$\not{CP}$ AND FLAVOR STRUCTURE IN SUSY

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$\not{CP}$: worries and hopes in

- Generic SUSY extension of the SM
- SUSY models with NEW $\not{CP}$ PHASES, BUT **NO NEW** FLAVOUR STRUCTURE (SUSY breaking and FLAVOUR origin unrelated)
- SUSY models with NEW $\not{CP}$ PHASES AND NEW FLAVOUR STRUCTURE (SUSY break related to the origin of flavour)

NEW SOURCES OF CP $\not{}$

[illegible] *** needed to have an efficient baryogenesis?

CP $\not{}$ →

- stringent constraints on new physics (if new physics is at scales close to the elw. scale)
- new physics may lead to (hopefully) sizeable departures from the SM predictions

→ [illegible]

SUSY WITH FLAVOR UNIVERSALITY

$$L_{SUSY} \Rightarrow \mu \tilde{H}_1 \tilde{H}_2$$

$$L_{SUSY} \Rightarrow m_0^2 \tilde{f}_i \tilde{f}_i^*$$

$$A \left[h_U \tilde{Q} H_2 \tilde{u}^c + h_D \tilde{Q} H_1 \tilde{d}^c + h_L \tilde{L} H_1 \tilde{e}^c \right]$$

$$+ \mu B H_1 H_2$$

$$+ M \left[\tilde{g}\tilde{g} + \tilde{W}\tilde{W} + \tilde{B}\tilde{B} \right]$$

2 physical (unremovable) phases: $\varphi_A, \varphi_B \rightsquigarrow \arg(M^*B)$

$\hookrightarrow \arg(AM^*)$

SUSY WITHOUT FLAVOR UNIVERSALITY

$$L_{SUSY} \Rightarrow \mu$$

$$L_{SUSY} \Rightarrow m_{ij}^2 \tilde{f}_i \tilde{f}_j^*$$

$$A_U \tilde{Q} H_2 \tilde{u}^c$$

$$A_D \tilde{Q} H_1 \tilde{d}^c$$

$$A_L \tilde{L} H_1 \tilde{e}^c$$

$$\mu B H_1 H_2$$

$$M_3 \tilde{g}\tilde{g}$$

$$M_2 \tilde{W}\tilde{W}$$

$$M_1 \tilde{B}\tilde{B}$$

many new $\not{CP}$ phases

A) $W = \mu \underbrace{H_u H_d}_{\to\ \text{superfields}}$

B) $\mathcal{L} = -\frac{1}{2} m_{\tilde{g}} \tilde{g}\tilde{g} - A\left(h^u Q H_u u^c - h^d Q H_d d^c - h^e L H_d e^c\right)$

$- m_{12}^2 H_u H_d + h.c.$

$\hookrightarrow$ scalar higgses (scalar components of the H_u H_d superfields)

$m_{12}^2 \equiv B\mu$

$\mu, m_{\tilde{g}}, A, m_{12}^2 \to$ **4 phases**

$\downarrow$

Dugan, Grinstein, Hall — ONLY 2 COMBINATIONS ARE PHYSICAL

(in the absence of A) and B) $\Rightarrow$ two additional global $U(1)$ symm. $\Rightarrow$ $U(1)_R$ and $U(1)_{PQ}$

	$m_{\tilde g}$	A	m_{12}^2	μ	H_u	H_d	Qu^c	Qd^c	Le^c
$U(1)_{PQ}$	0	0	−2	−2	1	1	−1	−1	−1
$U(1)_R$	−2	−2	−2	0	1	1	1	1	1

Dimopoulos, Thomas

μ, $m_{\tilde g}$, A, m_{12}^2 treated as spurions which break the $U(1)_{PQ}$ and $U(1)_R$ symmetries $\Rightarrow$ way to ... the selection rules)

physical observables depend on combinations of μ, $m_{\tilde g}$, A, m_{12}^2 that are neutral under $U(1)_{PQ}$ and $U(1)_R$ $\Rightarrow$ $m_{\tilde g}\,\mu\,(m_{12}^2)^*$ $\quad A\mu(m_{12}^2)^*$

$A\, m_{\tilde g}$

two of their phases are independent

$\phi_A = \arg(A^* m_{\tilde g})\ ;\ \phi_B = \arg\left(m_{\tilde g}\,\mu\,(m_{12}^2)^*\right)$

- IN A GENERIC SUSY EXTENSION OF THE SM

- QUANTIFY THE SEVERITY OF THE CONSTRAINTS FROM ε, ε'/ε

- IS IT POSSIBLE TO SATURATE ε and ε' WITH THE SUSY CONTRIBUTIONS TO $CP\!\!\!/$?

- GIVEN ALL EXISTING BOUNDS ON FCNC (in particular $b \to s\gamma$ and $B_d - \bar{B}_d$ mixing) HOW LARGELY CAN SUSY $CP\!\!\!/$ in B PHYSICS DEVIATE FROM THE SM EXPECTATIONS ?

HOW TO ACCOUNT FOR FCNC IN GENERAL SUSY MODELS

$\tilde{g}$ - fermion - sfermion

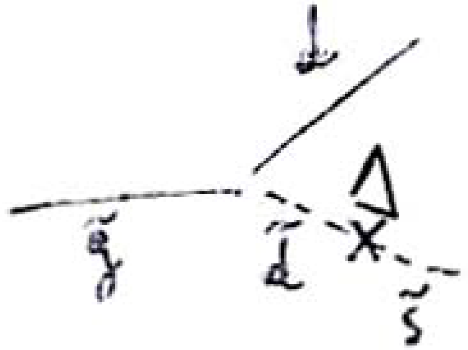
FCNC vertices without a detailed knowledge of the sfermion mass matrices:

ex: $M_q \rightarrow \begin{array}{c|cc} & s & d \\ \hline s & a & b \\ d & c & d \end{array}$ $\qquad$ $M^2_{\tilde{q}} \rightarrow \begin{array}{c|cc} & \tilde{s} & \tilde{d} \\ \hline \tilde{s} & a' & b' \\ \tilde{d} & c' & d' \end{array}$

$\Big\downarrow$ U, V rotations $\qquad\qquad\qquad$ $\Big\downarrow$ U, V rotations

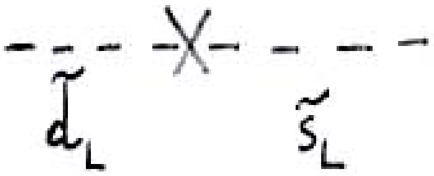
$M^{diag}_q \rightarrow \begin{pmatrix} m_s & \\ & m_d \end{pmatrix}$ $\qquad$ $M'^2_{\tilde{q}} = \begin{pmatrix} \tilde{m}^2 & \Delta \\ \Delta & \tilde{m}^2 \end{pmatrix}$

$\Delta \ll \tilde{m}^2$

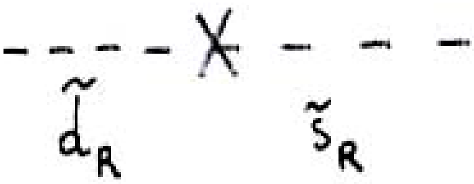


amount FCNC $\dfrac{\Delta}{\tilde{m}^2} \equiv \delta$

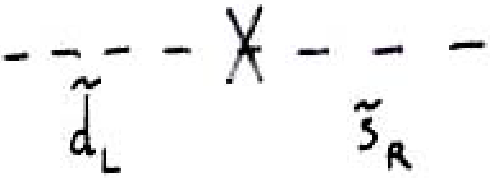
Hall, Raby, Kostelecki



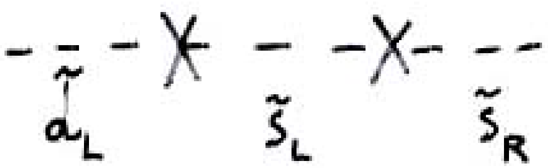
$$\left(\delta^d_{12}\right)_{LL}$$



$$\left(\delta^d_{12}\right)_{RR}$$



$$\left(\delta^d_{12}\right)_{LR}$$



$$\left(\delta^d_{12}\right)_{LL} \cdot \left(\delta^d_{22}\right)_{LR}$$

$$\vdots$$

CONSTRAINTS ON δ's

FROM $\tilde{g}$ EXCHANGE

Gabbiani, A.M.
Hagelin et al.
Nir, Seiberg
Gabbiani, Gabrielli, A.M., Silvestrini
Bagger, Matcher, Zhan

ex. : ΔM_K , ε_K

NLO QCD corrections to $\Delta S = 2$ H_{eff}

+

Lattice computation of full set of B_K Ciuchini et al

$$\left| Re\left(\delta^d_{12}\right)^2_{LL} \right| < 2 \times 10^{-4} \qquad \left| Im\left(\delta^d_{12}\right)^2_{LL} \right| < 3.6 \times 10^{-6}$$

$$\left| Re\left(\delta^d_{12}\right)^2_{LR} \right| < 8 \times 10^{-6} \qquad \left| Im\left(\delta^d_{12}\right)^2_{LR} \right| < 10^{-7}$$

$$\left| Re\left(\delta^d_{12}\right)_{LL}\left(\delta^d_{12}\right)_{RR} \right| < 10^{-6} \qquad \left| Im\left(\delta^d_{12}\right)_{LL}\left(\delta^d_{12}\right)_{RR} \right| < 1.7 \times 10^{-1}$$

for $m_{\tilde{q}} = m_{\tilde{g}} = 500$ GeV

limits scale with $\sim \left(m_{\tilde{q}}(\text{GeV}) / 500\text{ GeV}\right)^2$

CP CHALLENGING SUSY

$$\varepsilon \Rightarrow \begin{cases} \sqrt{\mathrm{Im}\,(\delta^d_{12})^2_{LL}} < 3 \cdot 10^{-3} \\ \sqrt{\mathrm{Im}\,(\delta^d_{12})^2_{LR}} < 3 \cdot 10^{-4} \end{cases}$$

$$\varepsilon' \Rightarrow \begin{cases} \left|\mathrm{Im}\,(\delta^d_{12})_{LL}\right| < 5 \cdot 10^{-1} \\ \left|\mathrm{Im}\,(\delta^d_{12})_{LR}\right| < 2 \cdot 10^{-5} \end{cases}$$

Gabbiani, A.M ;
Hagelin et al. ;
Nir, Seiberg ;
Gabbiani, Gabrielli, A.M., Silvestrini ;
Bagger, Matchev, Zhang ;
Ciuchini et al.

$$d^e_n \Rightarrow \mathrm{Im}\,(\delta^d_{11})_{LR} < 10^{-6}$$

for $m_{\tilde{q}} = m_{\tilde{g}} = 500$ GeV

$$d^e_e \Rightarrow \mathrm{Im}\,(\delta^\ell_{11})_{LR} < 10^{-7}$$

for $m_{\tilde{\ell}} = m_{\tilde{\gamma}} = 100$ GeV ([illegible] scales as [illegible])^2

$$\varepsilon \Rightarrow \ \mathrm{Im}\left(\delta^d_{12}\right)^2_{LR} = 2\,\mathrm{Im}\left(\delta^d_{12}\right)_{LR}\ \mathrm{Re}\left(\delta^d_{12}\right)_{LR} < 10^{-7}$$

$$\varepsilon' \Rightarrow \ \mathrm{Im}\left(\delta^d_{12}\right)_{LR} < 2\cdot 10^{-5}$$

only possibility to saturate both ε and ε'

$$\begin{cases} \mathrm{Im}\left(\delta^d_{12}\right)_{LR} \simeq 2\cdot 10^{-5} \\ \mathrm{Re}\left(\delta^d_{12}\right)_{LR} \simeq 2\cdot 10^{-3} \end{cases}$$

from $K-\bar{K} \Rightarrow \ \mathrm{Re}\left(\delta^d_{12}\right)^2_{LR} \simeq \left(\mathrm{Re}\left(\delta^d_{12}\right)_{LR}\right)^2 < 8\cdot 10^{-6}$

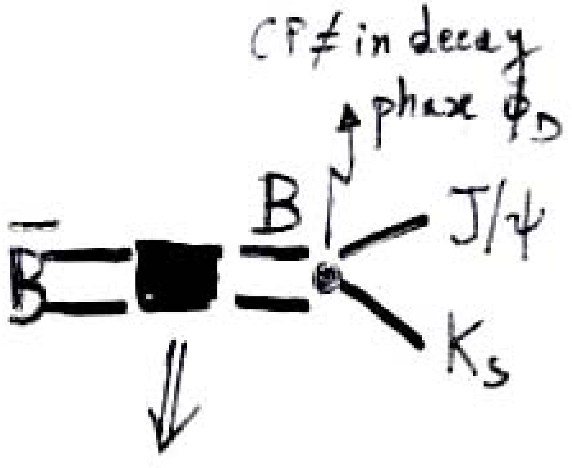
$\Longrightarrow \mathrm{Re}\left(\delta^d_{12}\right)_{LR} \simeq 2\cdot 10^{-3}$ just at the border of a possible saturation also of $K-\bar{K}$

if $\mathrm{Re}\left(\delta^d_{12}\right)_{LR} \simeq \mathrm{Im}\left(\delta^d_{12}\right)_{LR} \simeq 10^{-5}$

$\Downarrow$

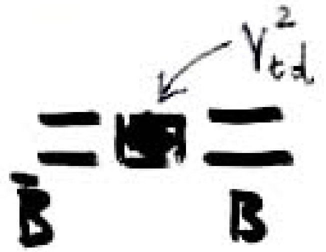
then the SUSY $CP\!\!\!/$ contributions can saturate ε' but they are negligible for $\varepsilon \Rightarrow$ possibility of explaining the "large" ε' through SUSY, while ε would be an SM effect

WILL SUSY SHOW UP IN CP≠ B DECAYS ?



CP≠ in mixing ⇒ phase ϕ_M

Nir, Quinn ;
Gronau, London ;
Grossman, Nir, Rattazzi

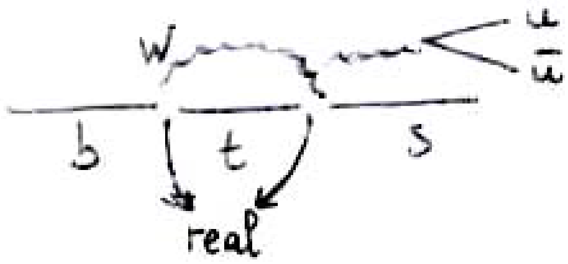


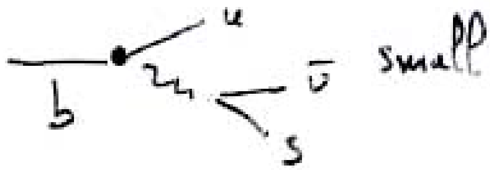
Ciuchini, Franco, Martinelli, A.M. and Silvestrini ; Grossman and Worah ; Barbieri and Strumia

if only one decay amplitude

⇒ CP≠ asymmetry depends on $\phi_M + \phi_D$

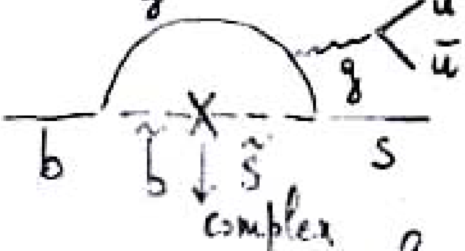
ex.: $B \to K_S \pi^0$





$$r_{SM} = \left(\frac{A_{subleading}}{A_{leading}}\right) < 8\%$$

SUSY :



$$r_{SUSY} = \left(\frac{A_{SUSY}}{A_{SM}}\right) \simeq 0.4 - 0.7$$

for SUSY masses ~ 250 GeV and maximal SUSY phase

$B \to J/\psi K_S$ $\quad r_{SUSY} < 0.10 \quad r_{SM} \sim 0$

$B \to \phi K_S$ $\quad r_{SUSY} \sim 0.4-0.7 \quad r_{SM} < 8\%$

$B \to D^0 \pi^0$ $\quad r_{SUSY} \sim 0 \quad r_{SM} < 4\%$

$\Rightarrow$ in SM all the above decays

$B_d \to \pi^0 K_S$; $B_d \to \phi K_S$;

$B_d \to J/\psi K_S$; $B_d \to D^0 \pi^0$

measure the MIXING PHASE $\beta \leftrightarrow V_{td}$

when SUSY is included some decays ($B \to D^0 \pi^0$) are not affected ($\phi = \phi_M \Rightarrow \beta$)

some may be significantly shifted ($B \to J/\psi K_S$)

($\phi = \phi_M + \phi_D \to$ comes from r_{SUSY} up to 10%)

some may be completely different ($B \to \phi K_S$, $B \to \pi K_S$)

($\phi = \phi_M + \phi_D \to$ from r_{SUSY} up to 70%)

- SUSY MODELS WITH OR WITHOUT FLAVOUR UNIVERSALITY

  - ε, ε'/ε

  - d_n^e

WHY ARE FCNC CONVENIENTLY SUPPRESSED IN MSSM (with universality)

UNIVERSALITY

— scale of Supergrav. breaking

ex. $\tilde{s}_L$-$\tilde{d}_L$

$$M^2_{\tilde{q}} = \begin{pmatrix} \tilde{m}^2 & 0 \\ 0 & \tilde{m}^2 \end{pmatrix} + m_d m_d^+$$

$m_d =$ (s-d) mass matrix

RGE

$\tilde{d}_L \tilde{d}_L^*$ contribution

— Fermi scale

$$M^2_{\tilde{q}_{LL}} = \begin{pmatrix} \tilde{m}^2 & 0 \\ 0 & \tilde{m}^2 \end{pmatrix} + m_d m_d^+ + c\, m_U m_U^+$$

$m_U =$ (u-c) mass matrix

in the basis where we diagonalize the q mass matrices

$$M^2_{\tilde{q}_{LL}} = \begin{pmatrix} \tilde{m}^2 & 0 \\ 0 & \tilde{m}^2 \end{pmatrix} + (m_d^{diag})^2 + c\, K (m_U^{diag})^2 K^+$$

CKM matrix

HOW "NATURAL" IS UNIVERSALITY ?

- In effective supergravities obtained from superstrings we expect NON-UNIVERSAL BOUNDARY CONDITIONS in general

SUSY breaking parametrized by $\langle F_S \rangle$ and $\langle F_T \rangle$
$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ dilaton $\qquad$ moduli

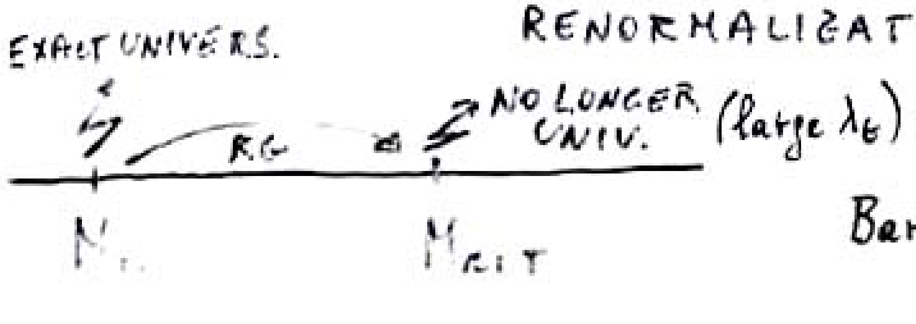
Luis, Kaplunovski ;
Brignole, Ibanez, Munoz ;
Kawamura, Murayama, Yamaguchi

$$m_i^2 = m_{3/2}^2 \left(1 + \underbrace{n_i^2}_{\text{modular weights}} \cos^2\theta\right)$$

$$\tan\theta \equiv \langle F_T \rangle / \langle F_S \rangle$$

- If SUSY is broken at a scale where new interactions affect the flavor structure, universality is generally lost

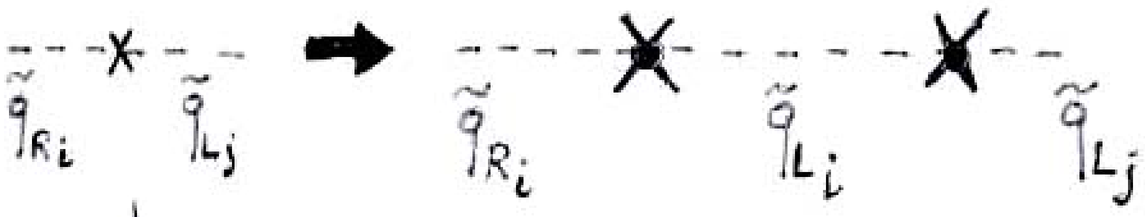
ex. : SUSY GUT's $\qquad$ LOSS OF UNIVERSALITY IN THE SOFT BREAKING TERMS DUE TO RENORMALIZATION FROM M_{PP} TO M_{GUT}



Barbieri, Hall, Strumia

ε'/ε IN SUSY

in MSSM only $\tilde{q}_{L_i} - \tilde{q}_{L_j}$ $(i \neq j)$ important



$\downarrow$ penalized by two (small) mass insertions

Gabrielli, Giudice

$\Rightarrow$ IN MSSM (or, more in general, in SUSY WITH exact UNIVERSALITY in the soft breaking sector)

the SUSY CONTRIBUTION TO ε'/ε is VERY TINY (in MSSM SUSY $CP\!\!\!/$ is of SUPERWEAK KIND)

BUT THIS STATEMENT DOES NOT APPLY TO MORE GENERAL SUSY REALIZATIONS

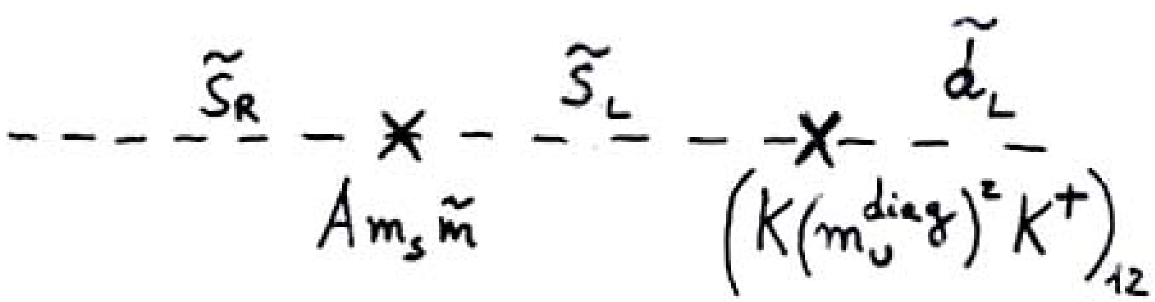
A.M., Murayama

$$W \supset y_d^{ij}(T)\, Q^i D^j H_d \qquad (T \text{ moduli fields})$$

Yukawa coupl: $y_d^{ij}(\langle T \rangle)$

trilinear scalar coupl. $(\tilde{d}_L \tilde{d}_R H)$: $\langle F_T \rangle \rightarrow$ break SUSY

$$\hookrightarrow \mathcal{L}_{\text{trilinear}} \supset \frac{\partial y_d^{ij}}{\partial T} \langle F_T \rangle \tilde{Q}_i \tilde{D}^j H_d$$

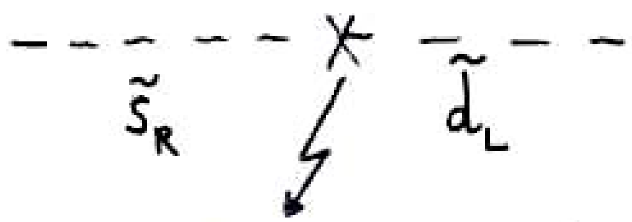


$$\left(\delta^d_{12}\right)^{MSSM}_{LR} \sim \frac{A m_s \tilde{m} \; K_{1i} \, (m_U^{diag})^2_{ii} \, K^+_{i2}}{\tilde{m}^4}$$

$$\simeq \; m_s \left(V_{cd} V_{cs} m_c^2 + V_{td} V_{ts} m_t^2\right) \left(\frac{1}{\tilde{m}}\right)^3 \lesssim 10^{-9}$$

completely negligible !

to obtain $(\delta^d_{12})_{LR} \sim 10^{-5}$ (of interest for ε')
need a model where



$A m_s \tilde{m} \cdot$ angle of $O(\sin \theta_c)$

$\Longrightarrow$ trilinear soft breaking terms $A_{ij} h_{ij} \tilde{d}_{L_i} H \tilde{d}^c_{L_j}$
NOT simultaneously diagonalizable with the
Yukawa couplings h_{ij}, i.e. NON-UNIVERSAL A_{ij}

$$M_d \propto \begin{pmatrix} m_d & m_s \sin\theta_c \\ & m_s \end{pmatrix}$$

$$M^2_{\tilde{d}_L \tilde{d}_R} \propto \begin{pmatrix} a\, m_d & b\, m_s \sin\theta_c \\ & c\, m_s \end{pmatrix}$$

a, b, c constants of $O(1)$ $\Longrightarrow$ unless $a = b = c$ exactly, M_d and $M^2_{\tilde{d}_L \tilde{d}_R}$ are

NOT SIMULTANEOUSLY DIAGONALIZABLE

$$\underset{\tilde{d}_L}{- - -} \times \underset{\tilde{s}_R}{- - -} \qquad \left(\delta^d_{12}\right)_{LR} \simeq \frac{\overset{\nearrow \langle F_T \rangle}{\tilde{m}}\, m_s \sin\theta_c}{m^2_{\tilde{q}}} =$$

$$= 2 \times 10^{-5} \left(\frac{m_s(M_{pe})}{50\,\mathrm{MeV}}\right) \left(\frac{\tilde{m}}{m_{\tilde{q}}}\right) \left(\frac{500\,\mathrm{GeV}}{m_{\tilde{q}}}\right)$$

A.M., Murayama; Babu, Dutta, Mohapatra
Khalil, Kobayashi, Vives

possibility of achieving it through double mass insertion $\underset{\tilde{d}_L}{-} \times \underset{\tilde{s}_R}{-} \times \underset{\tilde{s}_L}{-}$

It is possible to obtain such large SUSY contributions to ε'/ε even if one has REAL SOFT TERMS provided that

- Yukawa coupl. λ_{ij} complex
- A terms have the form $A_{ij}\,\lambda_{ij}$ (A_{ij} real and non-universal)
- no negligible entry in the 1,2 sector of the Yukawa matrix

implications:

- d_n^e close to the exp. bound
- if μ real $\rightarrow$ d_e^e not very significant
- simple minded correlation between quarks and leptons makes $\mu \to e\gamma$ very constraining
  $\mu \to e\gamma$ very close to the exp. bound

Barbieri, Contino, Strumia

IMPLICATIONS FOR $\mu \to e\gamma$ $\quad d_e^e$

present exp. bounds on $\begin{cases} \mu \to e\gamma \Rightarrow (\delta_{12}^{\ell})_{LR} < (1.3 \div 3.4) \times 10^{-5} \\ d_e^e \Rightarrow \mathrm{Im}(\delta_{11}^{\ell})_{LR} < (2.7 \div 6.3) \times 10^{-6} \end{cases}$

for $0.4 < m^2_{\tilde\gamma}/m^2_{\tilde\ell} < 5.0$, $m_{\tilde\ell} = 300$ GeV

using the analogue of our previous expression for $(\delta_{12}^{d})_{LR}$ in ε'/ε, we obtain:

$$(\delta_{12}^{\ell})_{LR} \sim \frac{\tilde m \; m_\mu V_{\nu_e \mu}}{m^2_{\tilde\ell}} \sim 3.3 \times 10^{-4}\, V_{\nu_e \mu}$$

A.M., Murayama

$$(\delta_{11}^{\ell})_{LR} \sim \frac{\tilde m \; m_e}{m^2_{\tilde\ell}} \sim 1.6 \times 10^{-6}$$

taking $V_{\nu_e \mu} \sim \sqrt{\dfrac{m_e}{m_\mu}}$ (in the small mixing MSW solution for the solar ν)

$V_{\nu_e \mu} \sim 0.05 \Rightarrow$ predicted $(\delta_{12}^{\ell})_{R} \sim 1.6 \times 10^{-5}$

in the ballpark of the range $(1.3 \div 3.4) \times 10^{-5}$

which yields $\mu \to e\gamma$ at a rate close to the present exp. bound

SUSY and ε'/ε

For SUSY to account for ε'/ε at least one of the following conditions should be met: EYAL, A.M., NIR, SILVESTRINI

$$\mathrm{Im}\left(\delta^d_{12}\right)_{LL} \sim \lambda \left(\frac{m_{\tilde{q}}}{500\,\mathrm{GeV}}\right)^2$$ $\Rightarrow$ violates the Δm_K, ε_K constraints

exception Kagan-Neubert mechanism

$$\mathrm{Im}\left(\delta^d_{12}\right)_{LR} \sim \lambda^7 \left(\frac{m_{\tilde{q}}}{500\,\mathrm{GeV}}\right)$$ $\Rightarrow$ possible with $A \not\propto M_q$

$$\mathrm{Im}\left[\left(\delta^u_{13}\right)_{LR}\left(\delta^u_{23}\right)_{LR}\right] \sim \lambda^2$$ $\Rightarrow$ COLANGELO, ISIDORI

$$\mathrm{Im}\left[V_{td}\left(\delta^u_{23}\right)^*_{LR}\right] \sim \lambda^3 \left(\frac{M_Z}{M_W}\right)$$

$$\mathrm{Im}\left[V^*_{ts}\left(\delta^u_{13}\right)_{LR}\right] \sim \lambda^3 \left(\frac{M_Z}{M_W}\right)$$

large Z_{ds} effective coupling

BURAS, SILVESTRINI

$\lambda \sim \sin\theta_c \sim 0.2$

- models of heavy $\tilde{q}$ and approximate CP (i.e. small CP phases) are excluded
- models of alignment and approximate CP are strongly disfavored by ε'/ε
- models of alignment without approximate CP are likely to give a significant SUSY contribution to ε'/ε

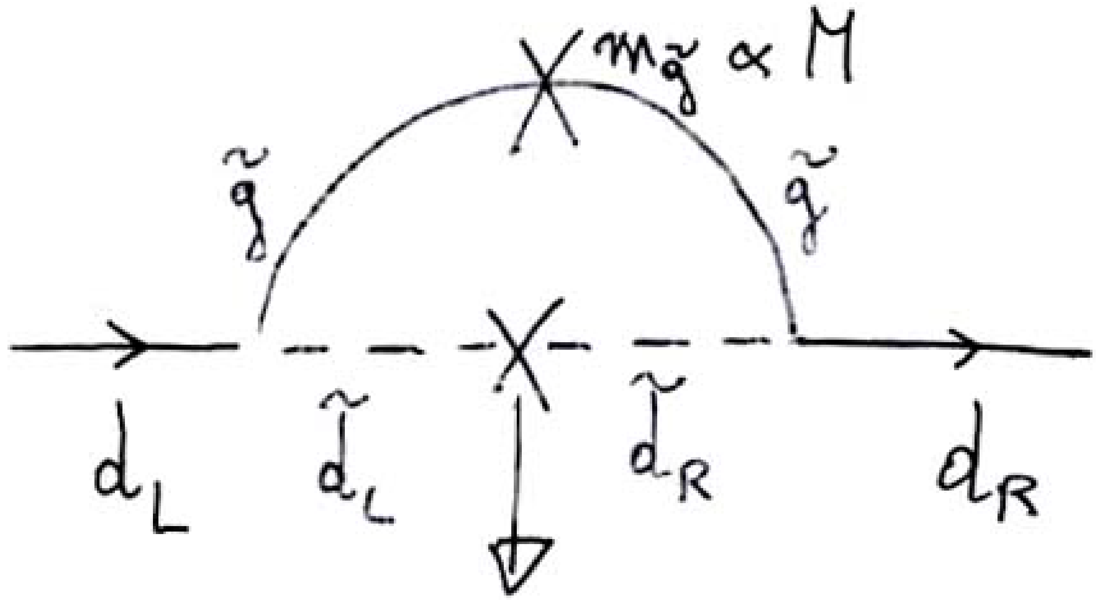
Potentially large contributions to ε'/ε from δ_{LL} if there is an isospin violation in the $\tilde{q}_R$ sector : $m_{\tilde{u}_R} \neq m_{\tilde{d}_R}$ KAGAN, NEUBERT

$\Longrightarrow$ gluino box $\Delta S = 1$ contributions in the exact isospin symmetry in the $\tilde{q}$ sector induce only $\Delta I = 1/2$ operators, but if $m_{\tilde{u}_R} \neq m_{\tilde{d}_R}$ then they generate also large $\Delta I = 3/2$ components.

SUSY contributions to the Wilson coeff. of QCD and ELW PENGUIN OPERATORS CAN BE OF THE SAME ORDER

need $\dfrac{m_{\tilde{u}_R} - m_{\tilde{d}_R}}{m_{\tilde{d}_R}} > 0.1$

ϕ_A, ϕ_B are severely bounded by Electric Dipole Moment of the Neutron (and Electron)



$$\propto (A + \mu \tan\beta)$$

EDMN $\Rightarrow$ $\phi_A, \phi_B < 10^{-2} \div 10^{-3}$

for $m_{\tilde{q}} < 1\ \mathrm{TeV}$

if $\phi_A = \phi_B = 0$

MSSM with $\phi_A = \phi_B = 0$

$\Rightarrow$ NO SIGNIFICANT DEVIATIONS FROM THE SM PREDICTIONS IN $CP\!\!\!/$ OBSERVABLES

(new contributions to $CP\!\!\!/$ through SUSY particles exchange with δ_{CKM})

Bertolini, Borzumati, A.M., Ridolfi
Branco, Cho, Kizukuri, Oshimo
Goto, Nihei, Okada

$\Rightarrow$ only potentially sizeable contributions from **light $\tilde{t}_R$ - chargino** exchange

Brignole, Feruglio, Zwirner
Misiak, Pokorski, Rosiek

region progressively excluded by LEP 2

CMSSM WITH $\phi_A, \phi_\mu \neq 0$

'83 Frère and Gavela : is it possible to put $\delta_{CKM} = 0$ and explain ε only as a SUSY effect.

Dugan, Grinstein, Hall : **NO** $\Rightarrow$ ϕ_A, ϕ_μ too small because of d_n^e

NEW DEVELOPMENTS ON THE THEME LARGE SUSY CP $\neq$ PHASES WHILE TAMING THE d_n^e

CANCELLATIONS AMONG THE SUSY CONTRIBUTIONS TO d_n^e

Ibrahim, Nath; Brhlik, Good, Kane; Brhlik, Everett, Kane, Lykken; Accomando, Arnowitt, Dutta

need for non-universal gaugino masses $\Rightarrow$ SUGRAGUT disfavored, D-branes within Type I strings favored

LARGE MASSES OF $\tilde{Q}$ OF THE FIRST TWO GENERATIONS

Dimopoulos, Giudice; Pomarol, Tommasini; Dine, Kagan, Samuel; Dine, Kagan, Leigh; Carena et al.; D.E. Kaplan et al

NON-UNIVERS. OF THE A-TERMS

Abel, Frere, Khalil, A.M. Kobayashi, Khalil, Kobayashi, Vives

SUSY **WITH** (large) NEW $CP\!\!\!/$ PHASES

→ Do we expect possibly large SUSY contributions to $CP\!\!\!/$?

DEMIR, A.M., VIVES; Baek, Ko

IF NO NEW FLAVOR STRUCTURE IN SUSY

i.e. [illegible]

$A_U \Rightarrow A_U h_U \tilde{Q} H_2 \tilde{u}^c m_0$

↳ c-number not a matrix

$A_D \Rightarrow A_D h_D \tilde{Q} H_1 \tilde{d}^c m_0$

↳ number

$A_L h_L \tilde{L} H_1 \tilde{e}^c m_0$

↳ number

⬇

NO LARGE SUSY CONTRIBUTION TO ε, ε'/ε, HADRONIC $B\bar{B}$ ASYMM.

IF SOME NEW FLAVOR STRUCTURE IN SUSY

(for instance

$A_U \Rightarrow A_{U_{ij}} h_{U_{ij}} \tilde{Q}_i H_2 \tilde{u}_j^c$

⋮

i.e. $A_U \not\parallel h_U$

$A_D \not\parallel h_D$

$A_L \not\parallel h_L$)

even if $CP\!\!\!/$ phases are flavor independent

⇒ possible to have large SUSY contributions to $CP\!\!\!/$ *

Brhlik, Everett, Kane, King, [illegible]

"Theorem": general MSSM with $\delta_{CKM} = 0$ with all possible phases in the soft breaking terms

Demir, A.M., Vives

$(A_U e^{i\varphi_{A_U}}, A_D e^{i\varphi_{A_D}}, A_E e^{i\varphi_{A_E}}$

$m_{\tilde{g}} e^{i\varphi_3}, m_{\tilde{W}} e^{i\varphi_2}, m_{\tilde{B}} e^{i\varphi_1}, \mu = |\mu| e^{i\varphi_\mu})$

but NO NEW FLAVOR STRUCTURE in addition to the usual Yukawa matrices

$\Rightarrow$ IMPOSSIBLE TO GIVE SIZEABLE CONTRIBUTIONS TO ε, ε'/ε, HADRONIC B^0 CP ASYMMETRIES

if some new flavor structure in the soft breaking terms even if the CP$\not\,$ phases are flavor independent
$\rightarrow$ it is possible to get sizeable CP

Brhlik, Everett, Kane, King, Lebedev

$\Rightarrow$ CP$\not\,$ probe of the link between origin of flavor and SUSY breaking

But to "saturate" ε, ε'/ε, ΔB
(taking into account the strong constraint from $b \to s\gamma$)

$\Rightarrow$ NEED OF A HIGHLY "NON TRIVIAL" STRUCTURE OF A_U, A_D

$\Rightarrow$ i.e. analog of CKM in the squark sector must be quite different from the ordinary CKM of the quark sector

ex: simultaneous saturation of ε, ε'/ε

$$\mathrm{Re}\,(\delta^d_{LR})_{12} \sim 10^{-3}$$

$$\underset{\tilde{s}_R}{- - -}\times\underset{\tilde{d}_L}{- - -} \qquad \frac{m_s \sin\theta_c}{\tilde{m}} \sim 10^{-5}$$

need
$$\frac{m_b \cdot \sin\theta_c}{\tilde{m}} \sim 10^{-3} - 10^{-4}$$

possibility of having m_b without small angles if A_d is very different from Y_d

A.M., Vives

CONCLUSIONS

- LOW ENERGY SUSY EXHIBITS NEW $CP\!\!\!/$ PHASES (2 in the CMSSM, more in less severely constrained SUSY extensions of the SM)

- SOME OF THESE PHASES ARE CONSTRAINED BY d_n^e and d_e^e, BUT OTHER PHASES CAN BE LARGE (or some cancellation can occur)

- IF SUSY DOES NOT HAVE SOME NEW FLAVOR STRUCTURE IN THE $\tilde{f}$ SECTOR $\longrightarrow$ THESE NEW PHASES DO NOT YIELD LARGE CONTRIBUTIONS TO ε, ε'/ε, $CP\!\!\!/$ ASYMMETRIES IN B DECAYS

- IF SOME NEW FLAVOR STRUCTURE IS PRESENT IN THE $\tilde{f}$ SECTOR (ABSENCE OF FLAVOR UNIVERSALITY $\Rightarrow$ LINK BETWEEN FLAVOR ORIGIN AND SUSY BREAKING MECHANISM)

$\longrightarrow$ THERE EXIST POTENTIALLY LARGE SUSY CONTRIBUTIONS TO ε, ε'/ε AND WE MAY HAVE LARGE DEVIATIONS FROM THE SM EXPECTATIONS IN $CP\!\!\!/$ B DECAYS