

ON THE $B \rightarrow X_s e^+ e^-$ DECAY IN GENERAL SUSY MODELS

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FCNC PROCESSES IN SUSY MODELS

- FLAVOR CHANGING NEUTRAL CURRENT PROCESSES PLAY AN IMPORTANT ROLE IN CONSTRAINING NEW PHYSICS BEYOND STANDARD MODEL (SM)
- NO TREE LEVEL FCNCs IN SM $\rightarrow$ PARTICULARLY SENSITIVE TO ANY NEW PHYSICS SOURCE OF FLAVOUR

- IN SUSY MODELS (MSSM (Minimal Supersym. SM))

- FCNC $\xrightarrow{\text{CONSTRAIN}}$ SUSY SOFT BREAKING SECTOR (SCALAR SECTOR)

- NEW SOURCES OF FLAVOUR VIOLATIONS IN SQUARK MASS MATRICES

- FCNC CONSTRAINTS REQUIRE HIGH DEGENERACY IN SQUARK MASS MATRIX

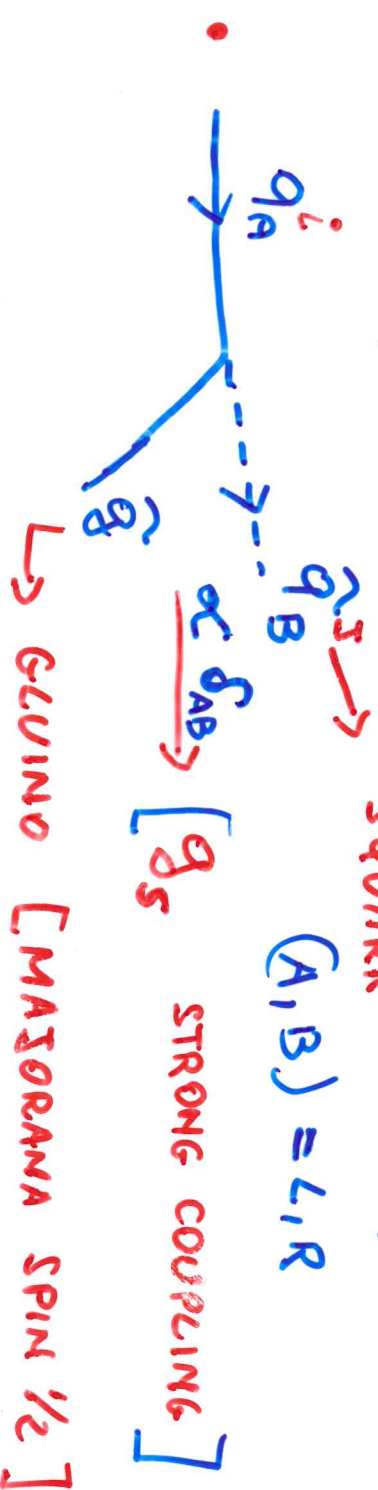
$\rightarrow$ (FLAVOR SPACE)

SQUARK MASS MATRIX $\tilde{m}^2$ 6×6

$$\tilde{m}^2 = \begin{pmatrix} [\tilde{m}_{LL}^2]^{ij} & [\tilde{m}_{LR}^2]^{ij} \\ [\tilde{m}_{RL}^2]^{ij} & [\tilde{m}_{RR}^2]^{ij} \end{pmatrix}$$

$i, j = 1, 2, 3$
 $\hookrightarrow$ FLAVOR INDICES

$\tilde{m}^2(U), \tilde{m}^2(D)$ $q = U, D$



$[\tilde{m}_{AB}^2]^{ij} = \mathbb{1}_{AB} \mathbb{1}^{ij} \tilde{M}^2 + \Delta_{AB}^{ij}$

$\hookrightarrow$ SOURCE OF LARGE EFFECTS IN FCNC PROCESSES

SUPER CKM BASIS : MASS EIGENSTATES FOR QUARK CURRENT EIGENST. FOR SQUARK

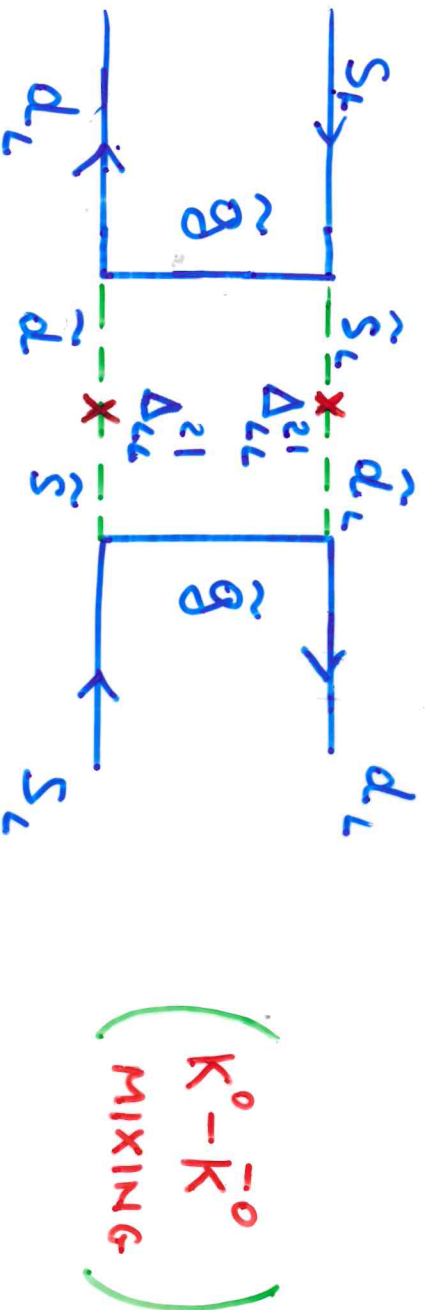
$\Delta \ll \tilde{M}^2$ EXPAND IN POWERS OF $\frac{\Delta}{\tilde{M}^2}$ PROPAG.

$\hookrightarrow$ MASS INSERTION APPROXIMATION

$\hookrightarrow$ REQUIRED BY FCNCs

$$\frac{i}{p^2 - \tilde{M}^2 - \Delta} \sim \frac{i}{p^2 - \tilde{M}^2} + \frac{i \Delta / \tilde{M}^2}{(p^2 - \tilde{M}^2)^2}$$

- SOME KNOWN PROCESSES IN FCNC



$$S \equiv \frac{\Delta}{\tilde{M}^2}$$

FCNC PROCESSES
→ SET CONSTRAINTS ON $\tilde{S}$

$$\sim \frac{g_s^2}{\tilde{M}^2} \left[\frac{\Delta_{LL}^{21}}{\tilde{M}^2} \right]^2 \times F\left(\frac{\tilde{M}^2}{M_i^2}\right)$$

$$\sim \frac{g_w^2}{M_w^2} \left[\frac{M_c^2}{M_i^2} \right]$$

SM → $\sim \frac{g_w^2}{M_w^2} \left[\frac{M_c^2}{M_i^2} \right]$

→ $O(10^{-3})$, $\tilde{M} \sim 500 \text{ GeV}$

- SUGRA SCENARIOS (MINIMAL MODEL)

GUT SCALE $\sim 10^{16} \text{ GeV}$

$$\tilde{m}^2 = \tau \tilde{M}^2$$

$\Delta = 0$

RGE → $\tau \tilde{M}_{\text{low}}^2 + \Delta_{AB}^{ij}$

LOW ENERGY $\sim 10^{-2} \text{ GeV}$

INDUCED BY RADIATIVE

CORRECTIONS DUE TO

YUKAWA SOURCES

- NO PROBLEMS WITH FCNC TESTS
- SMALL EFFECTS ON $K^0-\bar{K}^0$, $B^0-\bar{B}^0$

$b \rightarrow ss$, $M \rightarrow sX$

NON UNIVERSAL SUSY MODELS

- SOFT BREAKING TERMS NON UNIVERSAL AT THE SCALE WHERE THEY ARE GENERATED
- SUPERSTRINGS INSPIRED MODELS NATURALLY FAVOURS NON-UNIVERSALITY IN THE SOFT BREAK TERMS

→ NON-FLAT KÄHLER METRIC AND FLAVOR DEPENDENT SOFT TERMS CAN ARISE DUE TO COMPACTIFICATION OF EXTRA-DIMENSIONS

- MODELS PARTICULARLY INTERESTING

NON-UNIVERSAL TRILINEAR SOFT BREAKING TERMS IN SCALAR SECTOR (A-TERMS)

(KHALIL, KOBAYASHI, MASIERO '99)
→ COULD SOLVE SUSY CP PROBLEM

- SATISFY ALL CONSTRAINTS ON FCNCs
- PROVIDE NEW SIGNIFICANT CONTRIBUTIONS TO DIRECT CP VIOLATING PARAMETER

$\epsilon'/\epsilon \rightarrow$ ENHANCE GLUINO CONTRIBUTION TO $\epsilon, \epsilon'/\epsilon$ BY ENHANCING $\gamma_m(\delta_{RL}^d)_{12}, \gamma_m[\delta_{RL}^d]_{12}$

- PASS THE STRONG CONSTRAINT ON $b \rightarrow s\gamma$
- LARGE CONTRIBUTION TO CP ASYMMETRY OF ORDER 10-15% ACCESSIBLE AT B-FABORIES

E.G. KHALIL, TORRENTI-UDARI ('00)
BALBIN, KHALIL ('01)

- WE ANALYZED A LARGE CLASS OF NON UNIVERSAL SUSY MODELS

↳ IMPACT ON THE RARE b DECAY

$$b \rightarrow s \ell^+ \ell^- \quad \ell = e, \mu$$

- IN ORDER TO PASS FCNC TESTS LIKE $K^0 - \bar{K}^0$ OR $B^0 - \bar{B}^0$ MIXING: SOFT TERMS IN SPERMION SECTOR $\rightarrow$ DIAGONAL AT GUT SCALE

PARAMETRIZATION SOFT SECTOR AT GUT SCALE 10^{16} GeV

- GAUGINO MASSES

$$M_a = \delta_a m_{1/2}$$

$$a = 1, 2, 3$$

- DOUBLET SCALARS

$$M_Q^2 = M_L^2 = m_0^2 \text{diag}\{1, 1, \delta_3\}$$

- RIGHT SCALARS

$$M_U^2 = m_0^2 \text{diag}\{1, 1, \delta_3\}, \quad M_D^2 = M_E^2 = m_0^2 \text{diag}\{1, 1, \delta_6\}$$

- HIGGS SCALARS

$$M_{H_1}^2 = m_0^2 \delta_7$$

$$M_{H_2}^2 = m_0^2 \delta_8$$

- TRILINEAR COUPLINGS

$$A^U = A^D = A^E = m_0 \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}$$

RANGES FOR δ_i, a_{is} -7-

$$0 < \delta_i < 1$$

$$-3 < a_{is} < 3$$

→ [LIMIT FROM CONSTRAINTS ON
COLOR AND CHARGE BREAKING]
MINIMA > REAL MINIMA

- WE ASSUME THAT YUKAWA AT EW SCALE

$$Y^D = \frac{1}{v_l} V_{CKM}^* \text{diag}(m_d, m_s, m_b)$$

$$Y^U = \frac{1}{v_t} \text{diag}(m_u, m_c, m_t) V_{CKM}^T$$

- FREE PARAMETER →

$$t_\beta = \frac{v_t}{v_l}$$

- μ AND B PARAMETERS

→ FIXED
DETERMINED FROM EW BREAKING
CONDITION

$$\mu^2 = \frac{m_{H_1}^2 - m_{H_2}^2 \tan^2 \beta}{\tan^2 \beta - 1} - \frac{M_Z^2}{2}$$

$$\left(\begin{array}{l} W = \mu \hat{H}_1 \hat{H}_2 \\ V_{\text{SOFT}} = \mu B \hat{H}_1 \hat{H}_2 \end{array} \right)$$

- THIS PARAMETRIZATION COVERS A LARGE

CLASS OF STRING INSPIRED SUSY MODELS

- STRATEGY → $[Y_{U,D}]_{\text{LOW}} \xrightarrow{\text{RG}} [Y_{U,D}]_{\text{GUT}}$

$$[Y_{U,D}]_{\text{GUT}} + [\text{SOFT-TERMS}]_{\text{GUT}} \xrightarrow{\text{RG}} [\text{SUSY SPECTRUM}]_{\text{LOW}}$$

- SEVERAL STUDIES ABOUT $b \rightarrow s \ell^+ \ell^-$ (01) ALI, LUNGHI, GAREB
(98) HILGER
- DETAILED ANALYSIS ABOUT SUSY MODELS WITH NON-UNIVERSAL
SOFT TERMS AT GUT WAS MISSING (98) E.G., SARID

A LOW ENERGY APPROACH TO SUSY MODELS

SUGGESTS THAT NON-UNIVERSALITY COULD GENERATE
SIGNIFICANT DEPARTURE FROM SM, AFTER RESPECTU

↳ BASED ON MASS INSERTIONS
(LUNGHI, MASIERO, SCIMEMI, SILVESTRAINI)

ALL CONSTRAINED
FCNC; $b \rightarrow s \ell^+ \ell^-$
V.S.B.

↳ LARGE EFFECTS ARE EXPECTED
FROM CONTRIBUTIONS TO

Q_3 AND Q_{10}

- EFFECTIVE HAMILTONIAN

- CHETYRKIN, MISIAK,
MUNZ (1997)
- BURAS, KWIATKOWSKI, PETT
(1997)

$$H_{\text{eff}} = - \frac{4 G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_{i=1}^{10} C_i(\mu_b) Q_i(\mu_b)$$

- RELEVANT OPERATORS AFFECTED BY SUSY

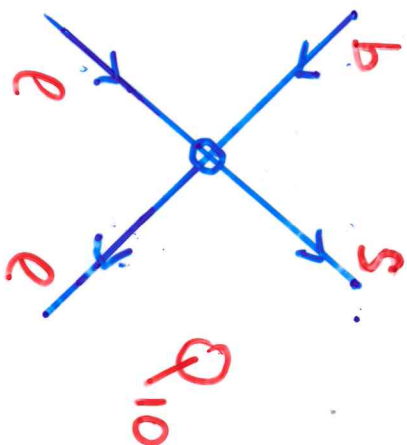
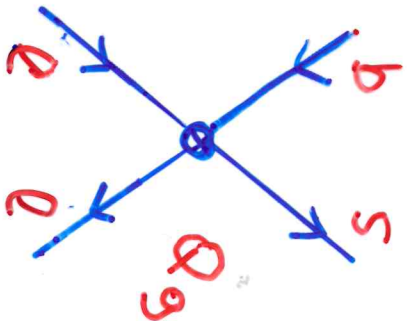
$$Q_7 = \frac{e}{16\pi^2} u_b [\bar{s}_L \sigma^{\mu\nu} b_R] F_{\mu\nu} \rightarrow b \rightarrow s \gamma$$

$$Q_8 = \frac{g_s}{16\pi^2} u_b [\bar{s}_L T^a \sigma^{\mu\nu} b_R] G_{\mu\nu}^a \rightarrow b \rightarrow s \text{ gluon}$$

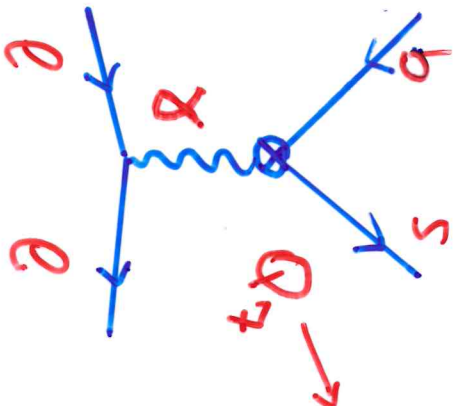
$$Q_9 = (\bar{s}_L \gamma_\mu b_L) \ell \gamma^\mu e \quad Q_{10} = (\bar{s}_L \gamma_\mu b_L) \ell \gamma^\mu \gamma_5 \ell$$

↳ SEMILEPTONIC OPERATORS

- AMPLITUDE $b \rightarrow s e^+ e^-$



SAME OPERATOR OF $b \rightarrow s \gamma$



(Q_8 ENTERS IN THE NLO CONTRIBUTION TO Q_7)

$Q_i: i=1, \dots, 6 \rightarrow$ RENORMAL. OF $Q_{9,10}, Q_7$

• $b \rightarrow s e^+ e^-$

CAN TEST NEW PHYSICS CONTRIBUTIONS TO Q_9 AND Q_{10} IN ADDITION TO

$Q_7 \rightarrow$ MAINLY CONSTRAINED BY $b \rightarrow s \gamma$

• THE CONTRIBUTION OF Q_7 IS SUPPRESSED IN

$\rightarrow$ CHIRALITY FLIPPING

THE SM BY W_b BUT IT IS ENHANCED

BY

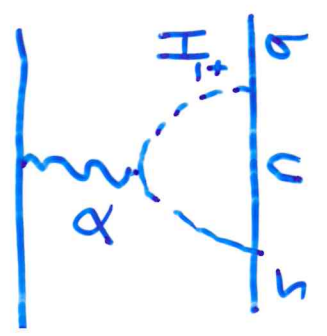
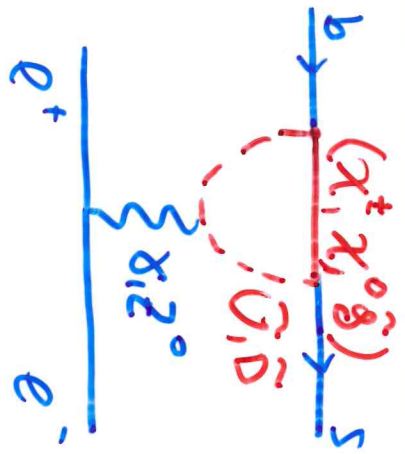
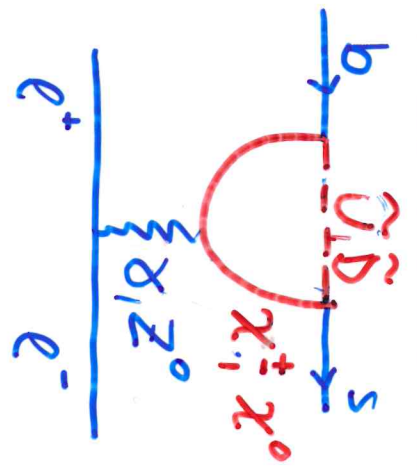
$$\frac{1}{q^2}$$

PHOTON PROPAGATOR

$$\rightarrow q_{min}^2 \sim 4 m_e^2$$

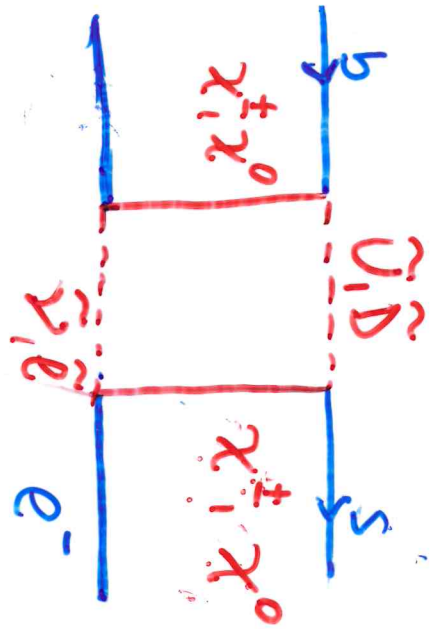
SUSY CONTRIBUTIONS TO $b \rightarrow se^+e^-$

PENGUIN DIAGRAMS



$\chi^{\pm}, \chi^0, \tilde{g}, H^{\pm}$

BOX DIAGRAMS

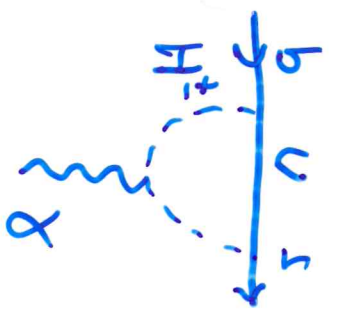
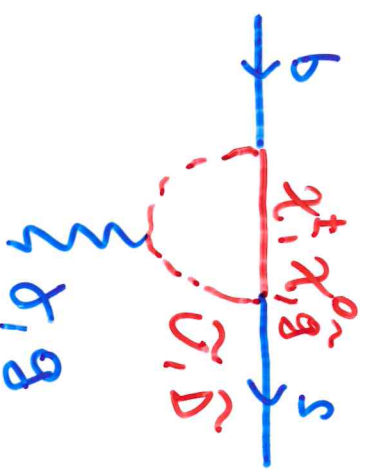
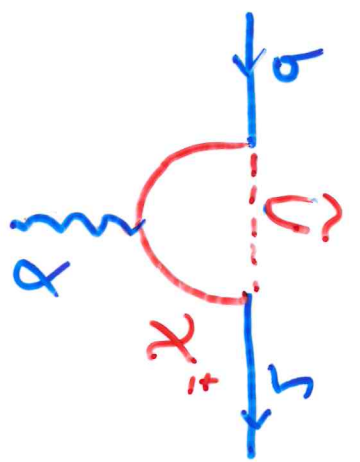


+ CROSSINGS

DIAGRAMS FOR

$b \rightarrow s \gamma$

AND $b \rightarrow s g$



→ + DIAGS WITH γ ATTACHED IN OTHER WAYS

- MODEL INDEPENDENT PARAMETRIZATION

$$R_i = \frac{C_i(M_W) - C_i^{SM}(M_W)}{C_i^{SM}(M_W)}$$

- NEW OPERATORS (RELEVANT)

$$\tilde{Q}_7 \rightarrow Q_7 (L \leftrightarrow R)$$

$$\tilde{Q}_8 \rightarrow Q_8 (L \leftrightarrow R)$$

- NON RESONANT $BR(B \rightarrow X_s e^+ e^-)$

NLO

$$BR(B \rightarrow X_s e^+ e^-) = 7.29 \times 10^{-6} [1 + 0.714 R_{10}$$

$$+ 0.357 R_{10}^2 + 0.35 R_7 + 0.0947 (R_7^2 + \tilde{R}_7^2)$$

$$+ 0.179 R_9 - 0.0313 R_7 R_9 + 0.045 R_9^2]$$

(96) CHO, MISIAK, WYLER

(97) E.G., SARID

- NON RESONANT $BR \xrightarrow{\text{red line}} \text{NON-PERTURBATIVE UNCERTAINTIES ARE REDUCED}$

ENERGY ASYMMETRY (FB)

$$A = \frac{N(E_{e^-} \rightarrow E_{e^+}) - N(E_{e^+} \rightarrow E_{e^-})}{N(E_{e^-} \rightarrow E_{e^+}) + N(E_{e^+} \rightarrow E_{e^-})}$$

$$A_{ee} = \frac{0.48 \times 10^{-6}}{R_{BR}(B \rightarrow \chi_s e^+ e^-)} \times$$

$$\times [1 + 0.911 R_{10} - 0.00882 R_{10}^2$$

$$- 0.625 R_7 (R_{10} + 1) + 0.884 R_9 (R_{10} + 1)]$$

$$R_{BR} = BR / BR^{SM}$$

(RELEVANT) CONSTRAINTS IN SUSY ANALYSIS

- EXP. LOWER BOUNDS ON SUSY SPECTRUM
- $2.0 \times 10^{-4} < BR(b \rightarrow ss) < 4.5 \times 10^{-3}$
2G CLEO
- $B^0 - \bar{B}^0$, $K^0 - \bar{K}^0$ MIXING
- HIGGS MASS BOUNDS $M_H > 114 \text{ GeV}$

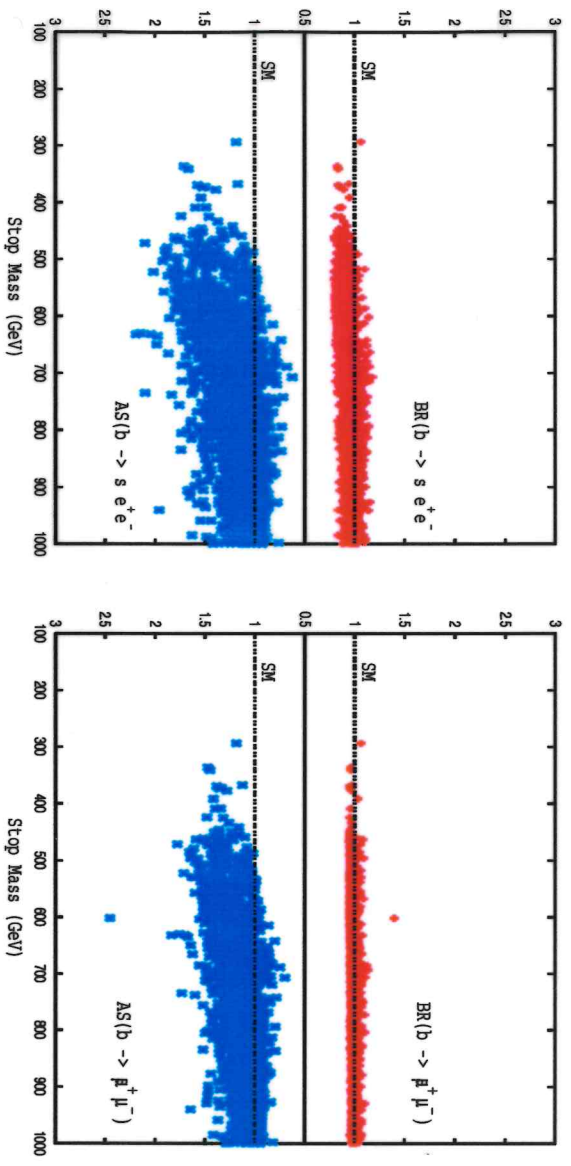


Figure 3: As in Fig. 1, but for a SUSY model with $U(2)$ flavour symmetry.

CONCLUSIONS

- WE CONSIDERED MODELS WITH
 - MINIMAL FLAVOR VIOLATION (UNIVERSAL MODELS)
 - MODELS WITH NON-UNIVERSAL SOFT SCALAR AND GAUGINO MASSES + NON DEGENERATE A-TERMS
 - SUSY MODELS NON-ABELIAN SYMMETRY $\rightarrow$ FLAVOR STRUCTURE FOR SOFT SCALAR MASSES
- MAJOR EFFECT IS DUE TO $b \rightarrow s \gamma$ OPERATOR
- GENERAL TREND : DECREASING BR INCREASING AS
- ONLY NON-UNIVERSAL MODELS GET VERY LARGE ENHANCEMENTS IN BOTH BR AND AS
 UP 3 (ee) 2 ($\mu^+ \mu^-$) TIME WITH RESPECT TO SM