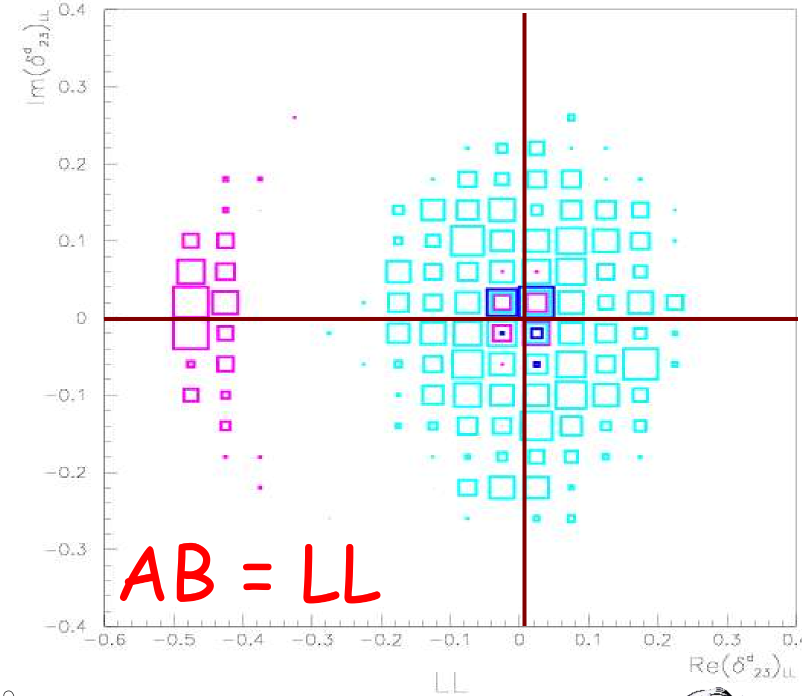
$$BR(B \to X_s l^+ l^-, {\rm high}) = (3.91 \pm 0.09) \times 10^{-7}$$

$$a_{\rm CP}(B \to X_s l^+ l^-) = 0.000 \pm 0.015$$

NB: NNLO and FB asymmetry in B -> Xs ll not yet implemented

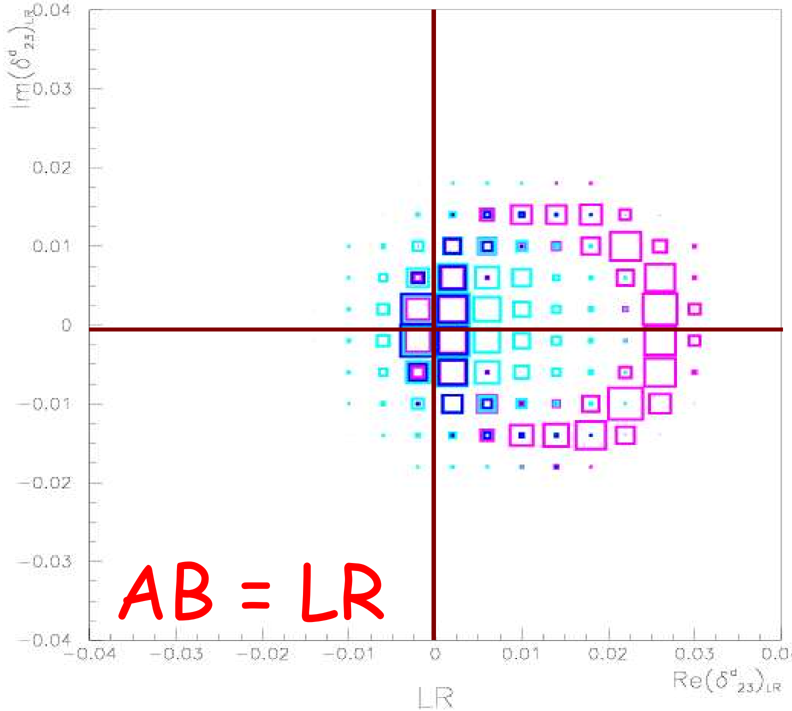


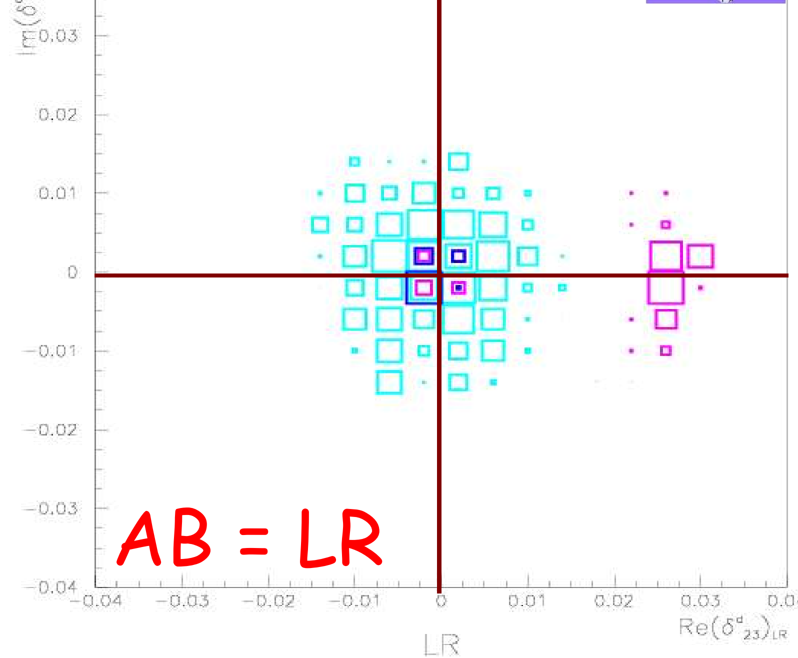
Re $(\delta^d_{23})_{AB}$ vs Im $(\delta^d_{23})_{AB}$



present | future

PRELIMINARY



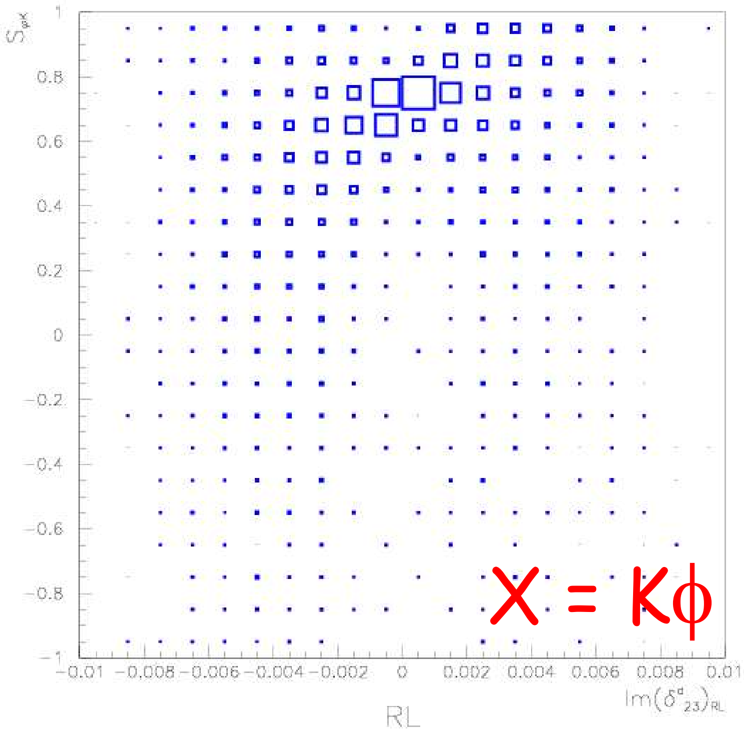


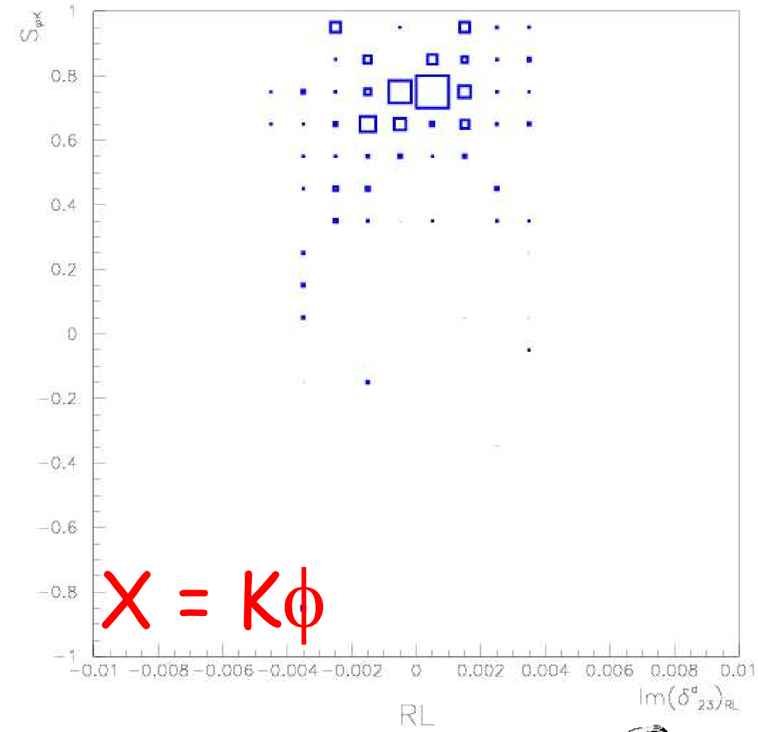
$b \to s\,\gamma$ only

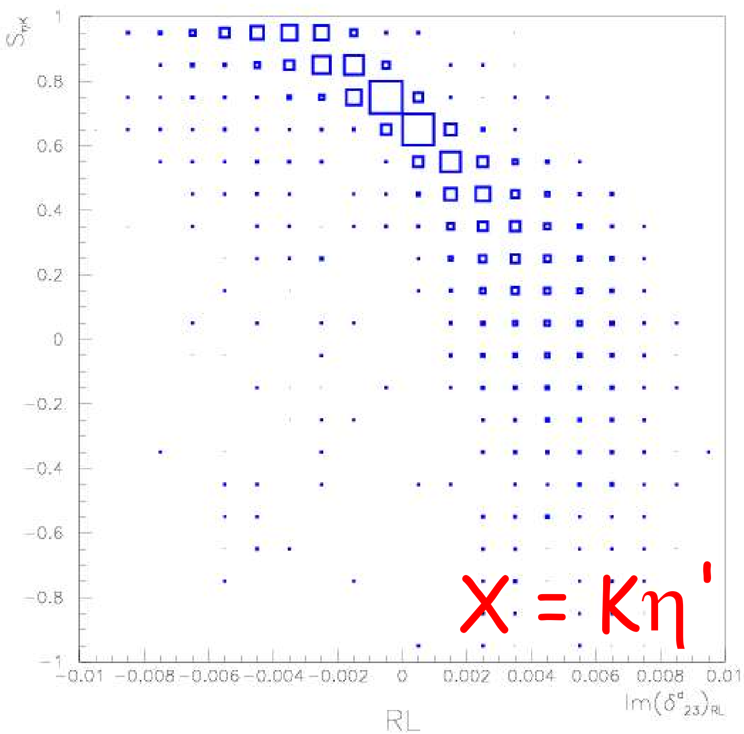
$b \to s\,ll$ only

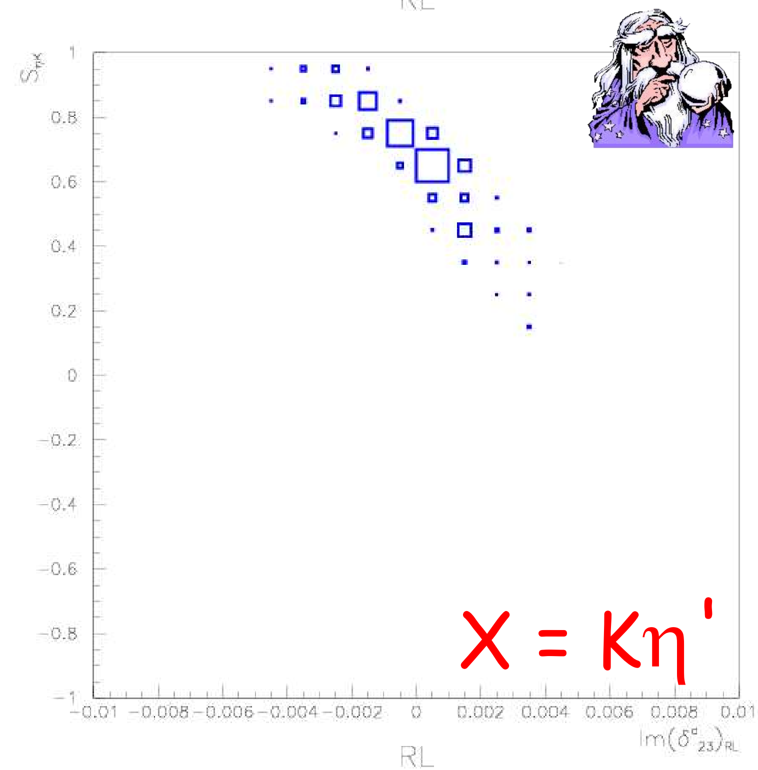
All constraints

S_X vs $\mathrm{Im}\,(\delta^d_{23})_{RL}$









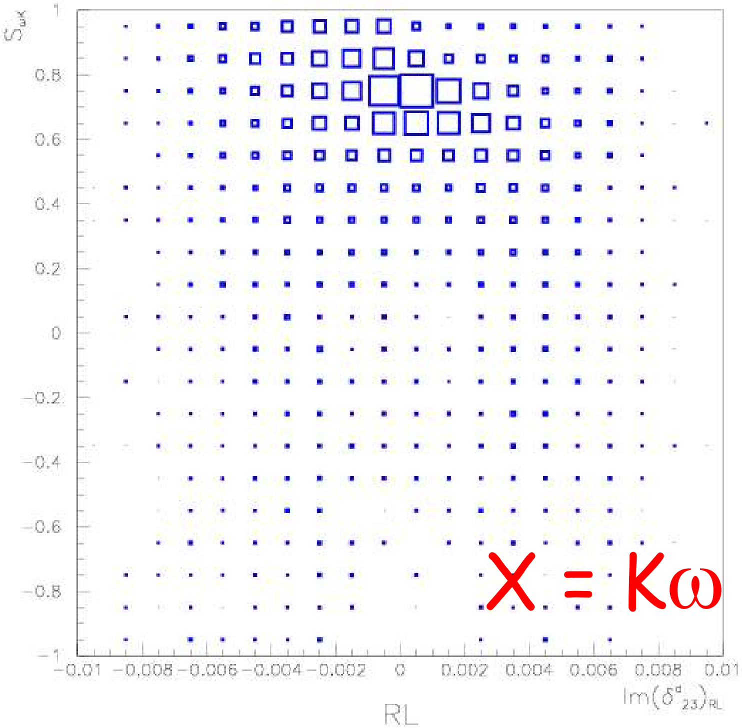
present | future

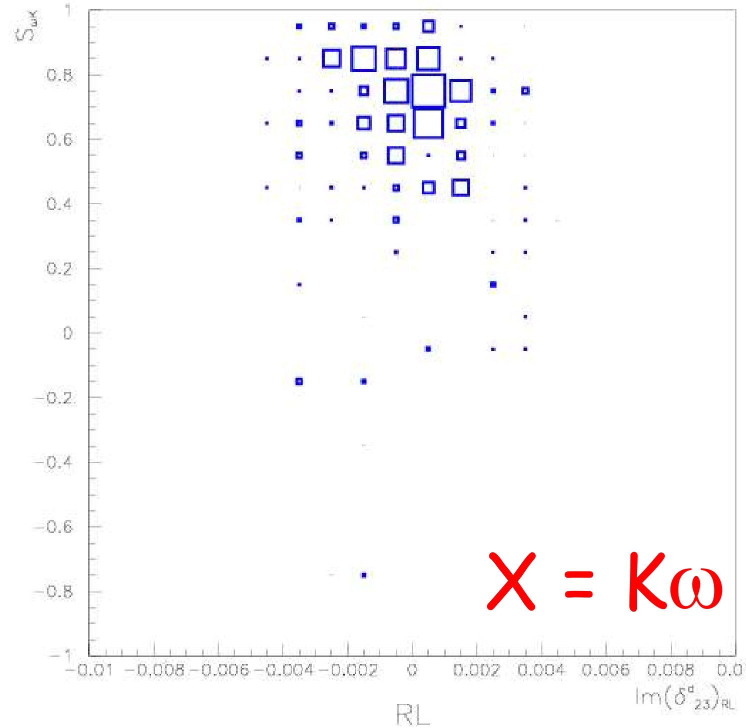
PRELIMINARY

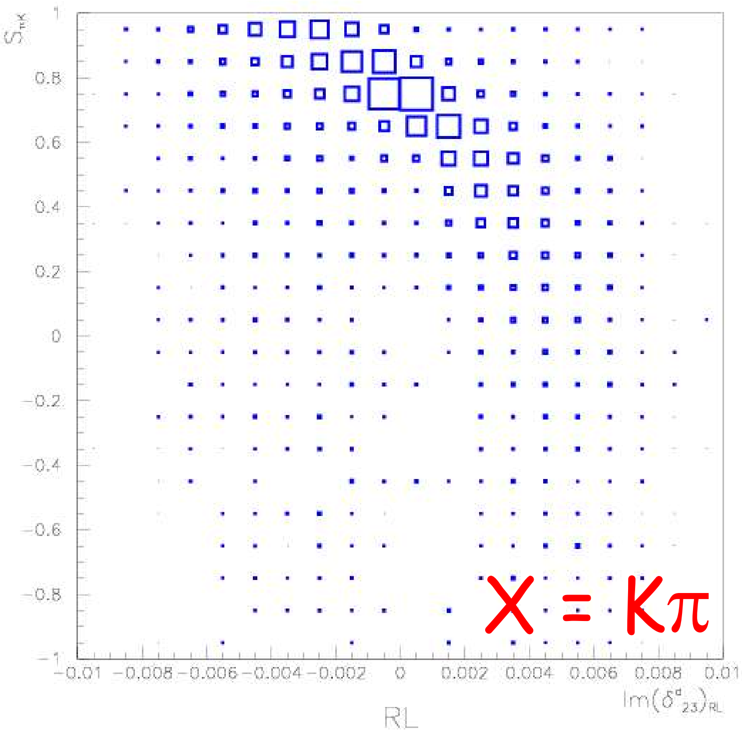
S_X vs $Im(\delta^d_{23})_{RL}$

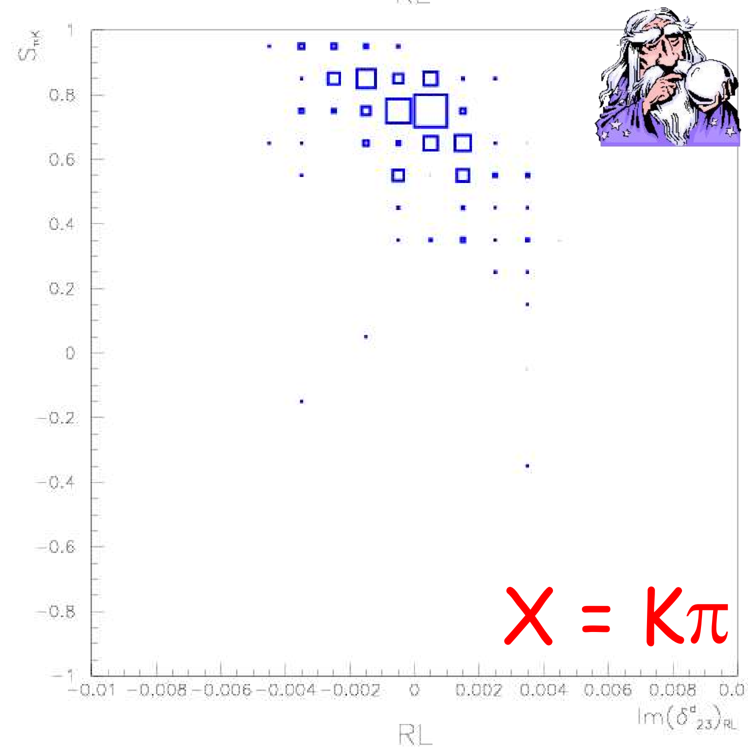
present | future

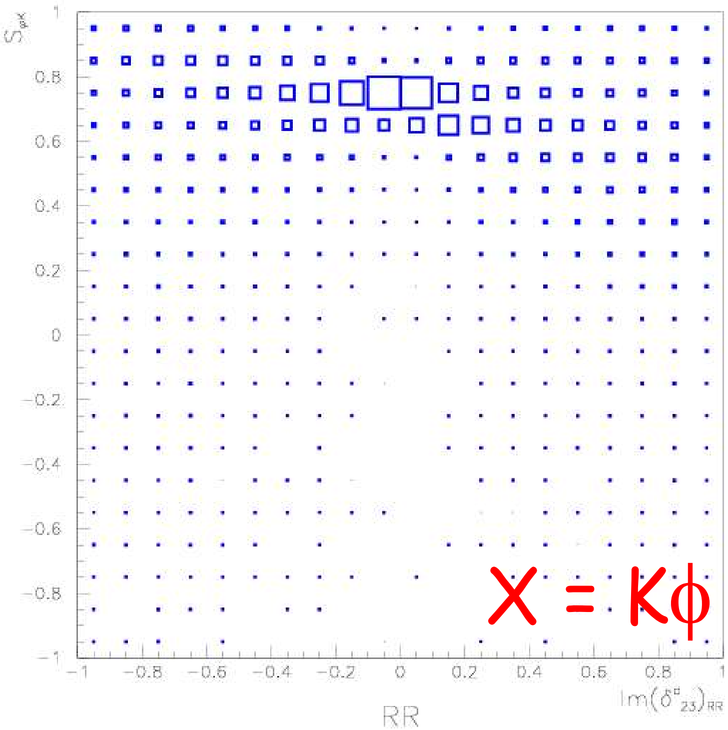
PRELIMINARY

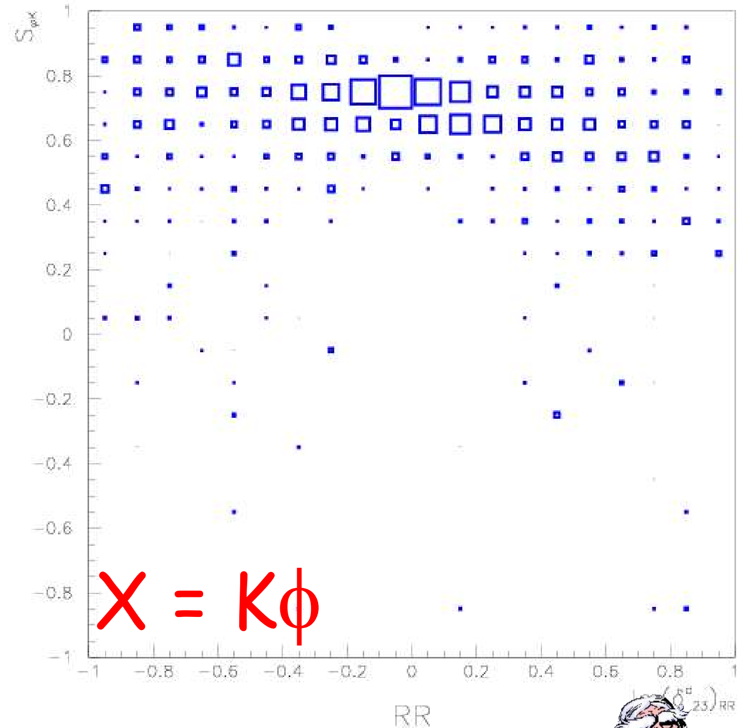








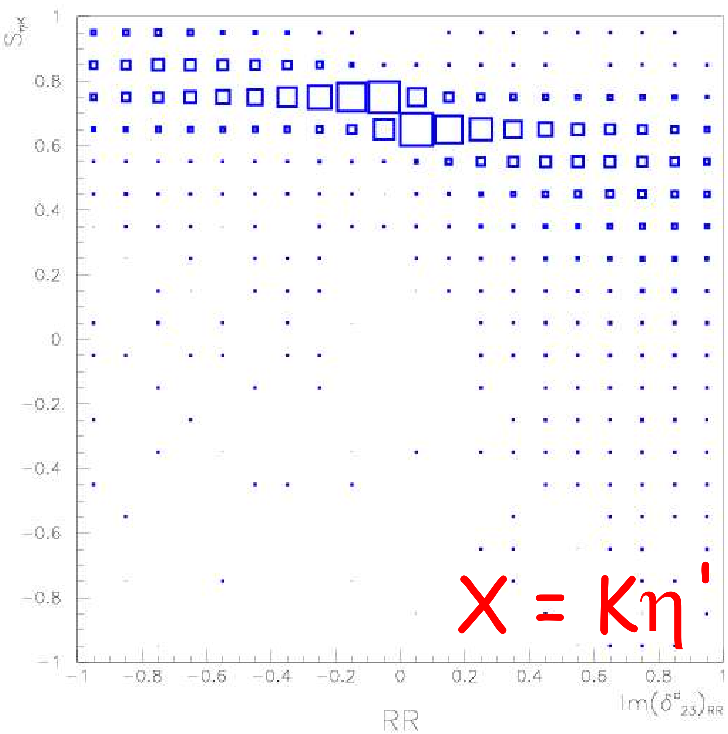


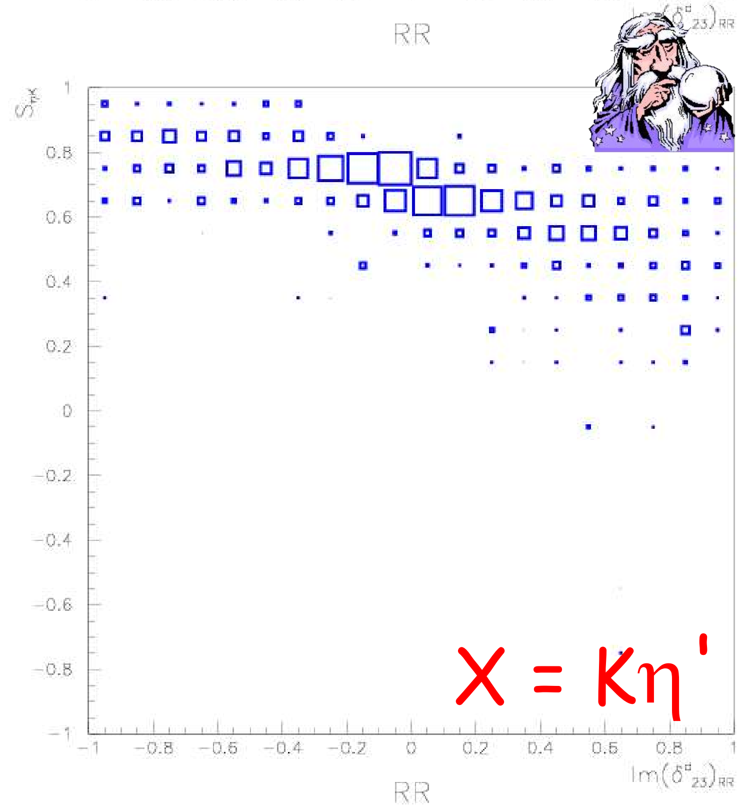


S_X vs $Im\,(\delta^d{}_{23})_{RR}$

present | future

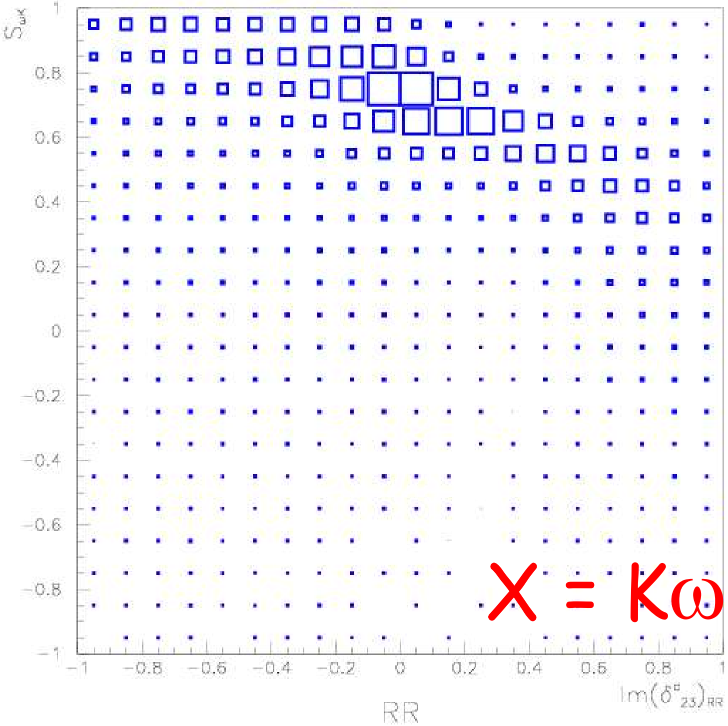
PRELIMINARY

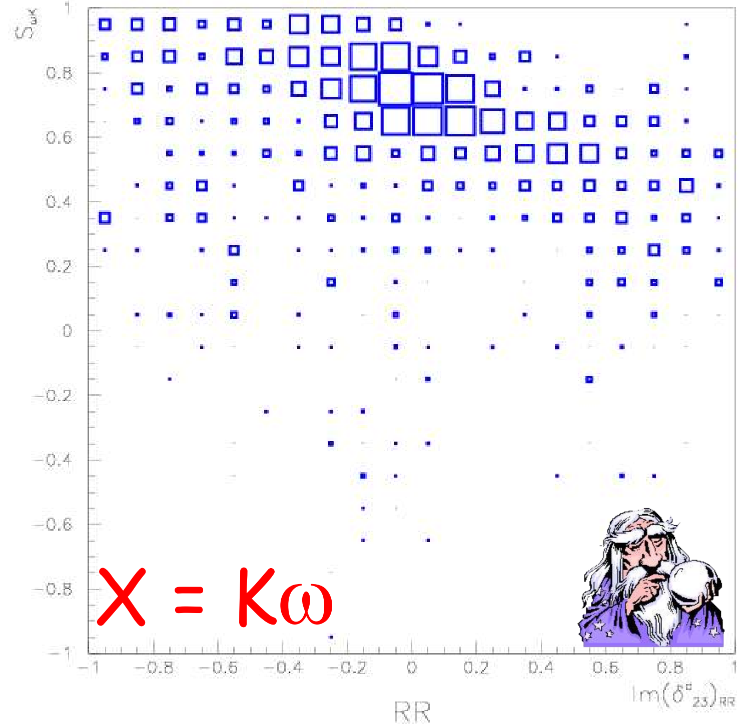


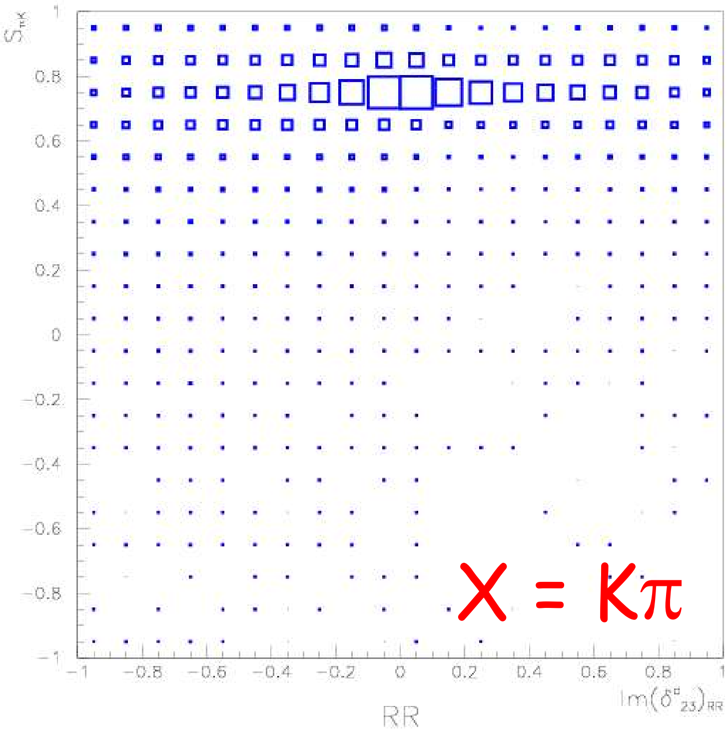


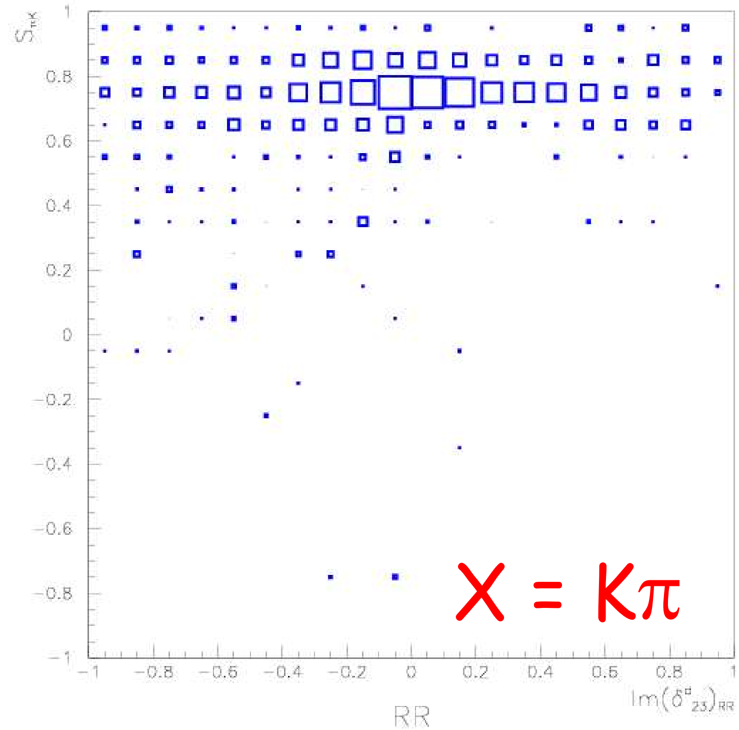
S_X vs $\mathrm{Im}(\delta^d_{23})_{RR}$

present | future









PRELIMINARY

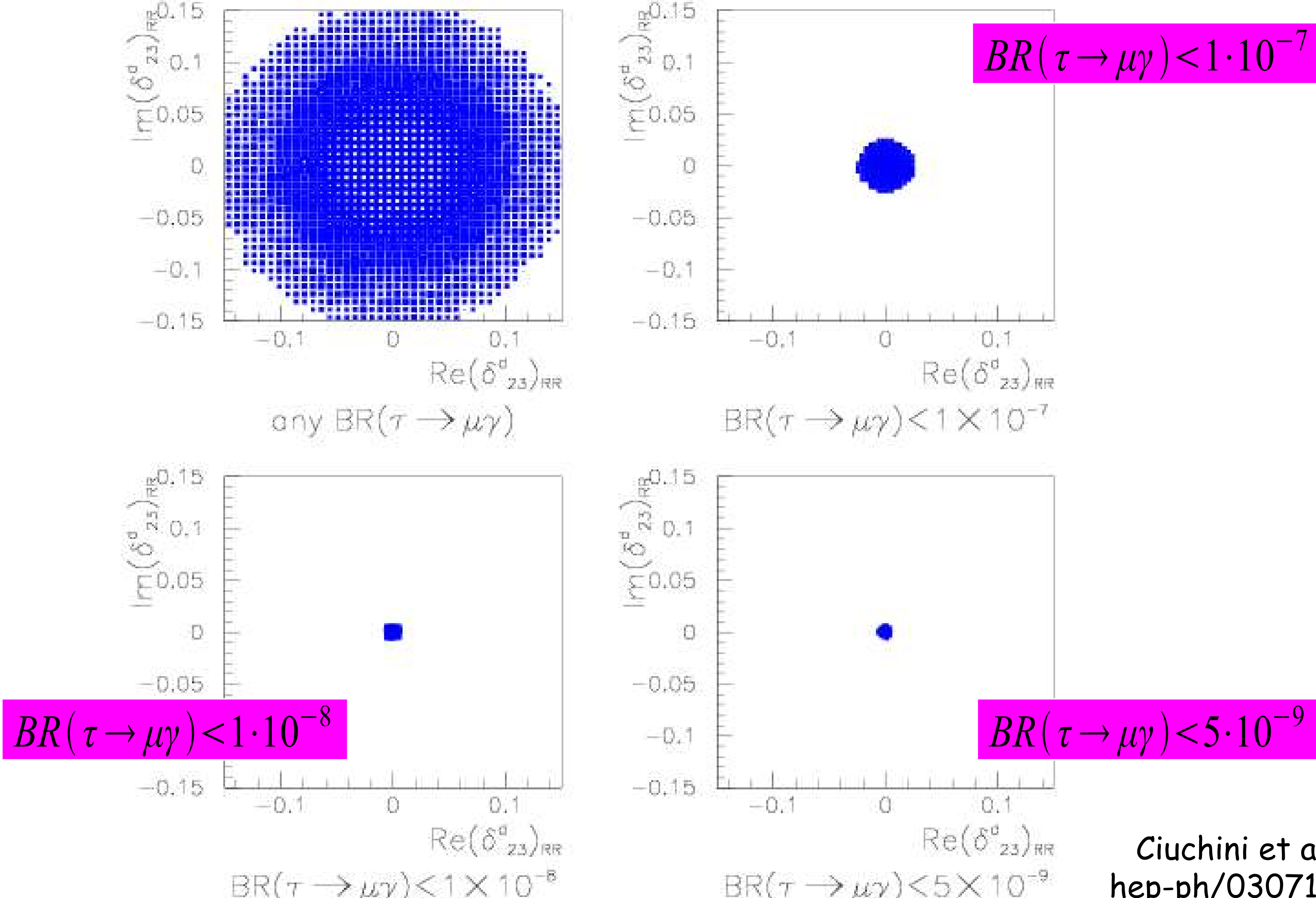
SUSY-GUT's and LFV

If flavour symmetry is broken at a scale larger than M_{GUT}, squark and slepton masses unify, including off-diagonal terms i.e. δs

$$(\delta^d_{23})_{RR} \Leftrightarrow (\delta^l_{23})_{LL}$$

quark FV $\Leftrightarrow$ lepton FV

$\tau \to \mu\gamma$, $\tau \to e\gamma$, and $\mu \to e\gamma$ probe different couplings $\Rightarrow$ complementary



Ciuchini et al
hep-ph/0307191
update in progress

Conclusions

The precision test/new physics era of B physics just began. It requires high statistics and a careful assessment of the uncertainties to be successful

Flavour physics probes the structure of NP models. A high-precision test program is like a NP genome project

Present results point to either no new physics in $\Delta F=2$ b/s $\rightarrow$ d transitions or models with (N)MFV. O(1) NP effects are still possible, yet MFV NP is better studied through correlations among different B (and K) decays

Ample room for visible NP in b $\rightarrow$ s transitions: motivations from theory, more precise data needed

Interplay between quark and lepton FV in SUSY-GUTs