Flavour and CP violation in the Standard Model and Beyond

Luca Silvestrini

INFN, Sez. di Roma

- Introduction
- The Unitarity Triangle in the Standard Model and beyond
- Flavour physics beyond the Standard Model:
  - Minimal Flavour Violation
  - Beyond MFV:
    - general SUSY models, SUSY GUT's
    - Extra dimensions
- Conclusions

Based on:
UTfit coll., hep-ph/0605213
UTfit coll., in progress
M. Ciuchini et al., in progress
R. Contino & L.S., in progress

INTRODUCTION

The Standard Model works beautifully up to a few hundred GeV's, but it must be an effective theory valid up to a scale $\Lambda \leq M_{planck}$:

$$\mathcal{L}(M_W) = \Lambda^2 H^\dagger H + \lambda \left(H^\dagger H\right)^2 + \mathcal{L}_{SM}^{gauge} + \mathcal{L}_{SM}^{Yukawa} + \frac{1}{\Lambda}\mathcal{L}^5 + \frac{1}{\Lambda^2}\mathcal{L}^6 + \ldots$$

EW scale

Has accidental symmetries

Violates accidental symmetries

THE HIERARCHY PROBLEM

- m_{EW} (10^2) << M_{Pl} (10^{19}), M_{GUT} (10^{15}) (in GeV)
  1. Supersymmetry: $m_{EW} \sim \Lambda = m_{SUSY} \ll M_{Pl}$
     Bonus: Grand Unification, Dark Matter
  2. Warped extra-dims (gauge-Higgs unification): $m_{EW} \sim \Lambda = m_{KK} \ll M_{pl}$
- Expect New Physics close to the electroweak scale!

HOW TO PROBE NEW PHYSICS: I. ELECTROWEAK SYMMETRY BREAKING

How can we explore NP with processes involving only SM particles?

I. Electroweak gauge symmetry spontaneously broken

⇨ tree-level relations between EW observables (masses, couplings, ...)

⇨ quantum corrections computable and sensitive to higher-dim operators

⇨ The LEP glorious legacy of precision EW fits: Λ > 2-10 TeV!!

HOW TO PROBE NEW PHYSICS: II. FLAVOUR PHYSICS

Three flavours of fermions with same gauge quantum numbers but different mass.

Flavour eigenstates are not weak interaction eigenstates

⇒ weak interactions change flavour

Accidental symmetry of the SM: Neutral current weak interactions conserve flavour!

⇨ quantum corrections computable and sensitive to higher-dim operators

EXPRESS REVIEW OF THE SM

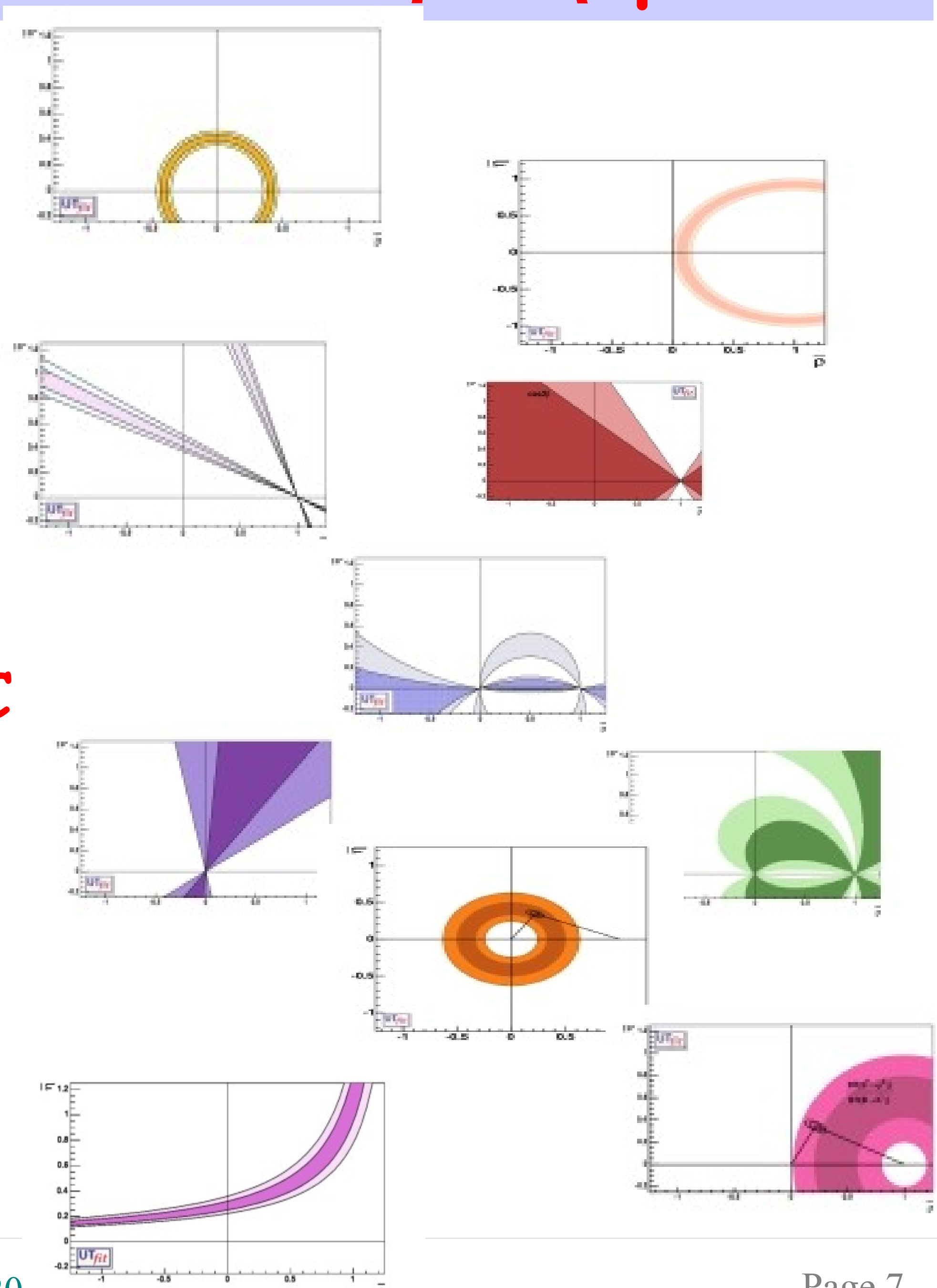
- All flavour violation from charged current coupling: CKM matrix V

$$V_{CKM} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\bar{\rho}-i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

- Top quark exchange dominates FCNC loops: third row (V_{tq}) determines FCNC's $\leftrightarrow$ $\bar{\rho}$, $\bar{\eta}$

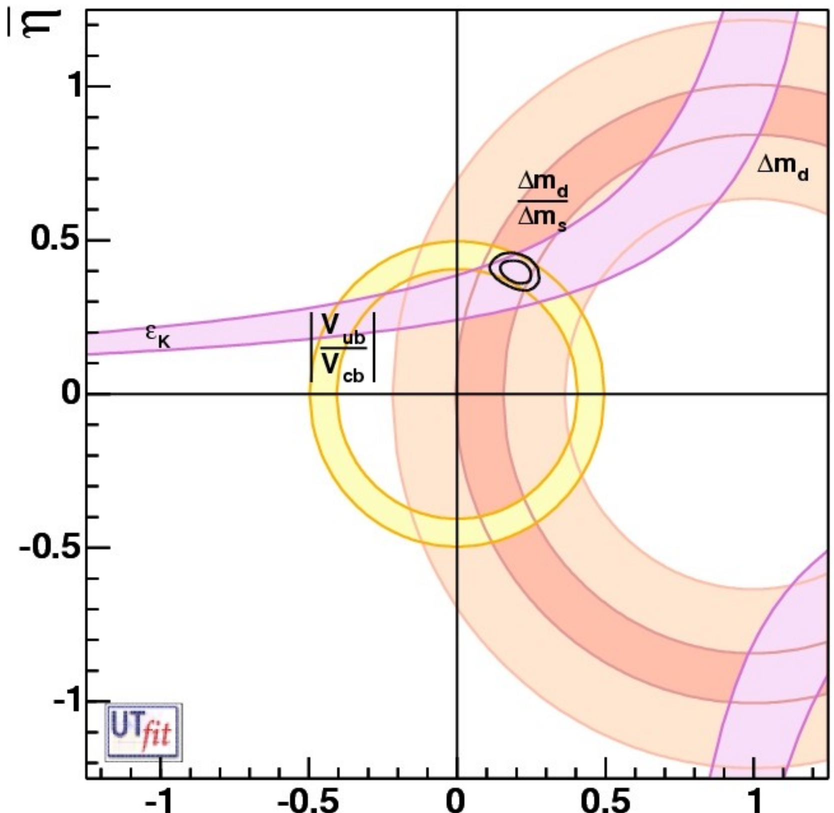
Flavour summarized on the $\rho-\eta$ plane

$BR(b \to c l \nu)$, $BR(B \to D^{(*)} l \nu)$	CC
$BR(b \to u l \nu)$, $BR(B \to \pi l \nu)$	CC
Δm_q (B_q-$\bar{B}_q$ mass diff.)	NC
$A_{CP}(b \to c\bar{c}s)$ (J/ψ K, ...)	CC
$A_{CP}(b \to s\bar{s}s,\ d\bar{d}s)$ (ϕ K, πK, ...)	NC
$A_{CP}(b \to d\bar{d}d,\ u\bar{u}d)$ ($\pi\pi$, $\rho\rho$, ...)	CC/NC
$BR(b \to c\bar{u}d,\ c\bar{u}s)$ (DK, ...)	CC
$BR(B \to \tau\nu)$	CC
$BR(B \to \rho\gamma)/BR(B \to K^*\gamma)$	NC
ε_K (CP violation in K mixing)	NC

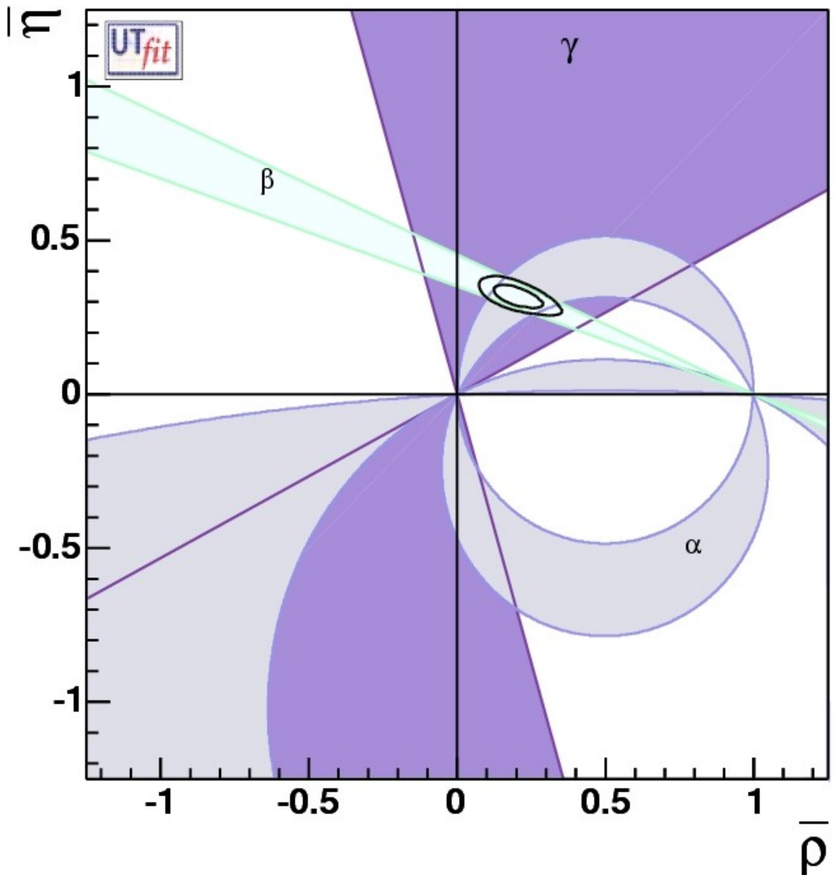


Progress of the UT analysis

End of parameter determination era, begin of precision test era: redundant determination of the triangle with new measurements from B-factories and Tevatron and test of new physics.



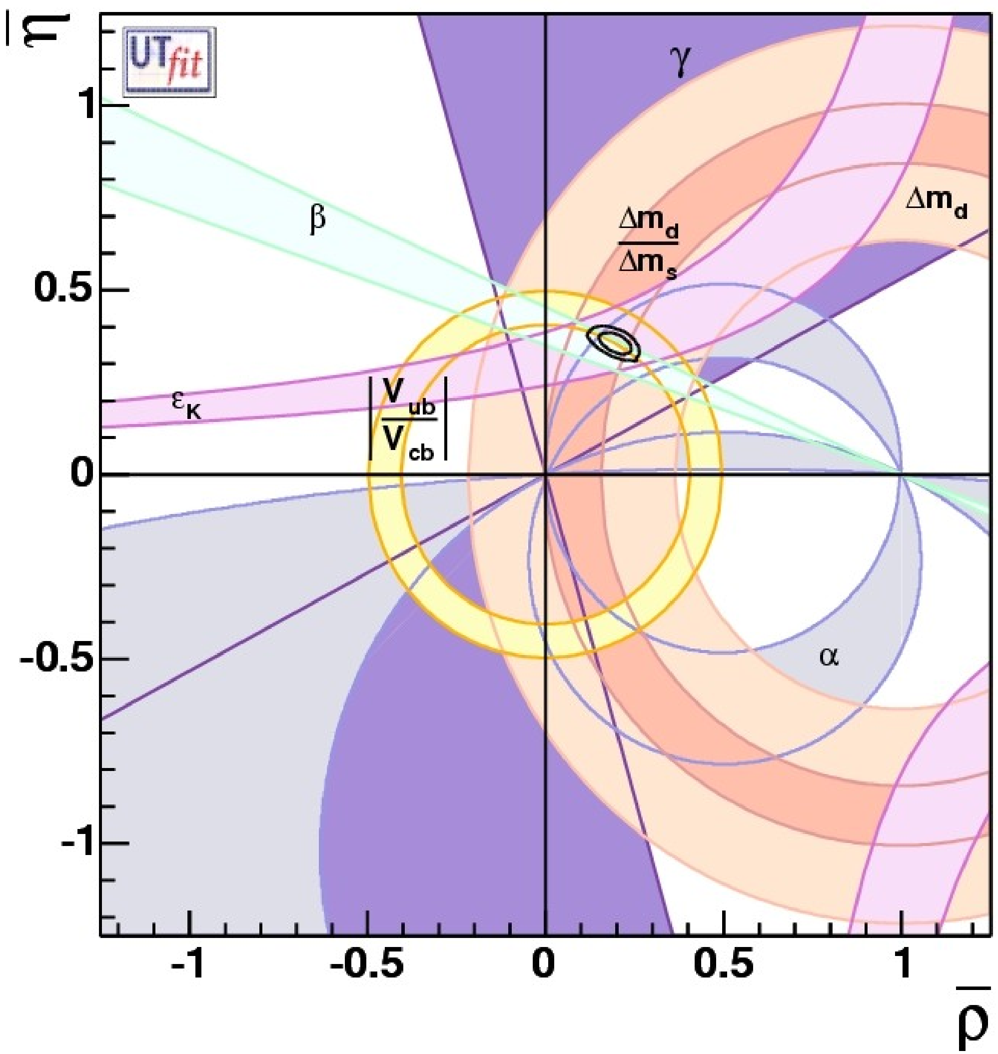
No angles: $|V_{ub}/V_{cb}|$, Δm_d, ΔM_s, ε_K



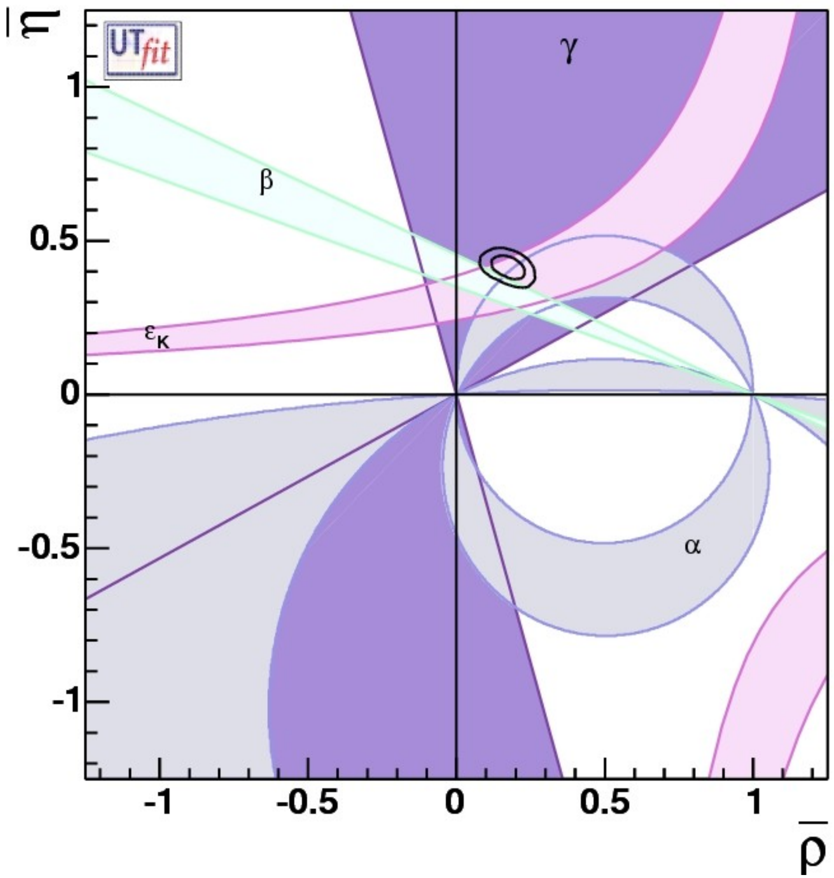
Angles only: α, β, γ

Progress of the UT analysis - II

Putting it all together:

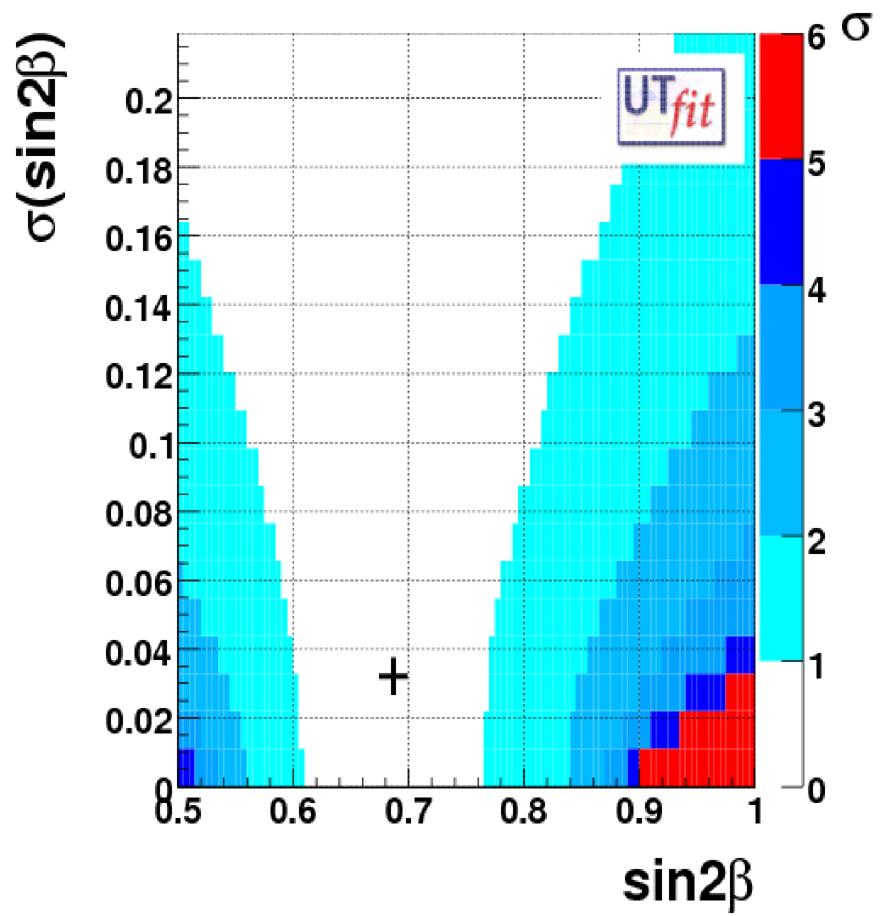


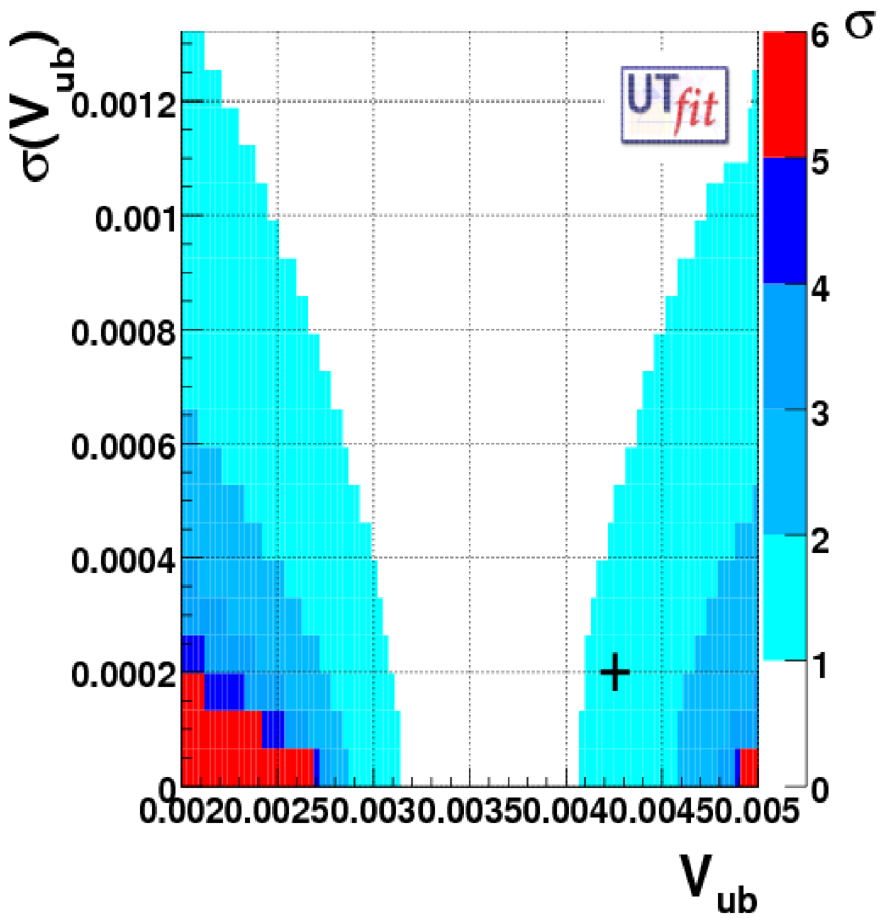
Slight disagreement between no-angles and angles:



Progress of the UT analysis - III

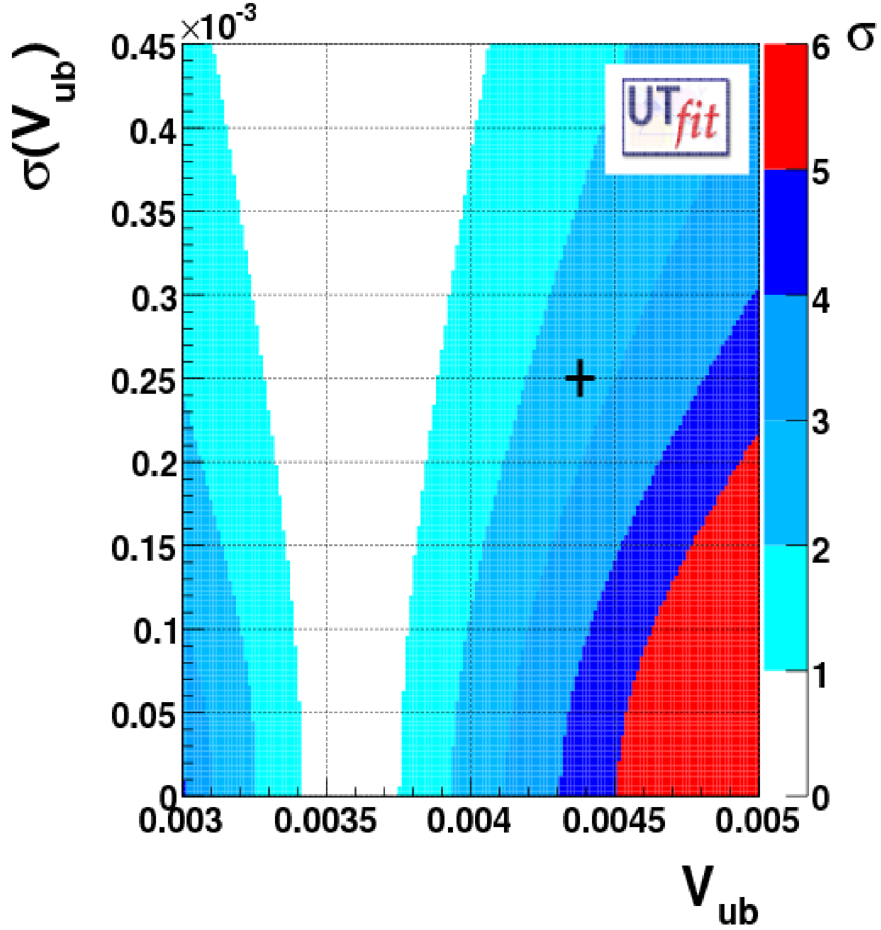
Where does the difference come from? Test the compatibility of sin2b and Vub with the rest of the fit:

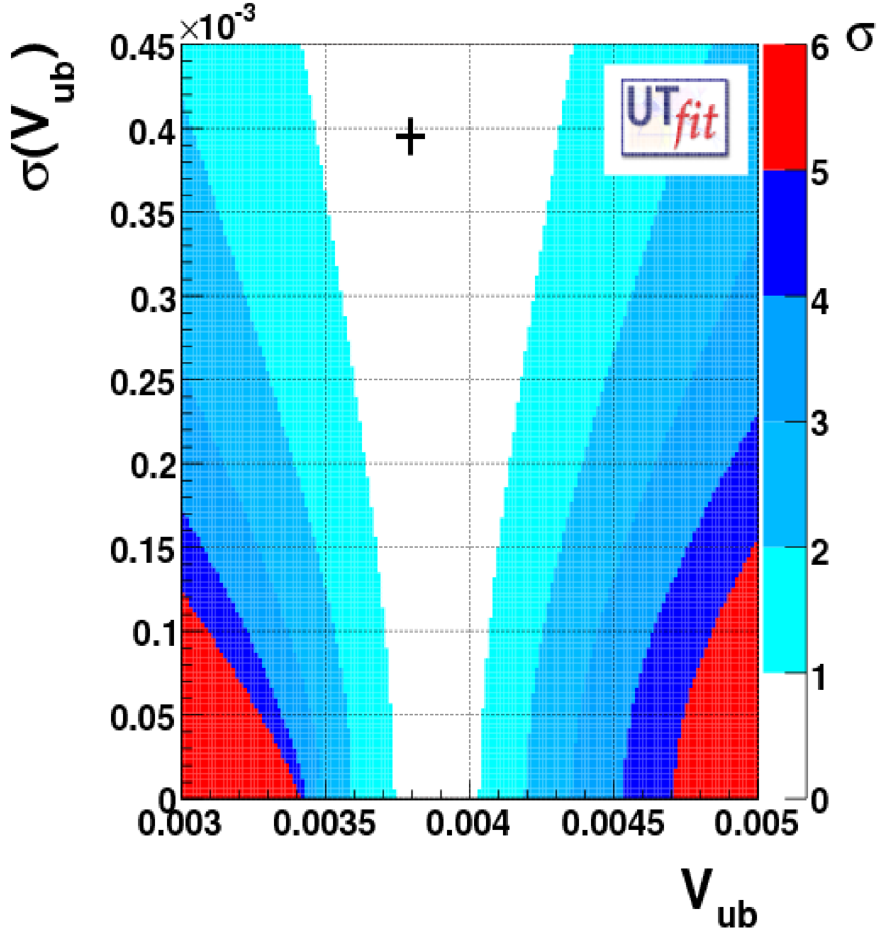




Progress of the UT analysis - IV

Test the compatibility of inclusive Vub and exclusive Vub with the rest of the fit:





A problem with the determination of V_{ub} from inclusive decays?

HOW DOES NP MODIFY FLAVOUR?

- Standard Model:
  - CKM matrix only, loop level only
  - GIM suppression ~ $(m_{qi}^2 - m_{qj}^2)/m_W^2$
- Minimal Flavour Violation, Minimal SUGRA:
  - same as above
- General MSSM:
  - New sources of flavour & CPV, loop level only
  - Super-GIM suppression ~ $(m_{sqi}^2 - m_{sqj}^2)/m_{gl}^2$
- Extra Dimensions:
  - New sources of flavour & CPV, tree-level
  - Mass suppression ~ m_q/m_{KK}

A strategy for New Physics:

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

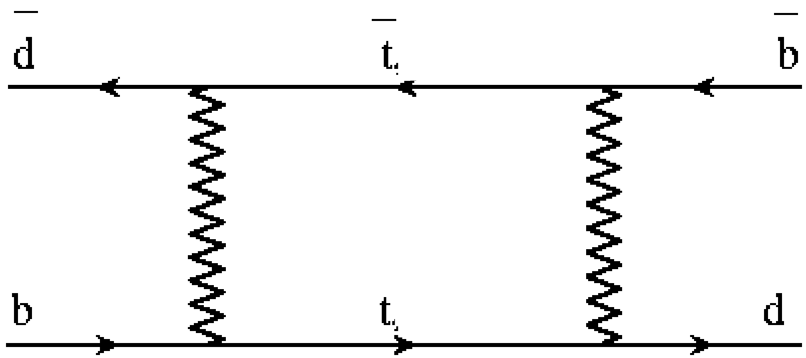
Only possible thanks to the new measurements of CKM angles

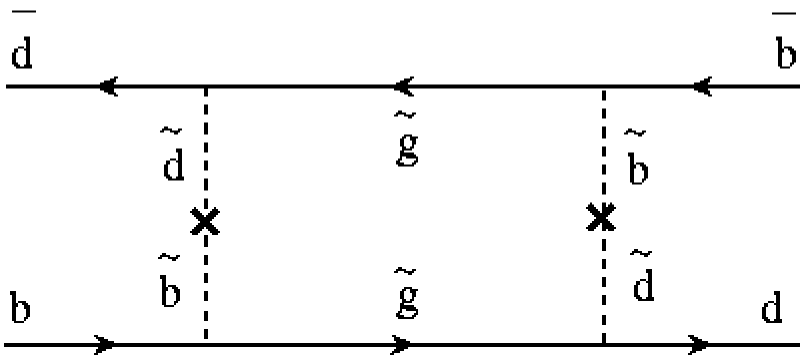
Recent info on Δm_s, $\Delta\Gamma_s/\Gamma_s$, leptonic asymmetries allows to constrain NP in $b \to s$ transitions

Will become the standard fit in the near future!

Utfit coll., hep-ph/0605213. See also Ligeti et al., hep-ph/0604112; Grossman et al, hep-ph/0605028. Previous attempts: Ciuchini et al., hep-ph/0307195; CKMfitter group, hep-ph/0406184; Ligeti, hep-ph/0408267; Botella et al., hep-ph/0502133; Agashe et al., hep-ph/0509117; UTfit coll., hep-ph/0509219.

General parametrization of the mixing amplitudes





Mixing amplitude = SM contribution + NP contribution

$$A_q^{\rm full} = A_q^{\rm SM} e^{2i\phi_q^{\rm SM}} + A_q^{\rm NP} e^{2i(\phi_q^{\rm SM}+\phi_q^{\rm NP})} = C_{B_q} e^{2i(\phi_q^{\rm SM}+\phi_{B_q})} A_q^{\rm SM}$$

$$(\Delta m_q) = |A_q^{\rm full}| = C_{B_q} (\Delta m_q)^{\rm SM} \qquad \frac{\Delta\Gamma_q}{\Delta m_q} = {\rm Re}\left(\frac{\Gamma_{12}^q}{A_q^{\rm full}}\right)$$

$$A_{CP}(J/\Psi K_S) = \sin\,\arg(A_d^{\rm full}) = \sin 2(\beta + \phi_{B_d})$$

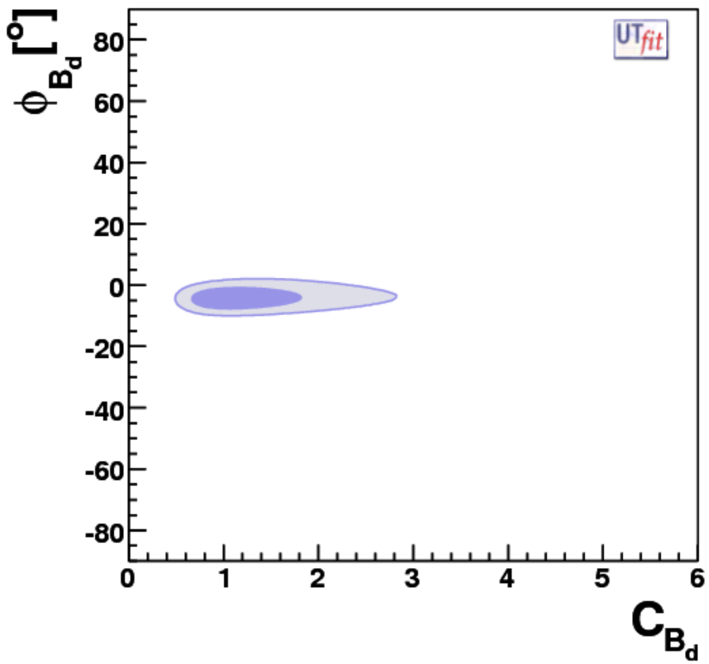
$$A_{CP}(J/\Psi \phi) = -\sin\,\arg(A_s^{\rm full}) = \sin 2(\beta_s - \phi_{B_s})$$

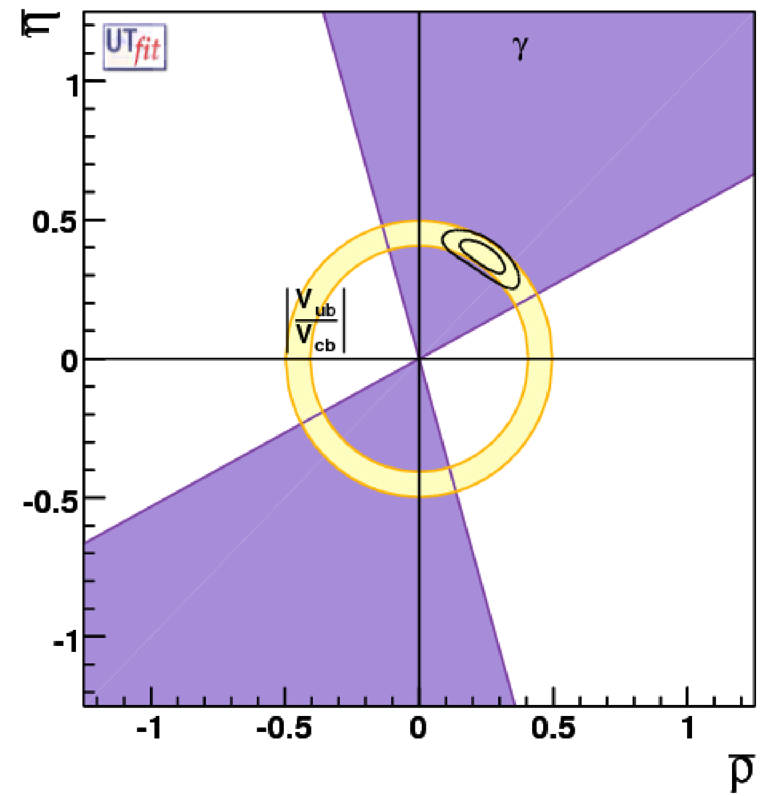
$$A_{\rm SL} \equiv \frac{\Gamma(\bar{B}^0 \to \ell^+ X) - \Gamma(B^0 \to \ell^- X)}{\Gamma(\bar{B}^0 \to \ell^+ X) + \Gamma(B^0 \to \ell^- X)} = {\rm Im}\left(\frac{\Gamma_{12}^d}{A_d^{\rm full}}\right) \qquad A_{\rm CH} \equiv \frac{N(\ell^+\ell^+) - N(\ell^-\ell^-)}{N(\ell^+\ell^+) + N(\ell^-\ell^-)}$$

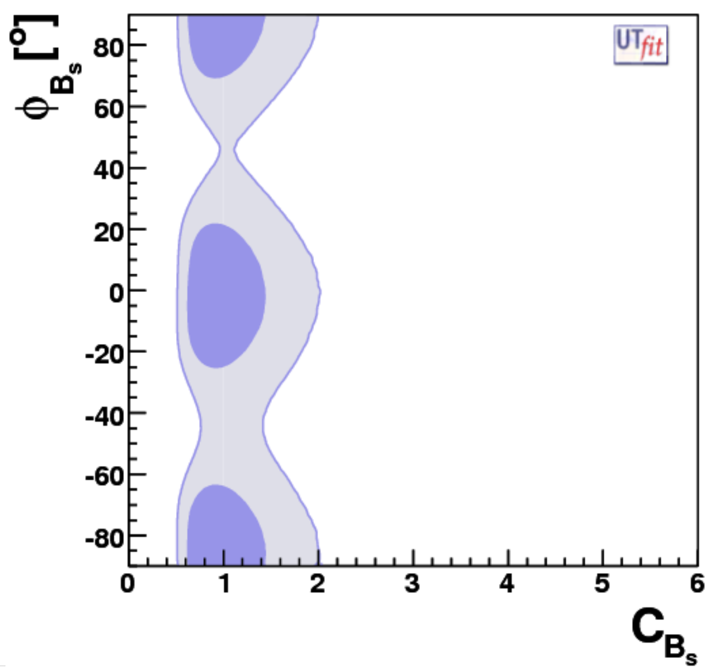
NP parameters & exp constraints

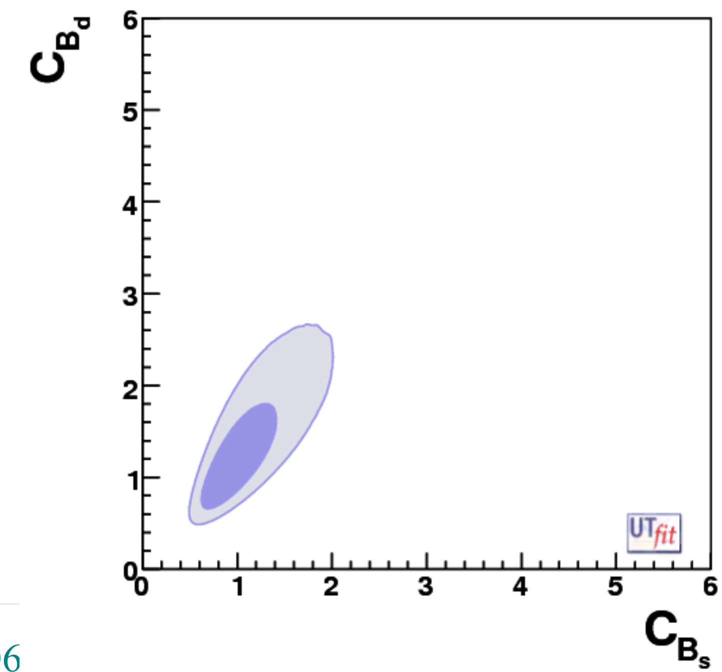
- Angle measurements determine ρ, η and ϕ_d up to an ambiguity of 180°
- Δm_d & Δm_s fix C_{Bd} & C_{Bs}, ε determines C_ε
- $\Delta\Gamma_s/\Gamma_s$ constrains ϕ_s
- A_{SL} and A_{CH} suppress the "wrong" solution in the $\rho - \eta$ plane
- $\Delta\Gamma_d/\Gamma_d$ improves the constraint on ϕ_d

• Using all constraints:









summary of constraints

Parameter	Output	Parameter	Output
C_{B_d}	1.17 ± 0.39	$\phi_{B_d}[^\circ]$	-4.2 ± 2.1
C_{B_s}	0.97 ± 0.27	$\phi_{B_s}[^\circ]$	$(-2 \pm 15) \cup (93 \pm 15)$
C_{ϵ_K}	0.95 ± 0.18		
$\overline{\rho}$	0.24 ± 0.06	$\overline{\eta}$	0.37 ± 0.04
$\alpha[^\circ]$	96 ± 9	$\beta[^\circ]$	26 ± 2
$\gamma[^\circ]$	57 ± 9	$\mathrm{Im}\lambda_t[10^{-5}]$	14.9 ± 1.6
$V_{ub}[10^{-3}]$	4.27 ± 0.20	$V_{cb}[10^{-2}]$	4.15 ± 0.07
$V_{td}[10^{-3}]$	7.9 ± 0.6	$\|V_{td}/V_{ts}\|$	0.194 ± 0.016
R_b	0.44 ± 0.02	R_t	0.85 ± 0.07
$\sin 2\beta$	0.788 ± 0.035	$\sin 2\beta_s$	0.040 ± 0.004

$\phi_{Bd} \neq 0$ @ 2 σ because of the tension in the SM fit.

Need more statistics + check of incl V_{ub}

THE LESSON OF THE UT ANALYSIS

New Physics in $\Delta B=2$ and $\Delta S=2$ can be up to ~50% of the SM only if NP has the same phase of the SM, otherwise it has to be at most ~ 20%.

This is a completely general result.

In the following, we will see what is the implication of this statement for various new physics models.

MINIMAL FLAVOUR VIOLATION

Gabrielli, Giudice, NPB433; Buras et al., PLB500;
D'Ambrosio et al., NPB 645; Bobeth et al., hep-ph/0505110

1) No new source of flavour and CP violation

NP contributions also governed by Yukawas

NP only modifies SM top contribution to FCNC & CPV

2a) One Higgs or small/moderate $\tan\beta$

No new operators, full correlations among K & B decays

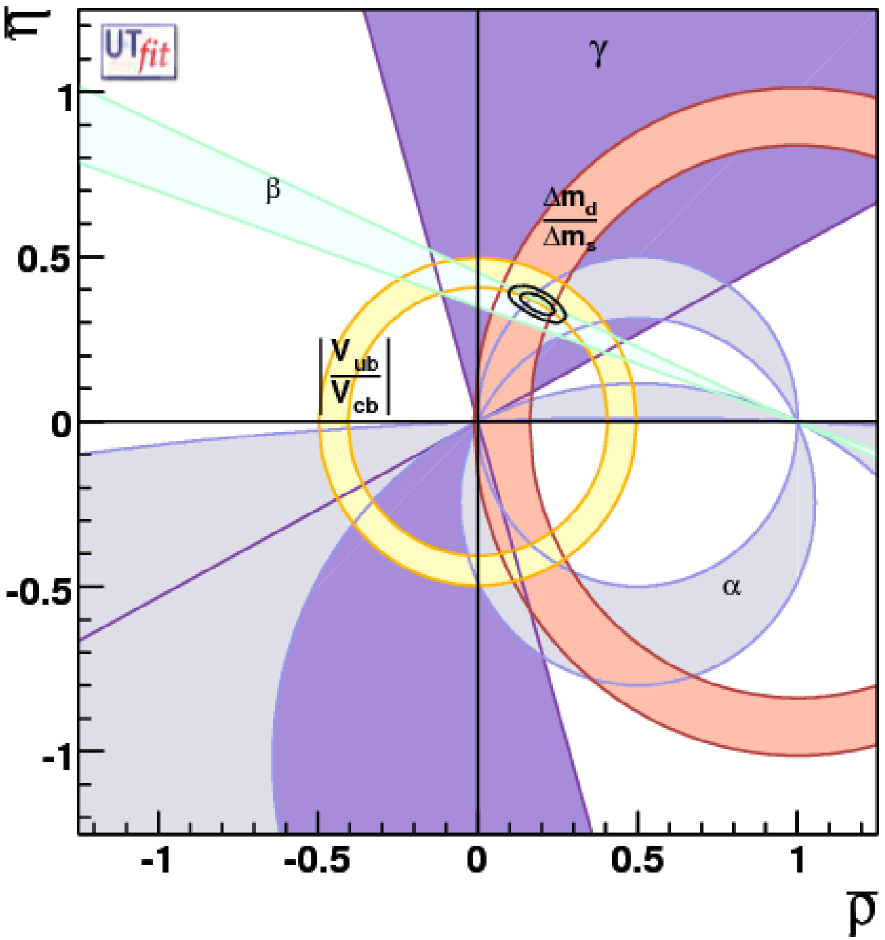
2b) Large $\tan\beta$

New operators, less correlations among K & B decays

The Universal Unitarity Triangle

Buras et al., PLB500

Angle measurements + $\Delta M_d/\Delta M_s$ unaffected by NP in MFV



valid in any MFV model for any value of tanβ

CONSTRAINTS ON MFV SCALE Λ

D'Ambrosio et al., NPB645

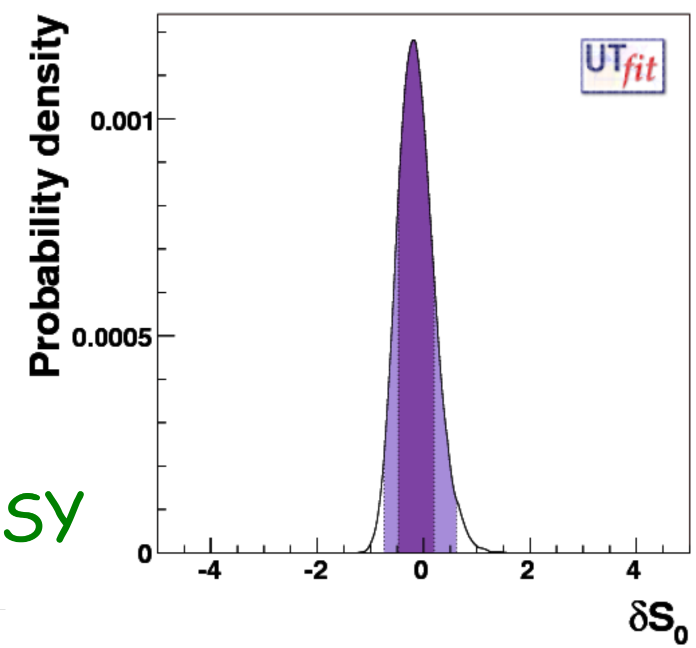
MFV models with one Higgs doublet or 2HD @ low/moderate tanβ: Universal NP effect in the ΔF=2 Inami-Lim function of the top

$$\mathcal{H}_{\rm eff}^{\Delta F=2} = \mathcal{H}_{\rm SM} + \mathcal{H}_{\rm NP} = \left(V_{tq}V^*_{tq'}\right)^2 \left(\frac{S_0(x_t)}{\Lambda_0^2} + \frac{a_{\rm NP}}{\Lambda^2}\right) (\bar{q}'q)_{(V-A)} (\bar{q}'q)_{(V-A)}$$

$$S_0(x_t) \to S_0(x_t) + \delta S_0, \quad |\delta S_0| = O\left(4\frac{\Lambda_0^2}{\Lambda^2}\right), \qquad \Lambda_0 = \frac{\pi Y_t}{\sqrt{2} G_F M_W} \sim 2.4\,\mathrm{TeV}$$

We can bound NP effective scale Λ:

Λ > 5.7 TeV @95% prob. for positive δS_0



Notice: strong int. ⇒ Λ ~ M (mass of new particles), weak int. ⇒ Λ >> M ! Ex. SM, SUSY

UPPER BOUNDS ON RARE DECAYS IN MFV

Bobeth et al., NPB726

Branching Ratios	MFV (95%)	SM (68%)	SM (95%)	exp
$Br(K^+ \to \pi^+ \nu\bar{\nu}) \times 10^{11}$	< 11.9	8.3 ± 1.2	$[6.1, 10.9]$	$(14.7^{+13.0}_{-8.9})$ [19]
$Br(K_L \to \pi^0 \nu\bar{\nu}) \times 10^{11}$	< 4.59	3.08 ± 0.56	$[2.03, 4.26]$	$< 5.9 \cdot 10^4$ [37]
$Br(K_L \to \mu^+\mu^-)_{SD} \times 10^9$	< 1.36	0.87 ± 0.13	$[0.63, 1.15]$	-
$Br(B \to X_s \nu\bar{\nu}) \times 10^5$	< 5.17	3.66 ± 0.21	$[3.25, 4.09]$	< 64 [38]
$Br(B \to X_d \nu\bar{\nu}) \times 10^6$	< 2.17	1.50 ± 0.19	$[1.12, 1.91]$	-
$Br(B_s \to \mu^+\mu^-) \times 10^9$	< 7.42	3.67 ± 1.01	$[1.91, 5.91]$	$< 2.7 \cdot 10^2$ [39]
$Br(B_d \to \mu^+\mu^-) \times 10^{10}$	< 2.20	1.04 ± 0.34	$[0.47, 1.81]$	$< 1.5 \cdot 10^3$ [39]

In MFV models (at low/moderate tan β) rare decays can be only slightly enhanced w.r.t the SM.

Strong suppressions still possible at present.

THE MSSM

- In the MSSM, two classes of contributions to FCNC's:
  - Supersymmetrization of SM contributions ($W \to \tilde{w}$, $t \to \tilde{t}$) + $H^{\pm}$: also present in MFV
  - pure SUSY contributions: $\tilde{g}$ – $\tilde{q}$: requires new sources of flavour violation in squark mass matrices

Hall, Kostelecky & Raby; Gabbiani et al.

THE MSSM W. MFV @ LARGE tanβ

Isidori & Paradisi, hep-ph/0605012

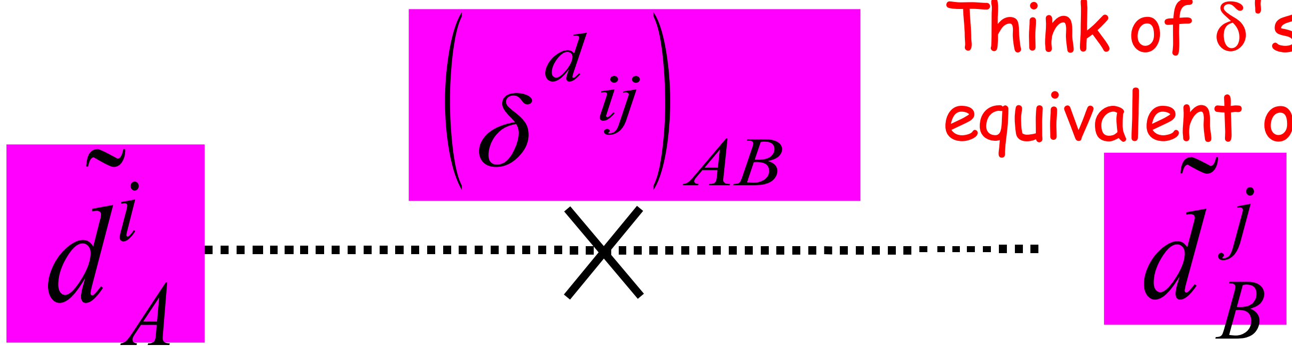
- Consider the MSSM with MFV at very large tanβ and squark masses at the TeV scale
- Only relevant contribution to FCNC from Higgs exchange
- Main effects: small suppression of Δm_s and of BR($B \to \tau \upsilon$), enhancement of BR($B_s \to \mu\mu$)
- Interesting scenario, need more data...

THE GENERAL MSSM

Ciuchini et al., in progress, Preliminary

- We consider a MSSM with generic soft SUSY-breaking terms, but
  - dominant gluino contributions only
  - mass insertion approximation

Think of δ's as SUSY equivalent of CKM mixing



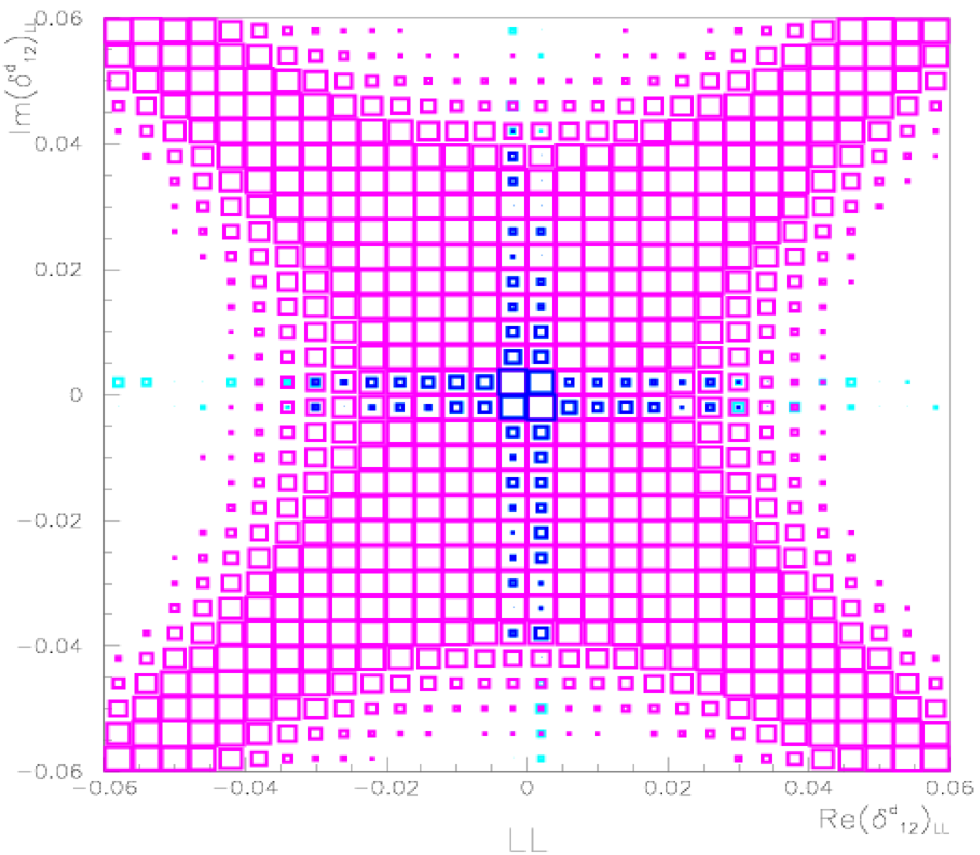
four insertions AB=LL, LR, RL, RR

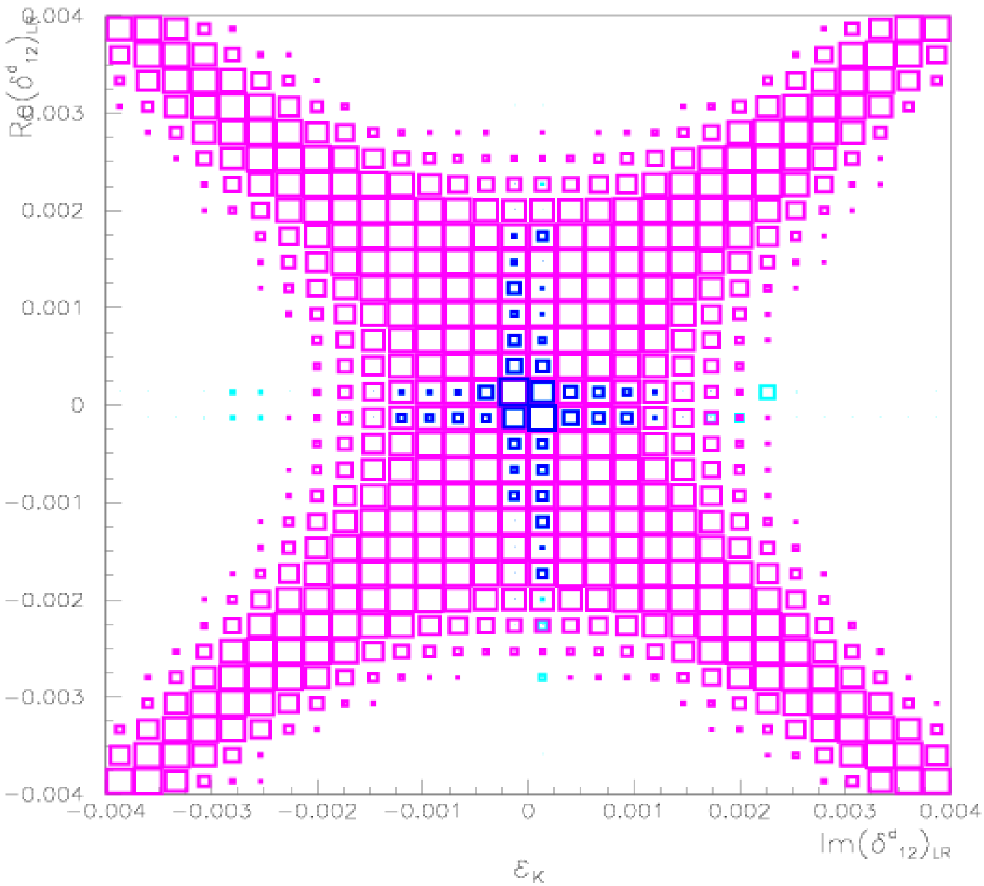
CONSTRAINTS ON δ's

- $\left(\delta^{d}{}_{12}\right)_{AB}$ contribute to Kaon mixing: constraints from Δm_K & ε_K
- $\left(\delta^{d}{}_{13}\right)_{AB}$ contribute to B mixing: constraints from Δm_B & $\sin 2\beta$
- $\left(\delta^{d}{}_{23}\right)_{AB}$ contribute to Bs mixing and $b \to s$ decays:

  constraints from Δm_{Bs}, $b \to s\gamma$, $b \to s l^+ l^-$
- for reference, choose $m_{gl}=m_{sq}=350$ GeV

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



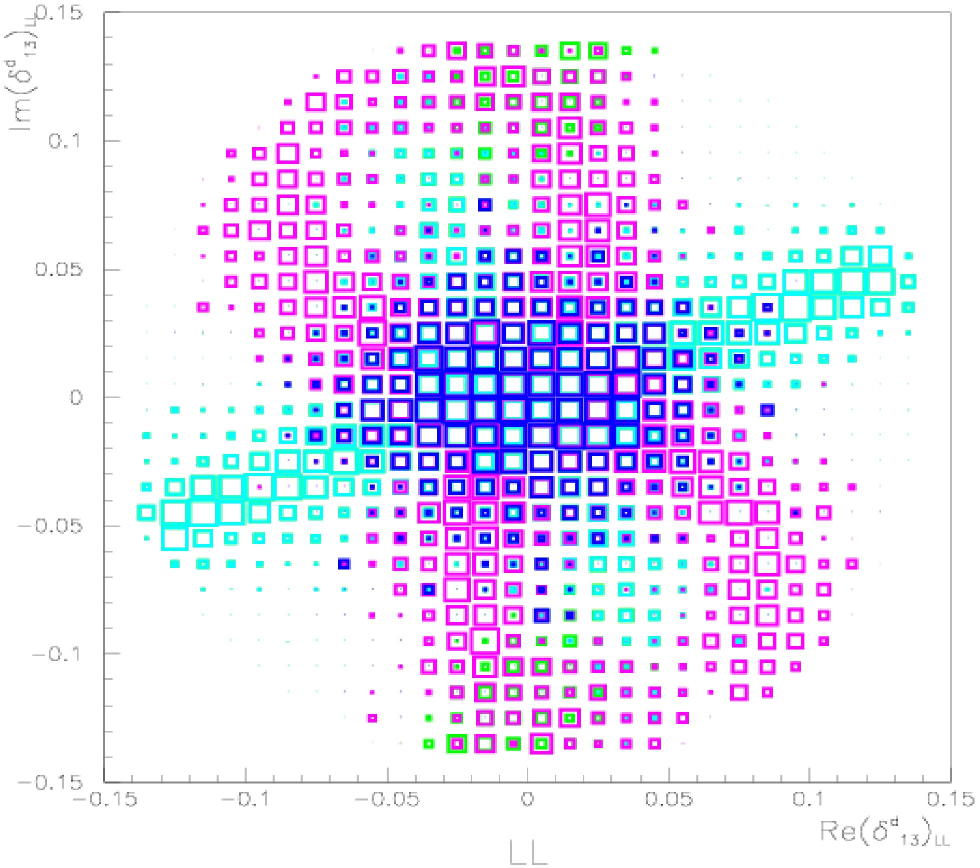


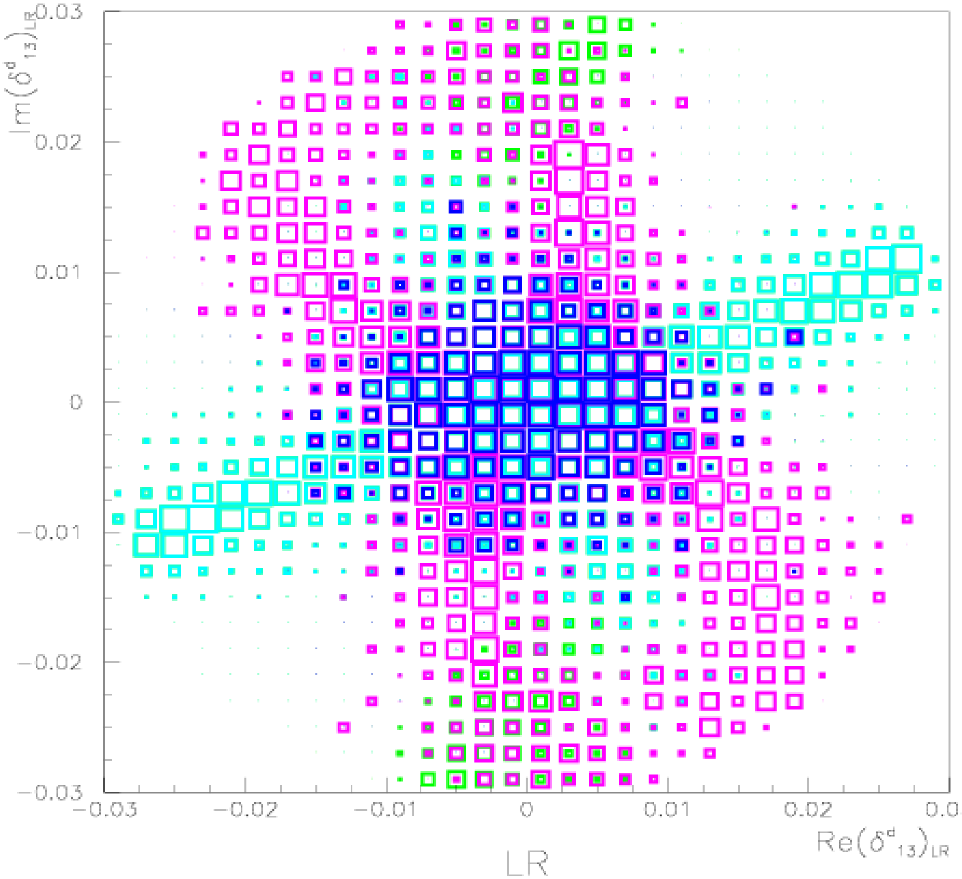
Δm_K only

ε_K only

Δm_K and ε_K

Full NLO analysis, including recently computed NLO corrections to the matching (Ciuchini et al., to appear soon)





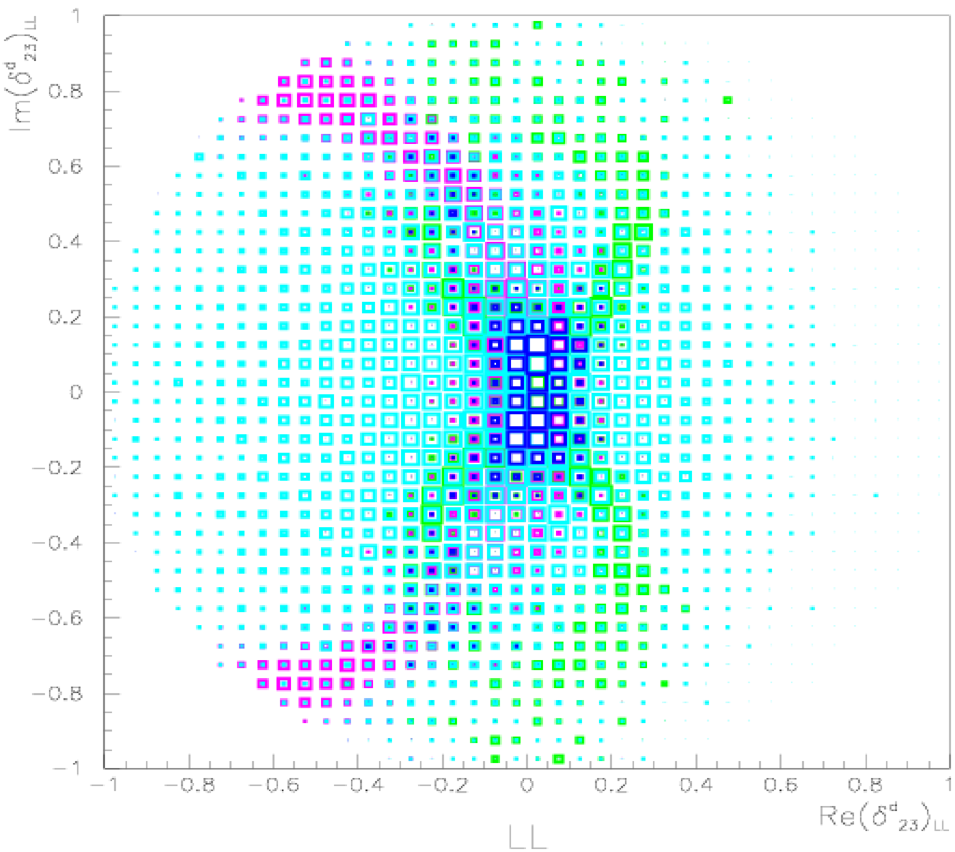
$Re\,(\delta^d{}_{13})_{LL,RR}$ vs $Im\,(\delta^d{}_{13})_{LL,RR}$ $Re\,(\delta^d{}_{13})_{LR,RL}$ vs $Im\,(\delta^d{}_{13})_{LR,RL}$

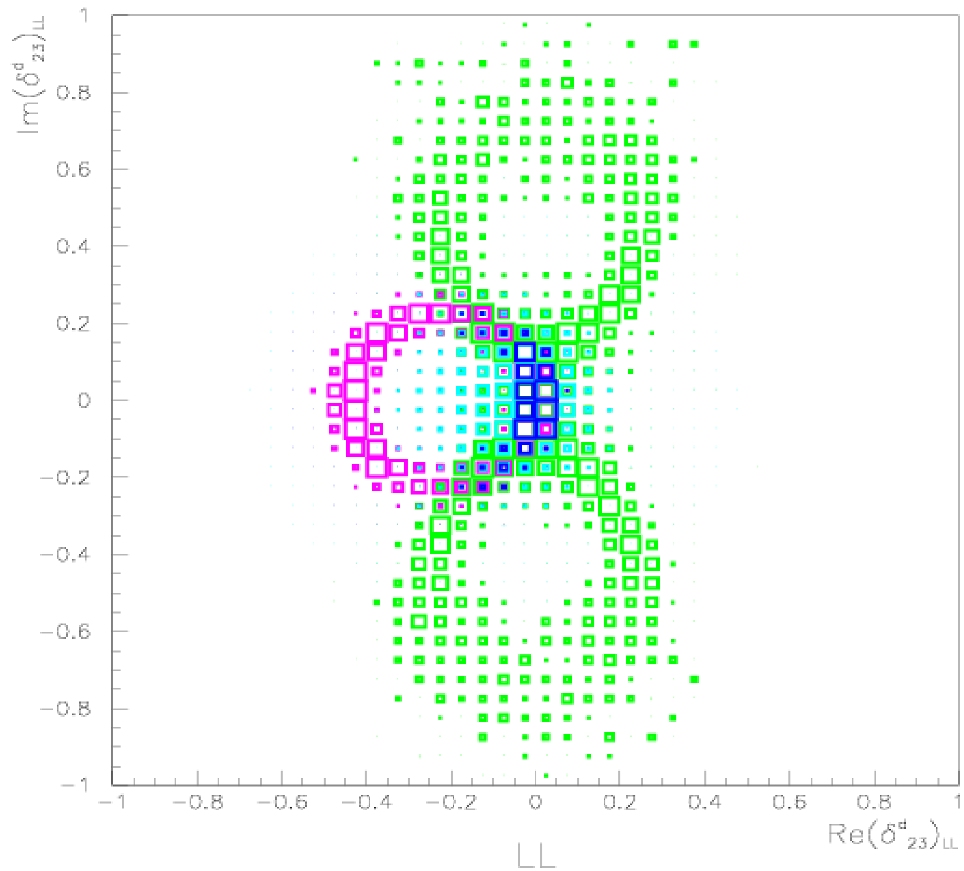
Δm_B only

sin 2β only

sin 2β and cos 2β

All constraints





Re $(\delta^d{}_{23})_{LL}$ vs Im $(\delta^d{}_{23})_{LL}$

tanβ=3

Re $(\delta^d{}_{23})_{LL}$ vs Im $(\delta^d{}_{23})_{LL}$

tanβ=10

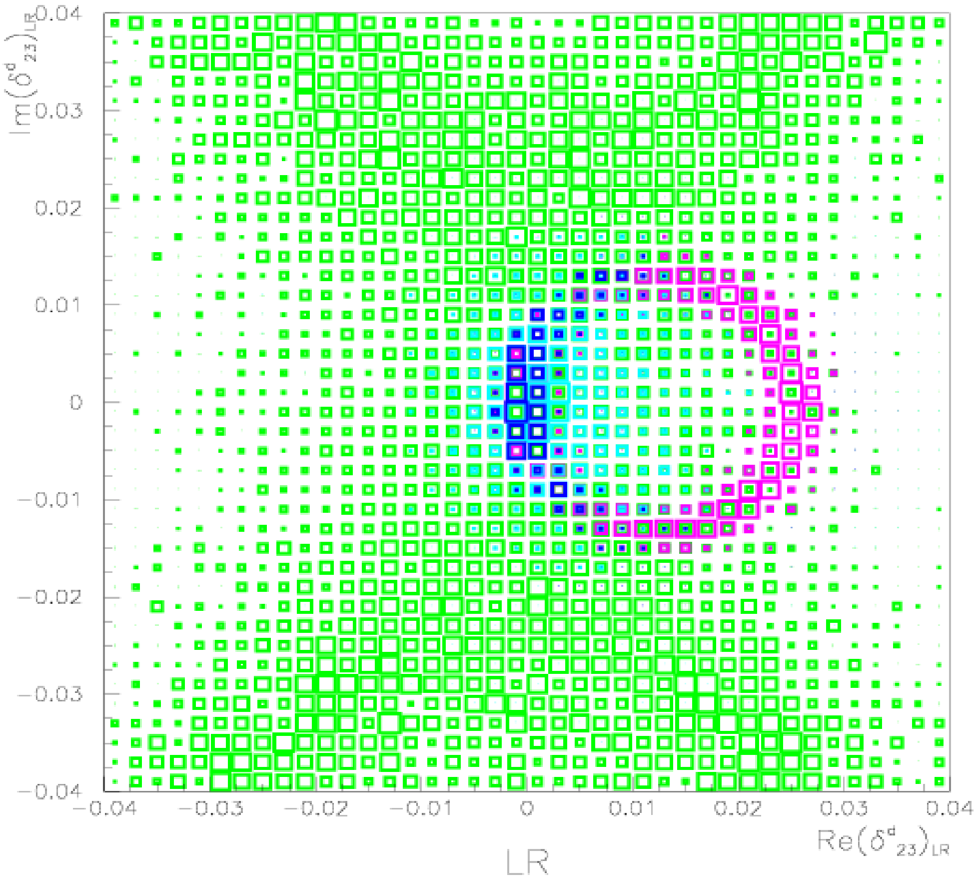
Constraint from $b \to s\, ll$

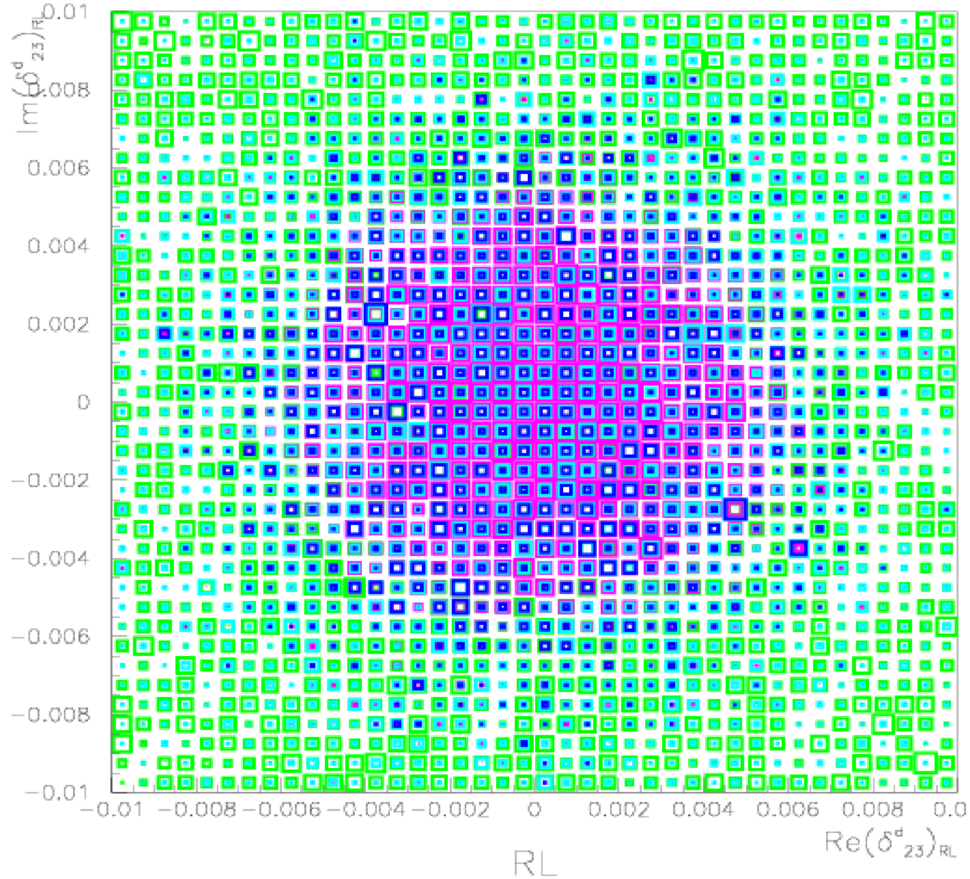
Constraint from $b \to s\, \gamma$

Constraint from Δm_s

All constraints

Contribution to $b \to s$ decays grows with tanβ



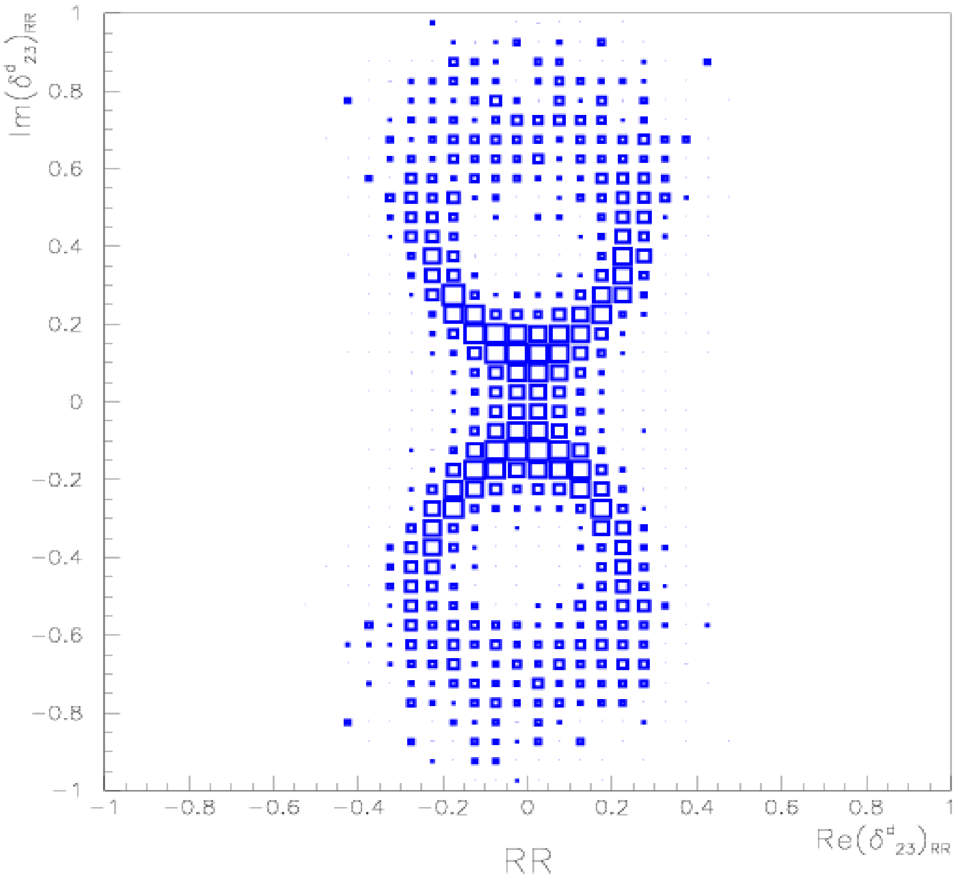


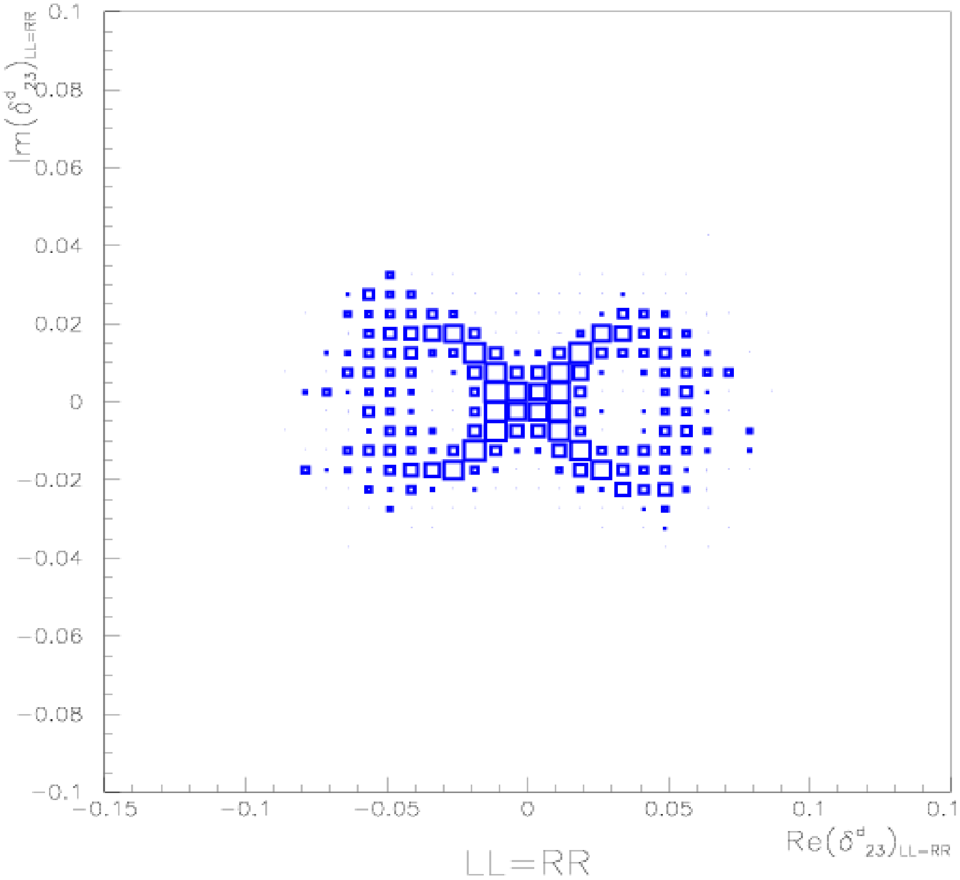
Re $(\delta^d_{23})_{LR}$ vs Im $(\delta^d_{23})_{LR}$

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

LR & RL dominated by BR($b \to s\,\gamma$) & BR($b \to s\, l^+ l^-$)

RL does not interfere with the SM





$Re\,(\delta^d_{23})_{RR}$ vs $Im\,(\delta^d_{23})_{RR}$ $Re\,(\delta^d_{23})_{LL=RR}$ vs $Im\,(\delta^d_{23})_{LL=RR}$

LL & LL=RR dominated by CDF measurement of Δm_s

THE SUSY FLAVOUR PROBLEM

$\left(\delta^d_{12}\right)_{LL,RR}$		$\left(\delta^d_{12}\right)_{LR,RL}$		$\left(\delta^d_{13}\right)_{LL,RR}$		$\left(\delta^d_{13}\right)_{LR,RL}$	
Re	Im	Re	Im	Re	Im	Re	Im
$4\,10^{-2}$	$4\,10^{-2}$	$2\,10^{-3}$	$2\,10^{-3}$	10^{-1}	$5\,10^{-2}$	$2\,10^{-2}$	10^{-2}

$\left(\delta^d_{23}\right)_{LL}$		$\left(\delta^d_{23}\right)_{RR}$		$\left(\delta^d_{23}\right)_{LR}$		$\left(\delta^d_{23}\right)_{RL}$	
Re	Im	Re	Im	Re	Im	Re	Im
0.2	0.8	0.4	1	$5\,10^{-3}$	10^{-2}	10^{-2}	10^{-2}

- Strong constraints on SUSY breaking mechanism:
  - Flavour-universal breaking?
  - Flavour symmetry?

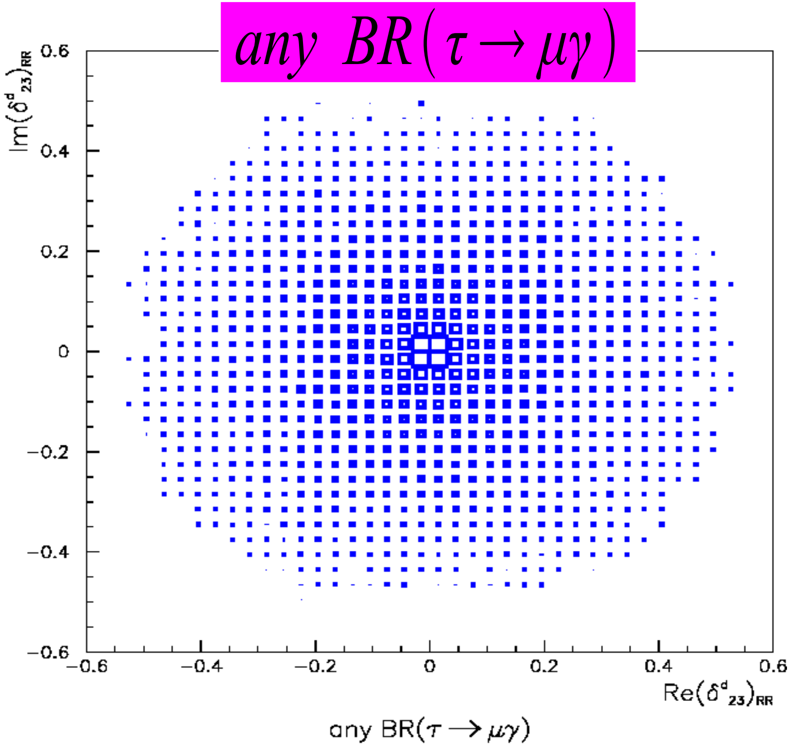
SUSY-GUTs

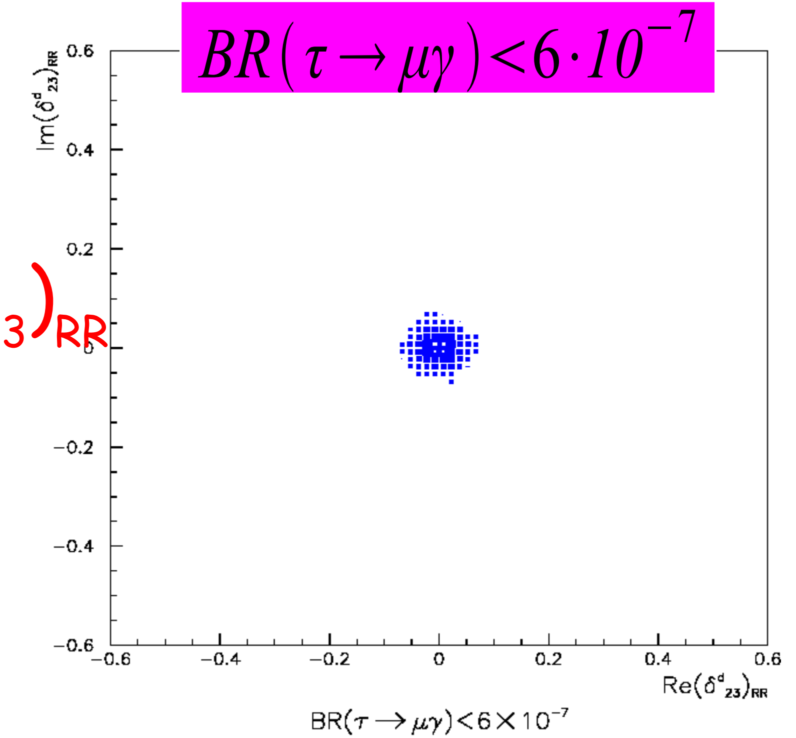
- In an SU(5)-like GUT, quark and leptons are unified, so also squark and sleptons.
- After running down to weak scale, one has:

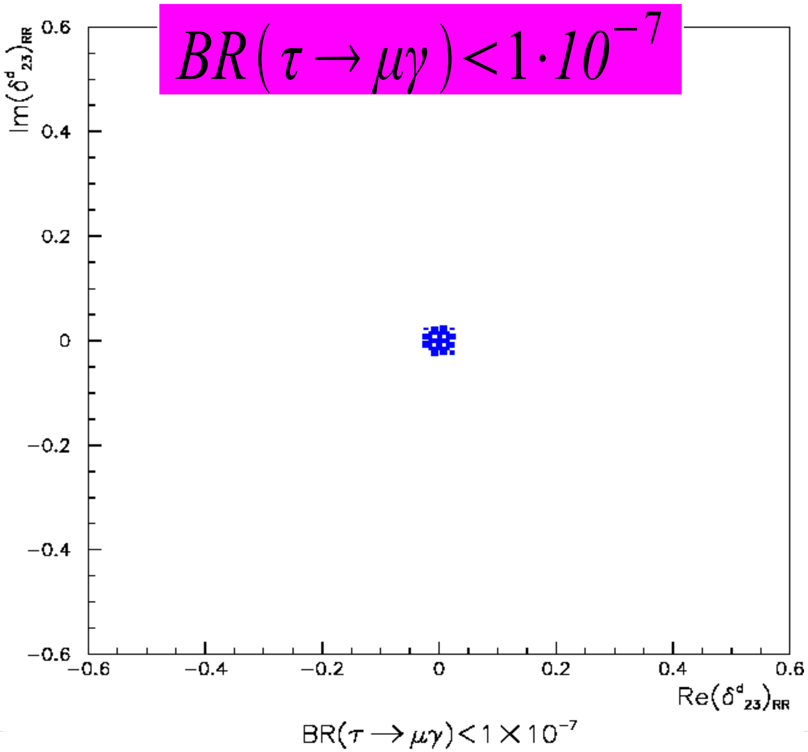
	Relations at weak scale	Additional Conditions at M_{GUT}
(1)	$(\delta^u_{ij})_{RR} \approx (m^2_{e^c}/m^2_{u^c})\ (\delta^l_{ij})_{RR}$	$m^2_{u^c}(0) = m^2_{e^c}(0)$
(2)	$(\delta^q_{ij})_{LL} \approx (m^2_{e^c}/m^2_{Q})\ (\delta^l_{ij})_{RR}$	$m^2_{Q}(0) = m^2_{e^c}(0)$
(3)	$(\delta^d_{ij})_{RR} \approx (m^2_{L}/m^2_{d^c})\ (\delta^l_{ij})_{LL}$	$m^2_{d^c}(0) = m^2_{L}(0)$
(4)	$(\delta^d_{ij})_{LR} \approx (m^2_{L_{avg}}/m^2_{Q_{avg}})\ (m_b/m_\tau)\ (\delta^l_{ij})^\star_{LR}$	$A^e_{ij} = A^d_{ji}$

- Correlations between quark & lepton FCNC!

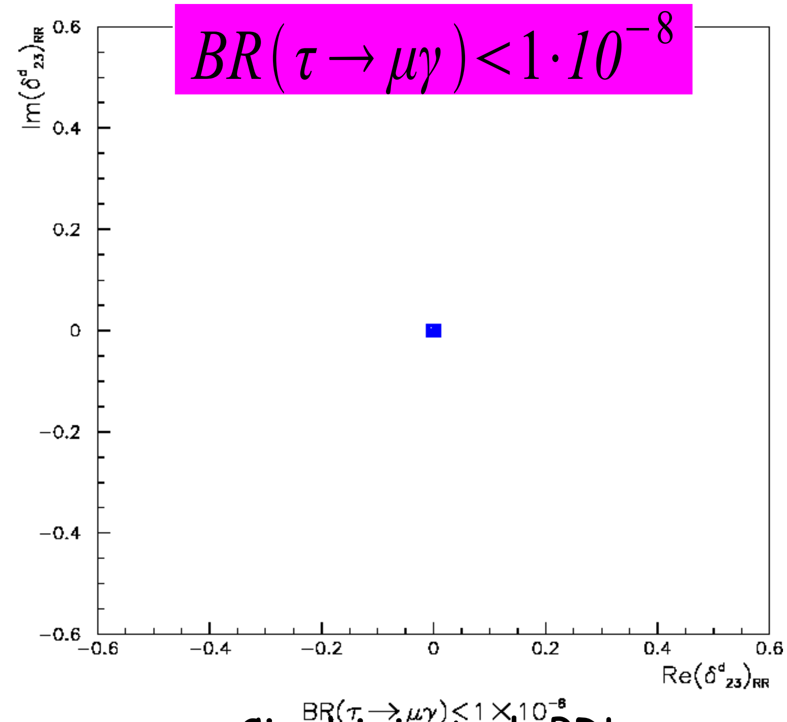
Im $(\delta^d_{23})_{RR}$ vs. Re $(\delta^d_{23})_{RR}$







$m_{\tilde{q}} = m_{\tilde{g}}$
350 GeV



Ciuchini et al, PRL

EXTRA DIMENSIONS

- Combine two ideas:
  - Gauge-Higgs unification: $h = A_5$
    - 5D gauge invariance protects the Higgs mass
    - Higgs interactions are (5D) gauge interactions
    - Higgs mass is calculable

    Manton; Hosotani; Czacki et al; Scrucca et al.
  - Warped spacetime
    - Planck scale gets redshifted to the TeV: solution to the hierarchy problem

    Randall-Sundrum; Agashe et al.

FERMION MASSES

Scrucca, Serone & LS; Agashe, Contino & Pomarol; ...

- In Gauge-Higgs unification, fermion masses come from gauge interactions in the bulk
- To obtain flavour structure, flavours must have different wave functions:

In 5D language: Light fermions localized, heavy fermions in bulk

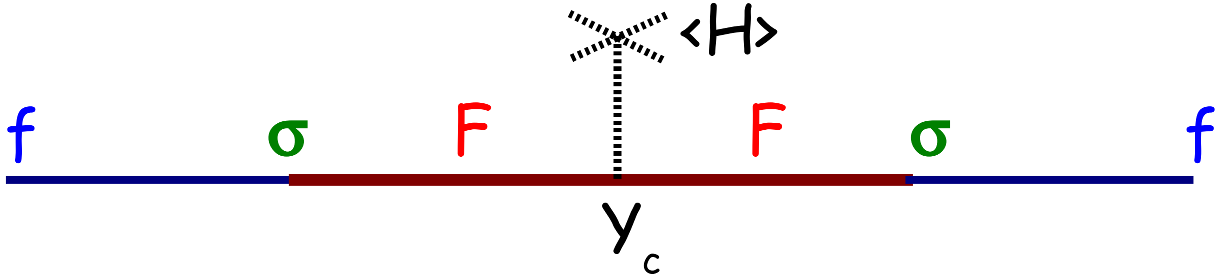
In effective theory language: Light fermions elementary, heavy fermions composite

A GENERAL LAGRANGIAN

- Fermion interactions in extra-dim(-like) models:

$$\mathcal{L}_{\rm ferm} = \bar{f}\sigma F + M\bar{F}F + Y_c\bar{F}HF + g_c\bar{F}GF$$

SM fermion masses are given by



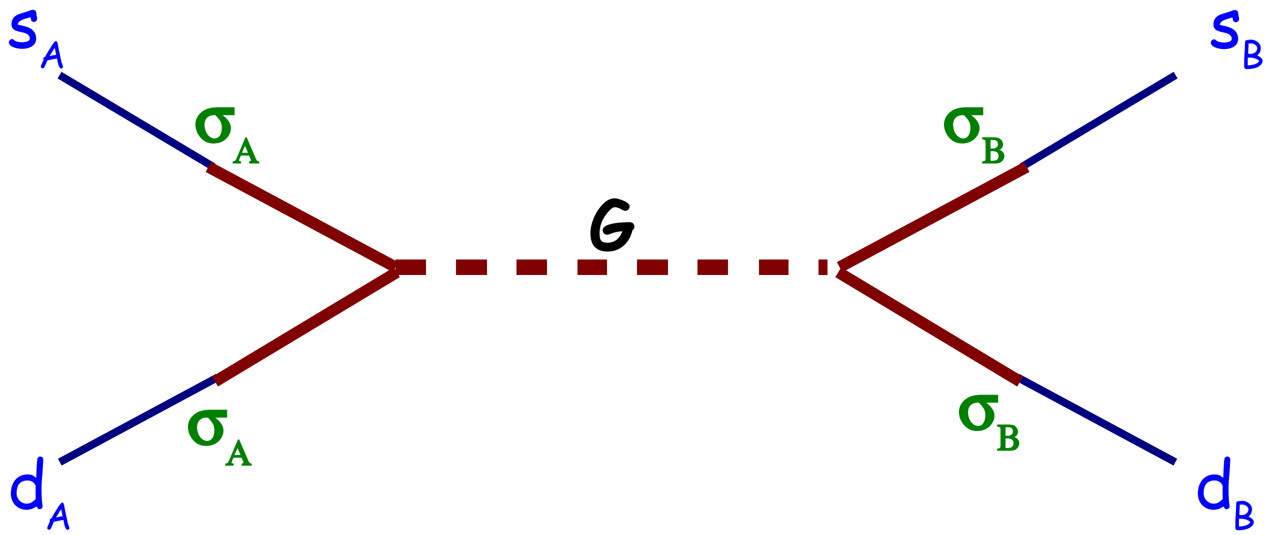
so that

$$m_q \sim \sigma_L \frac{1}{M} Y_c \frac{1}{M} \sigma_R v$$

ΔF=2 PROCESSES

Contino & L.S., in progress - Preliminary

- The relevant Feynman diagram is



$$\mathcal{H}_{\text{eff}} \sim \left(\bar{s}_A \sigma_A \frac{1}{M} g_c T^A \gamma_\mu \frac{1}{M} \sigma_A d_A\right) \left(\bar{s}_B \sigma_B \frac{1}{M} g_c T^A \gamma^\mu \frac{1}{M} \sigma_B d_B\right) \frac{1}{m_{KK}^2}$$

ΔF=2 PROCESSES: RESULTS

- Expressing the unknown couplings and masses in terms of quark masses and mixing angles, we obtain, for A=L and B=R,

$$\varepsilon_K \sim 14\varepsilon_K^{\exp}\left(\frac{g_c}{Y_c}\right)^2\left(\frac{3\mathrm{TeV}}{m_{KK}}\right)^2$$

assuming that CP violating phases are of O(1)

All other ΔF=2 processes are below 20%

ε_K requires $m_{KK} \sim 10$ TeV and/or $g_c/Y_c \sim 1/3$

stronger than precision EW constraints

CONCLUSIONS

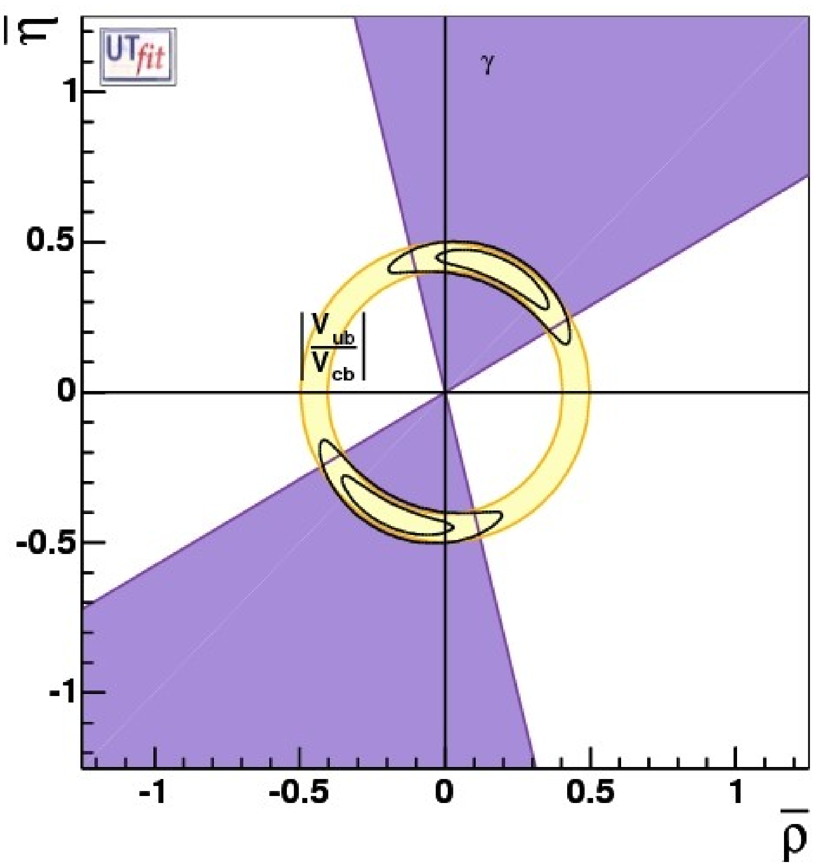
- Flavour physics is a powerful probe of new physics
- Sensitive to scales much higher than m_{EW}:
  - mechanism of SUSY breaking
  - grand unification structure
- Very constraining also for extra dimensions
- LHC-flavour complementarity to explore NP in the near future

BACKUP SLIDES

THE REFERENCE UT

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

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



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

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

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

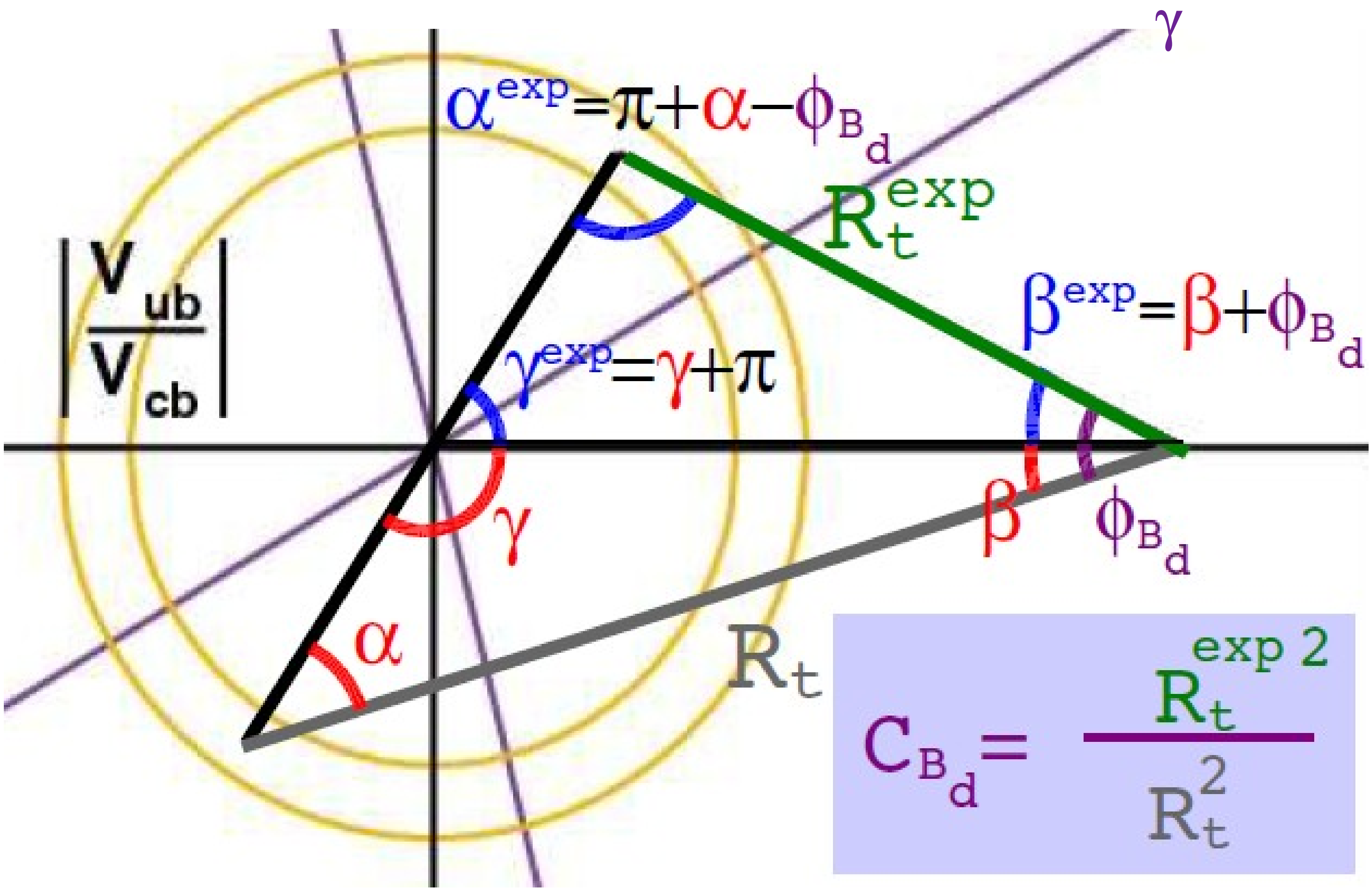
$\gamma = (65 \pm 18)^\circ \cup (-115 \pm 18)^\circ$

$\alpha = (87 \pm 15)^\circ \cup (-46 \pm 15)^\circ$

Any model of new physics must satisfy these constraints

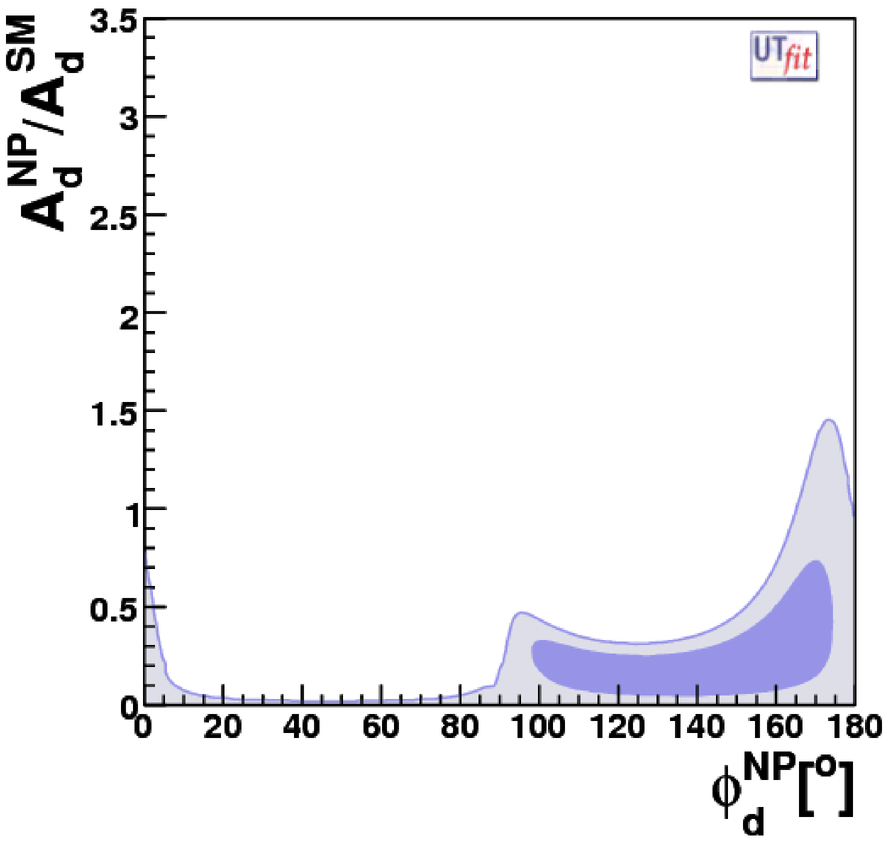
UTfit coll., hep-ph/0501199;
Botella et al., hep-ph/0502133

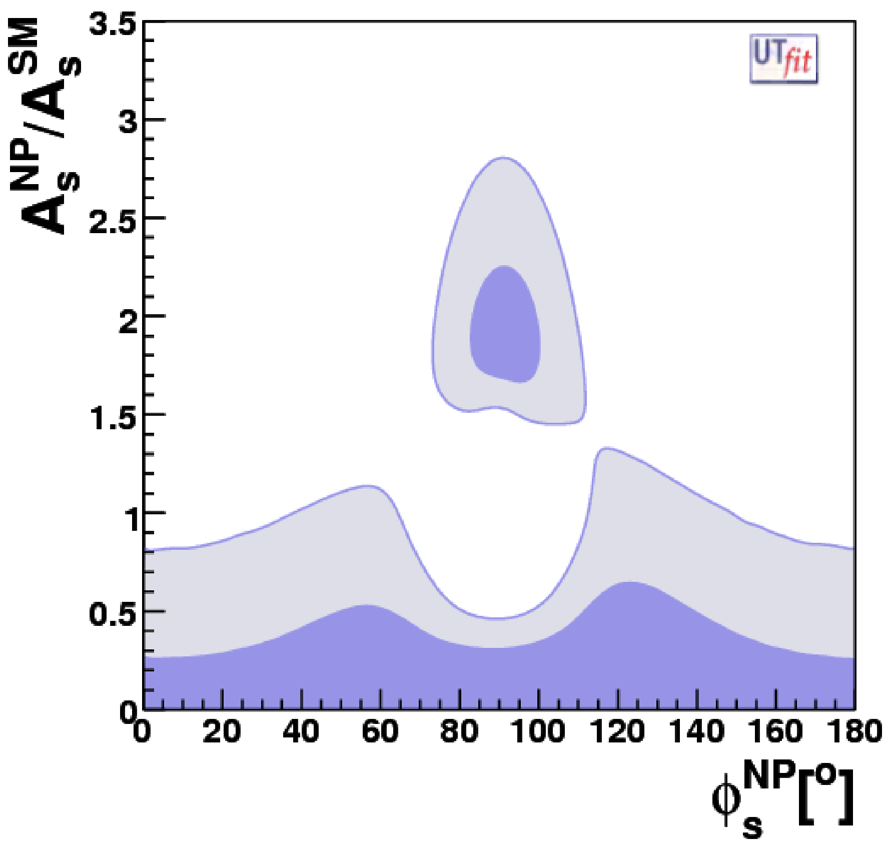
UT constraints in the presence of NP



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

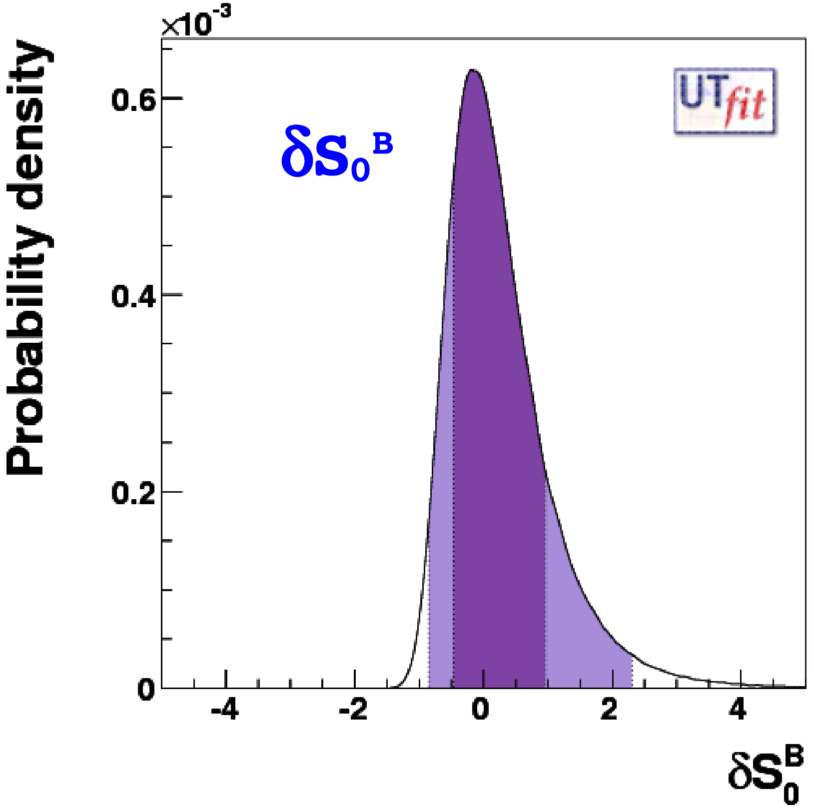
Another look at NP in B_q mixing

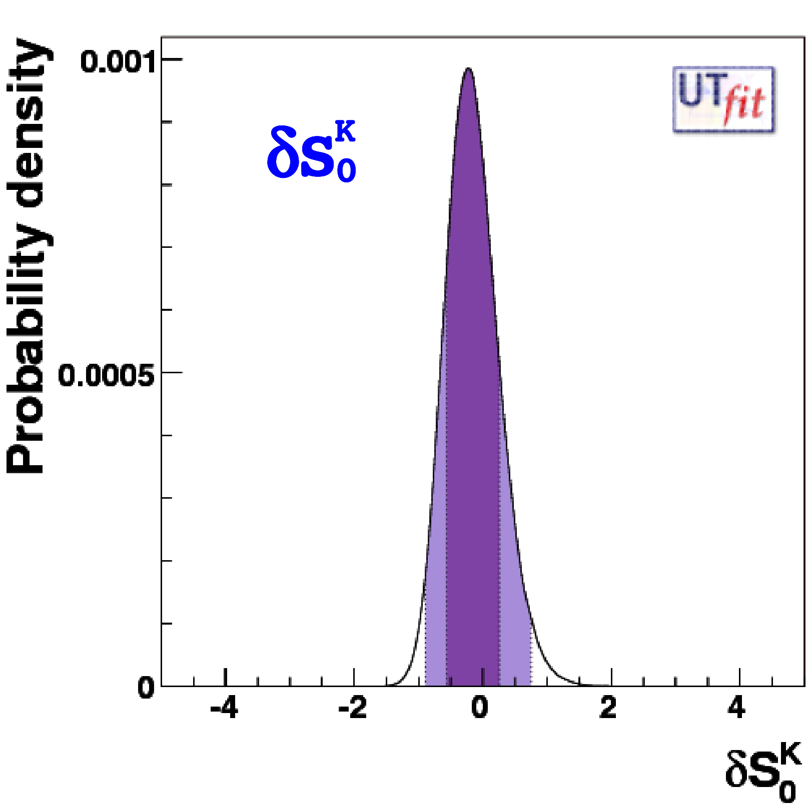




2H + large tanβ: terms proportional to the bottom Yukawa coupling are enhanced and cannot be neglected any more

$$\delta S_0^B \neq \delta S_0^K$$

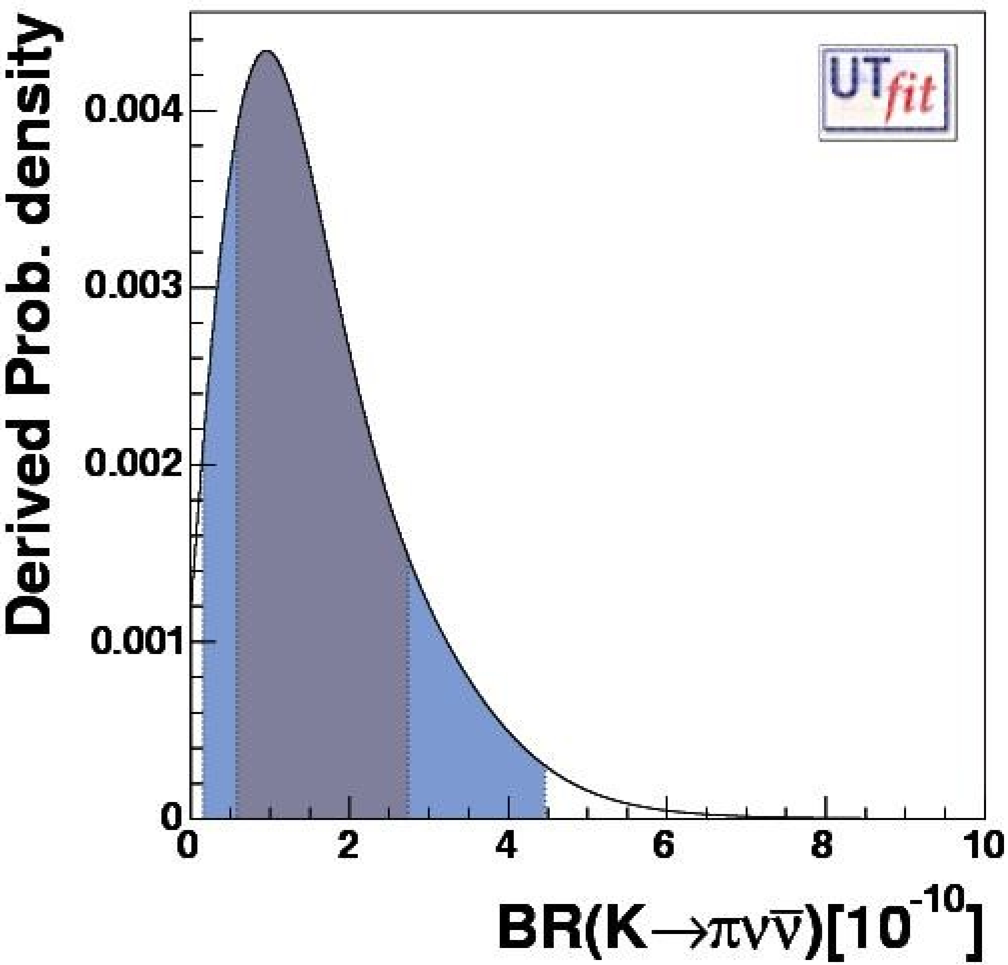


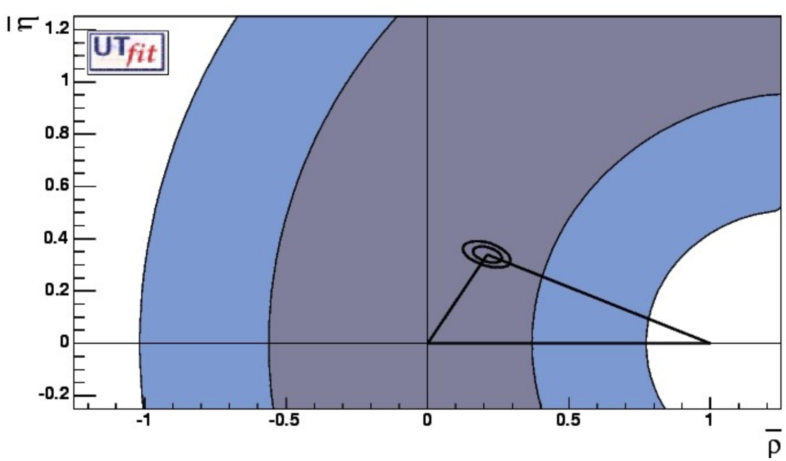


Λ > 5.2 TeV @95% prob.

A COMMENT ON BR($K^+ \to \pi^+\nu\nu$)

The experimental pdf is peaked at the SM prediction:





SM prediction (not using exp):
$(8.3 \pm 1.2)\ 10^{-11}$

RARE DECAYS IN MFV

- What are the constraints on MFV from rare decays?
- What are the predictions for yet unmeasured rare decays? Where could we see effects of MFV? How can we test MFV?

Bobeth et al., NPB726

Identify leading NP contributions:

1) dimension 4 operators: FCNC effective Z vertex

$\Rightarrow C = C_{SM} + \Delta C$

2) dimension 5 operators: (chromo)magnetic penguin

$\Rightarrow C_7^{eff} = (C_7^{eff})_{SM} + \Delta C_7^{eff}$

3) dimension 6 operators: penguins, boxes

$\Rightarrow$ subleading NP contributions to rare decays

Rare decays $\Leftrightarrow$ SM functions(m_t) + ΔC, ΔC_7^{eff}

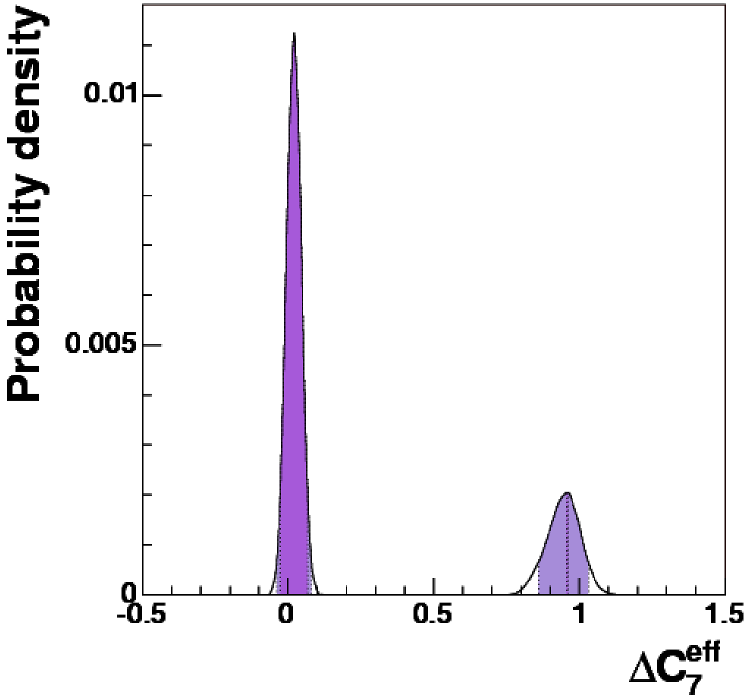
Model-independent analysis in terms of ΔC, ΔC_7^{eff}

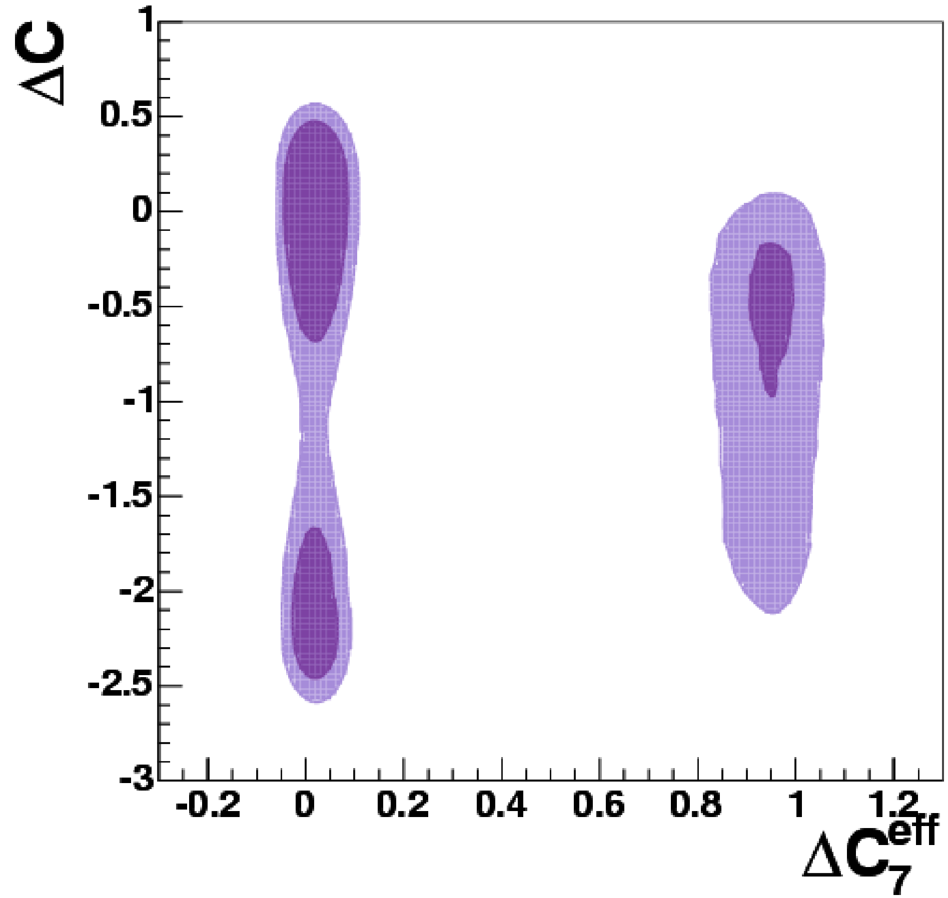
Can be refined in specific MFV models (ex. CMSSM)

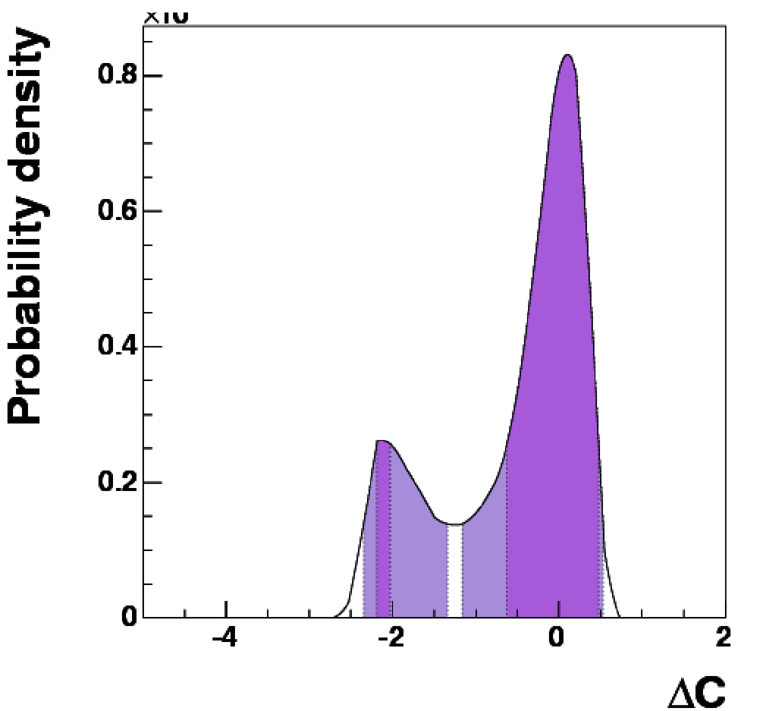
MFV GENERAL ANALYSIS

- ρ, η from the UUT analysis
- ΔC_7^{eff} can be constrained using $BR(B \to X_s \gamma)$
- ΔC can be constrained using $BR(B \to X_s l^+ l^-)$ and $BR(K^+ \to \pi^+ \nu\nu)$
- Get predictions for all other rare decays

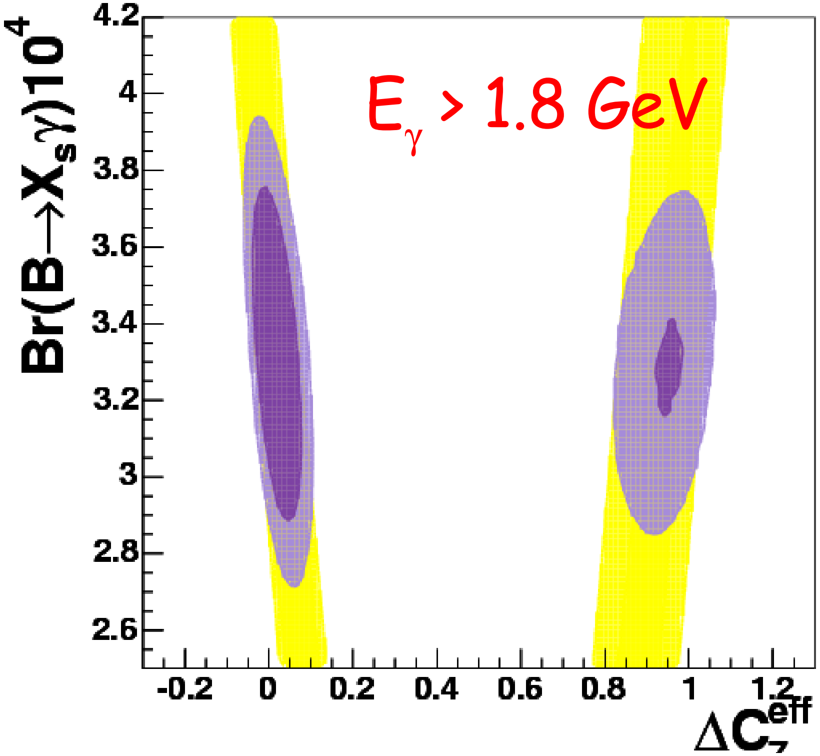
CONSTRAINTS ON NP

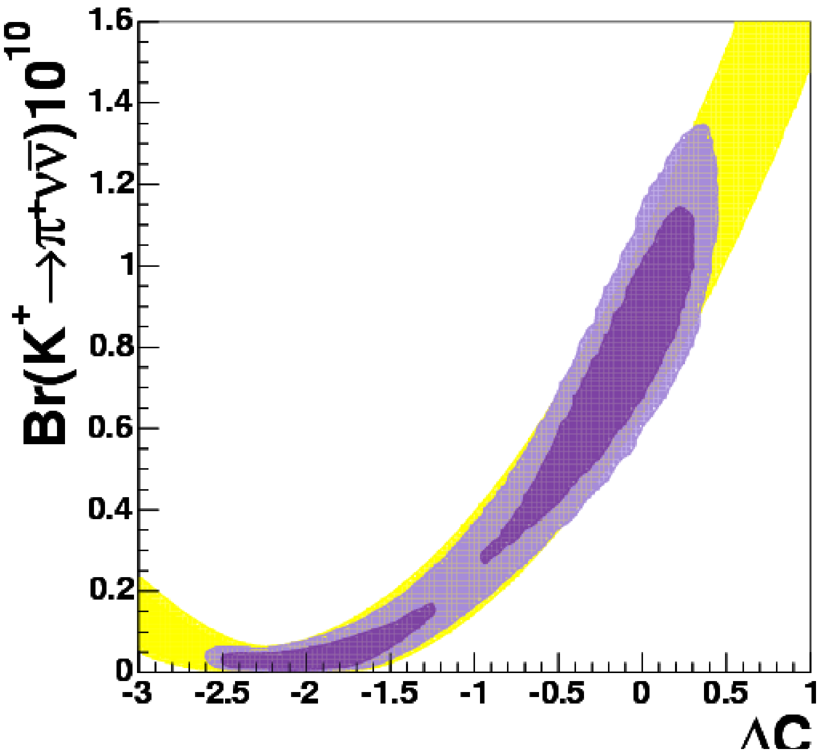


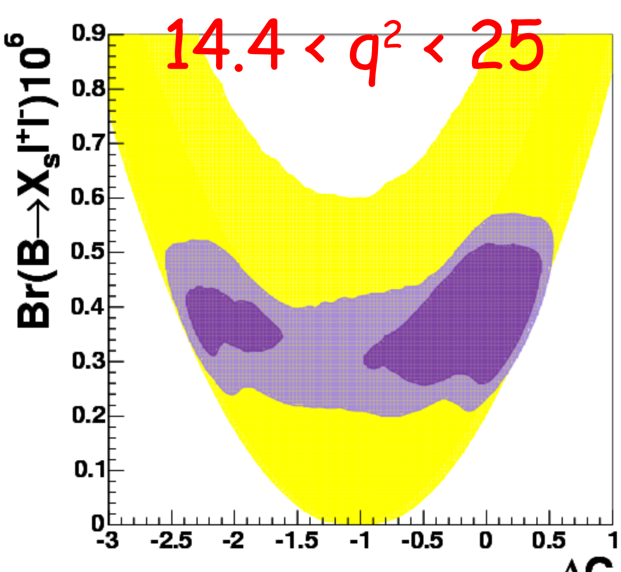


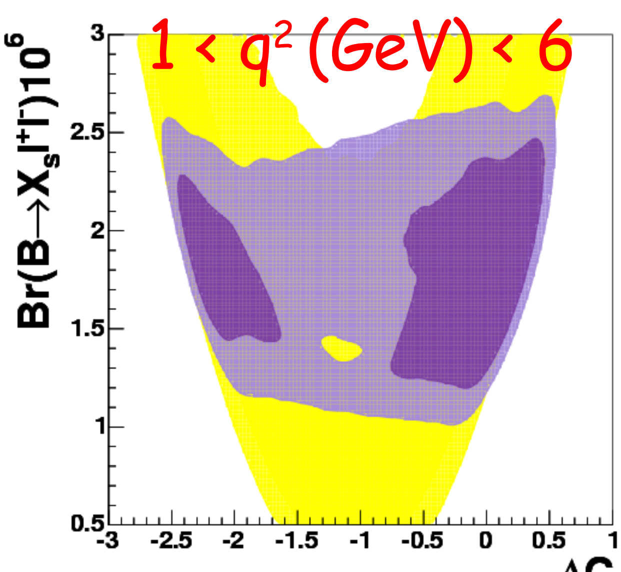


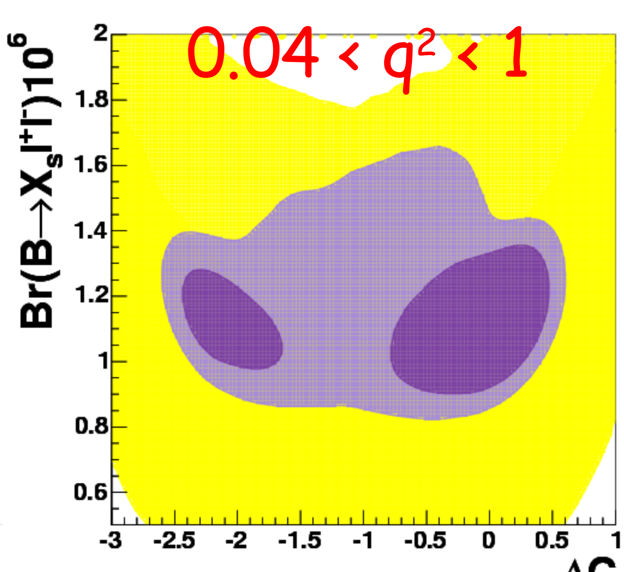
NP CONTRIBUTIONS vs EXP CONSTRAINTS











PREDICTIONS FOR RARE DECAYS