Patterns of flavor signals in supersymmetric models

Toru Goto (KEK)

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T. G., Y. Okada (KEK), T. Shindou (DESY) and M. Tanaka (Osaka),

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Introduction

Flavor physics: probe for new physics.

- Heavy particles and their interactions contribute in various ways.

$\Rightarrow$ Plays a complementary role with direct measurements (@LHC).

  - ▷ SM: $b \to s, d$ (flavor) $\oplus$ m_t (direct) $\Rightarrow$ V_{td}, V_{ts}.
  - ▷ Similar case will occur in the study of physics beyond the SM.
    - $*$ $b \to s, d \oplus m_{\tilde{q}} \Rightarrow q_i - \tilde{q}_j - \tilde{g}$ coupling.

Experimental improvements expected.

- LHCb: $S_{\mathrm{CP}}(B_s \to J/\psi\phi)$, $\cdots$.
- MEG: search for $\mu \to e\,\gamma$ with b.r. down to 10^{-13}.
  - ▷ current upper limit: $\mathrm{B}(\mu \to e\,\gamma) < 1.1 \times 10^{-11}$.
- Super B factories (under discussion) with $\int \mathcal{L} = 50 - 75\mathrm{ab}^{-1}$:

$\Rightarrow$ uncertainties reduced by $\sim \frac{1}{7}$ ($\int \mathcal{L}(\mathrm{KEKB} + \mathrm{PEPII}) \approx 1.3\mathrm{ab}^{-1}$).

In this work, we study quark/lepton flavor signals:

- LFV ($\mu \to e\,\gamma$, $\tau \to \mu\,\gamma$, $\tau \to e\,\gamma$),
- CP Asymmetries in B decays,
  - ▷ $S_{\mathsf{CP}}(B_d \to K^*\,\gamma)$, $S_{\mathsf{CP}}(B_d \to \rho\,\gamma)$
  - ▷ $S_{\mathsf{CP}}(B_d \to \phi\,K_S)$
  - ▷ $S_{\mathsf{CP}}(B_s \to J/\psi\,\phi)$

in SUSY models with typical flavor structures:

- mSUGRA,
- MSSM with ν_R's,
- SU(5) SUSY GUT with ν_R's,
- U(2) Flavor Symmetry model.

We show the pattern of flavor signals varies depending on the model.

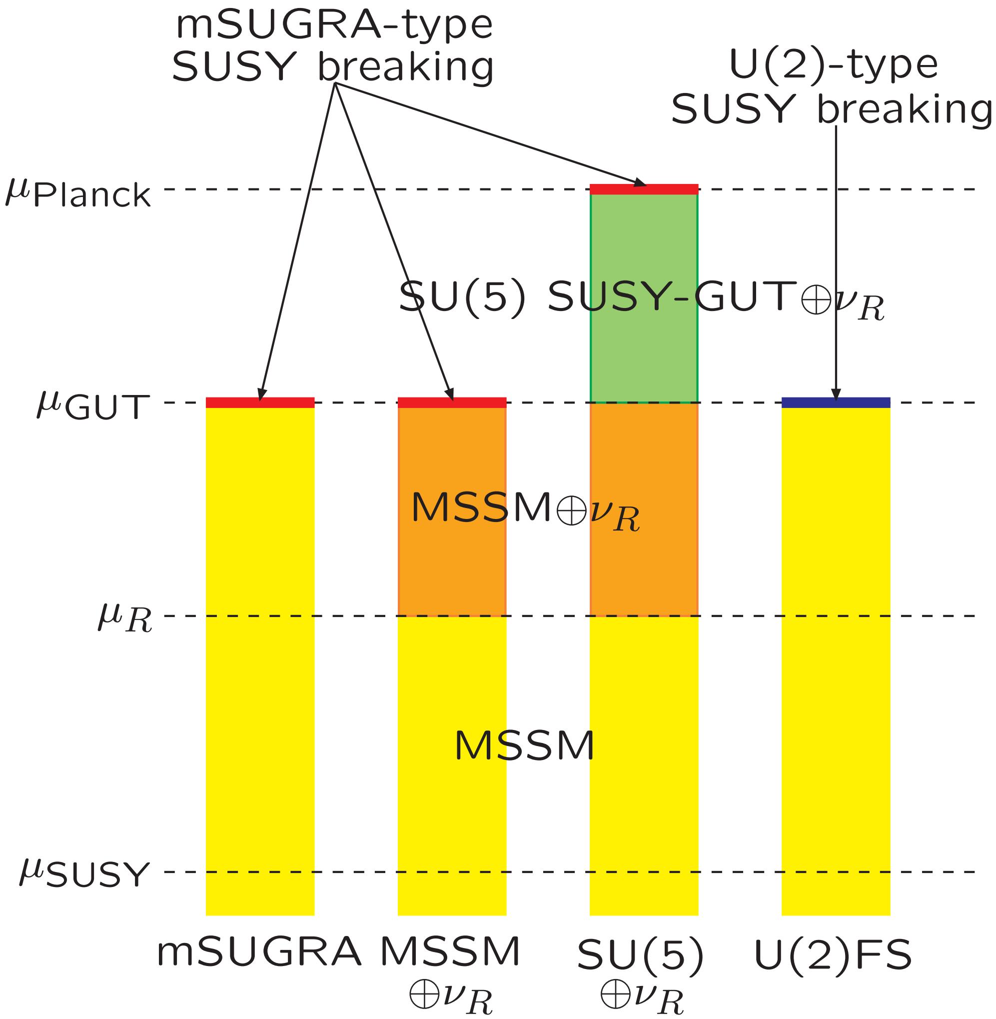
$\Longrightarrow$ Flavor measurements are useful to distinguish models.

Contents:

- Models
- Numerical results
- Summary

Models: Minimal Supersymmetric Standard Model $+\alpha$

"$+\alpha$": mechanism which controls flavor mixing in SUSY breaking.



- mSUGRA: $Y_{U,D}$ (V_{CKM}) only.
  - ▷ Flavor-blind SUSY breaking m_0, $m_{1/2}$, A_0.
- MSSM$\oplus\nu_R$: Y_ν affects running.
  - ▷ SUSY breaking = mSUGRA.
  - ▷ GUT: quark $\leftrightarrow$ lepton.
- U(2) flavor symmetry:
  - ▷ $Y_{U,D} \sim \begin{bmatrix} & \epsilon' & \\ \epsilon' & \epsilon & \epsilon \\ & \epsilon & 1 \end{bmatrix}$,
    ($\epsilon \sim V_{cb}$, $\epsilon'/\epsilon \sim V_{us}$).
  - ▷ $m^2_{Q,U,D} \sim m_0^2 \begin{bmatrix} 1 & & \\ & 1 & \epsilon \\ & \epsilon & O(1) \end{bmatrix}$,

Flavor mixing/CPV source

- V_{CKM} (all cases) $\Longrightarrow$ $\tilde{q}_L$ mixing (running).
  - ▷ Significant in B$(b \to s\,\gamma)$; small in others.
  - ▷ GUT $\Longrightarrow$ $\tilde{\ell}_R$ mixing (Barbieri-Hall). $\mathbf{10} = \{q_L,\ (u_R)^c,\ (e_R)^c\}$.
- Y_ν (cases with ν_R's) $\Longrightarrow$ $\tilde{\ell}_L$ mixing (running above μ_R).
  - ▷ GUT $\Longrightarrow$ $\tilde{d}_R$ mixing (Moroi) $\overline{\mathbf{5}} = \{(d_R)^c,\ \ell_L\}$.
- $m^2_{Q,U,D}(\mu_{\text{GUT}})$ (U(2)FS).
  - ▷ U(2) structure neglected in (s)lepton sector.
- SUSY CPV phases $(\phi_A,\ \phi_\mu,\ \cdots)$.
  - ▷ Affect CP asymmetries in b decays, EDMs (e, n, Hg).

Structure of the neutrino mass matrices (MSSM$\oplus\nu_R$, SU(5)$\oplus\nu_R$)

Light: $|\Delta m^2_{32}|$(atm) $\gg \Delta m^2_{21}$(sol)

- Normal Hierarchy
  - ▷ $m_3 \gg m_2 \gg m_1 = 0.003$eV. $(\Delta m^2_{21} \gg m_1^2)$
- Inverted Hierarchy
  - ▷ $m_2 > m_1 \gg m_3$.
- Degenerate
  - ▷ $m_3 > m_2 > m_1$, $m_1^2 = (0.1\text{eV})^2 \gg |\Delta m^2_{32}|$.

Heavy (ν_R):

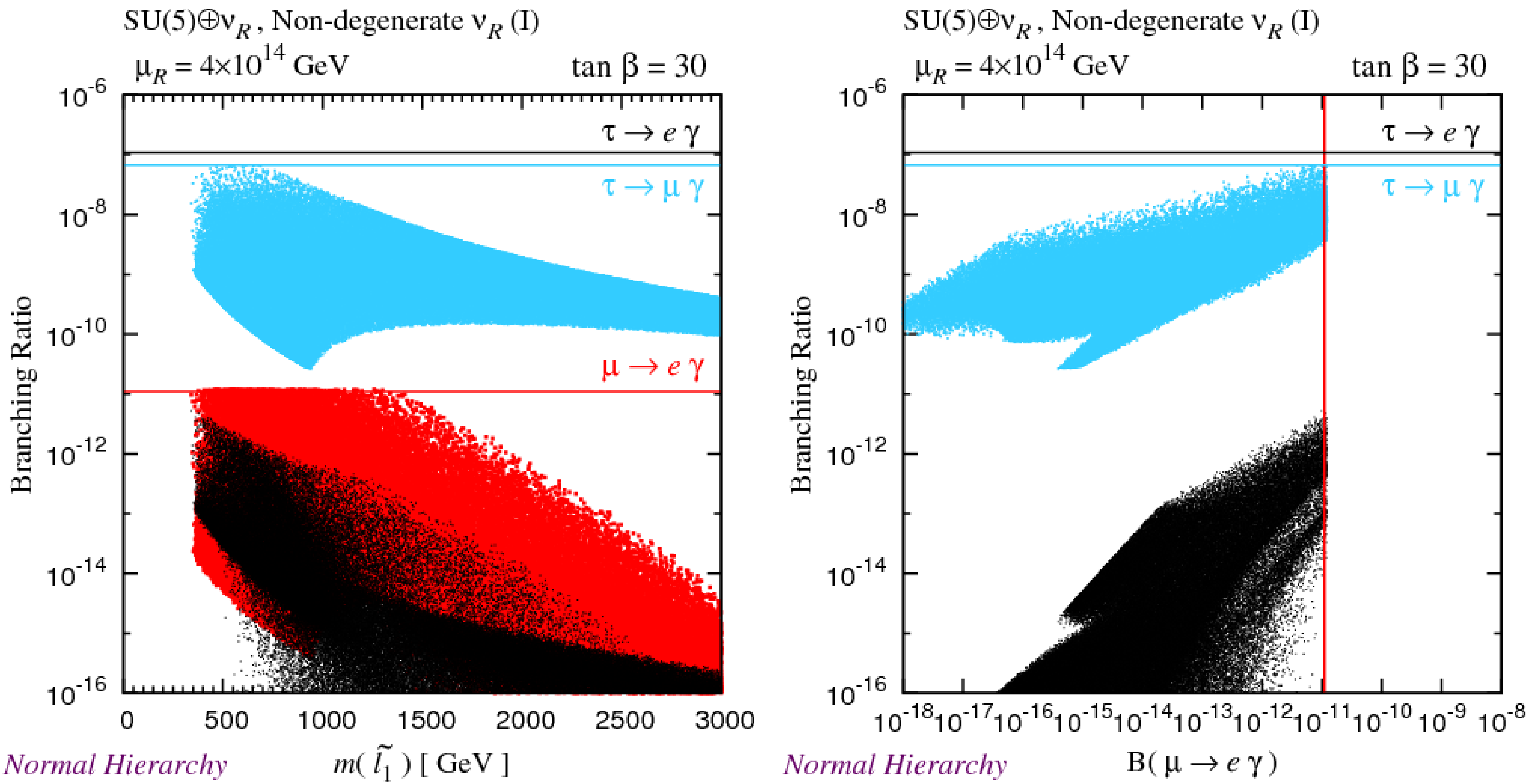
- Degenerate ν_R: $M_{\nu_R} \propto \mathbf{1}$.
  - ▷ $\mu \to e\,\gamma$ enhaced.
- Non-Degenerate ν_R: $M_{\nu_R} \not\propto \mathbf{1}$.
  - ▷ More free parameters in Y_ν.
  - ▷ $\mu \to e\,\gamma$ suppression possible.

(I) $(Y_\nu)_{12} = (Y_\nu)_{21} = 0$, $(Y_\nu)_{13} = (Y_\nu)_{31} = 0$.

(II) $(Y_\nu)_{12} = (Y_\nu)_{21} = 0$, $(Y_\nu)_{23} = (Y_\nu)_{32} = 0$.

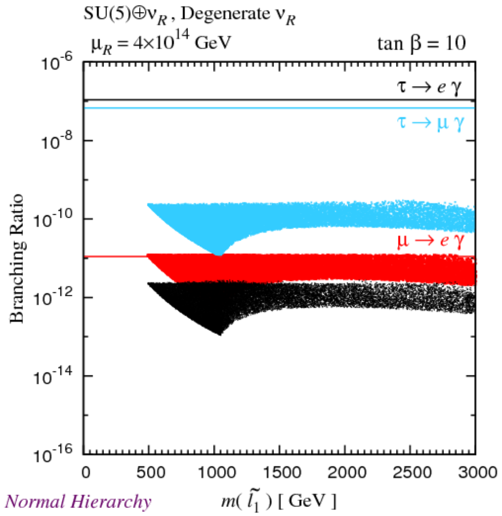
LFV: $\mu \to e\gamma$, $\tau \to \mu\gamma$, $\tau \to e\gamma$

SU(5)$\oplus\nu_R$, Non-degenerate ν_R (I), Normal Hierarchy

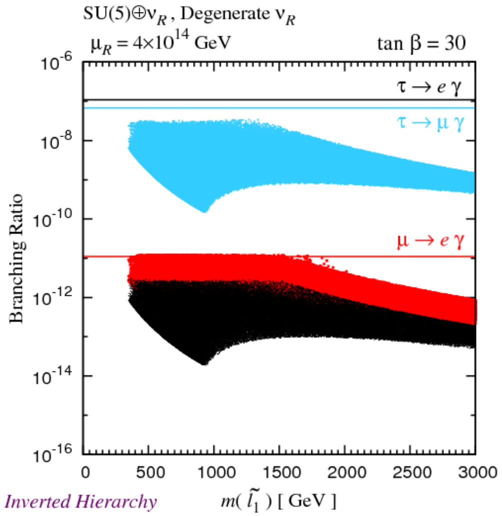


$m_{1/2}(\mu_G) \leq 1.5$TeV, $m_0(\mu_P) \leq 4$TeV scanned.

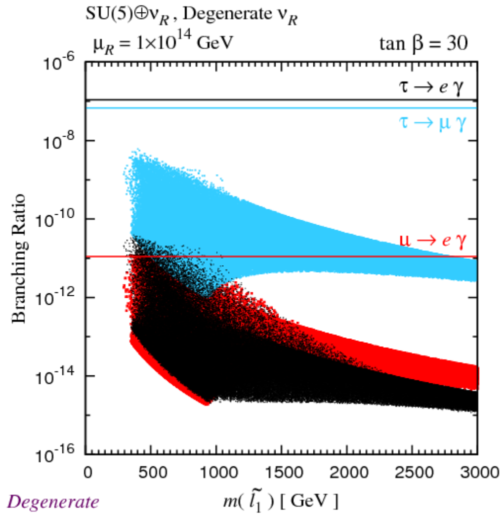
$\mu \to e\gamma$, $\tau \to \mu\gamma$, $\tau \to e\gamma$: SU(5)$\oplus\nu_R$ (Y_ν & $\mu_P \leftrightarrow \mu_G$ running)



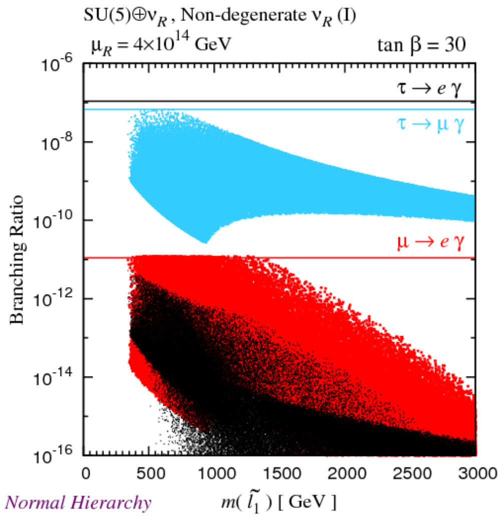
$D\nu_R$-NH



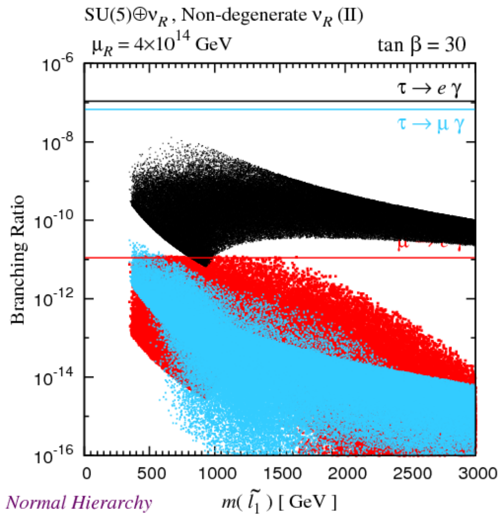
$D\nu_R$-IH



$D\nu_R$-D

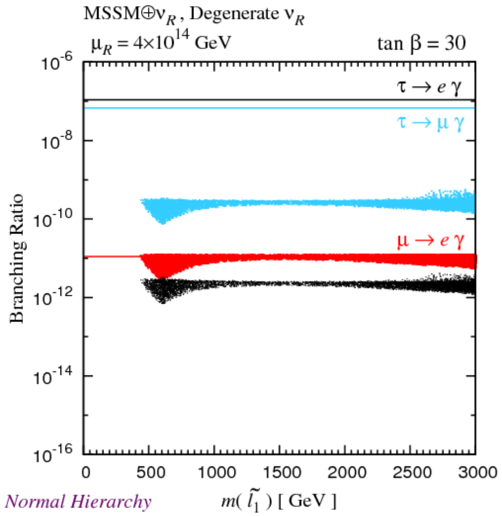


$ND\nu_R$(I)-NH

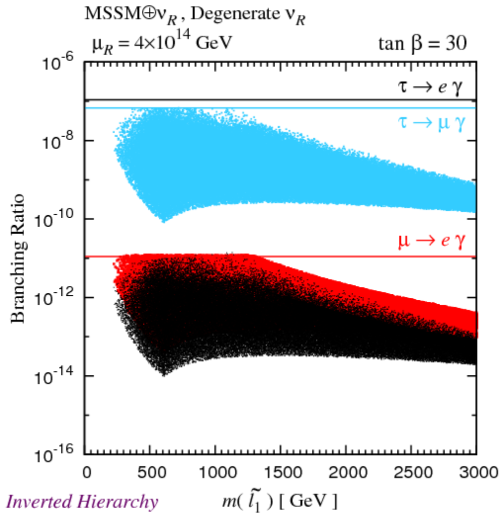


$ND\nu_R$(II)-NH

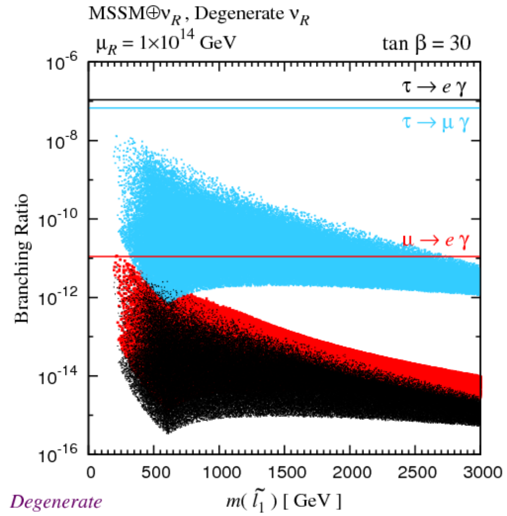
$\mu \to e\gamma$, $\tau \to \mu\gamma$, $\tau \to e\gamma$: MSSM$\oplus\nu_R$ (Y_ν only)



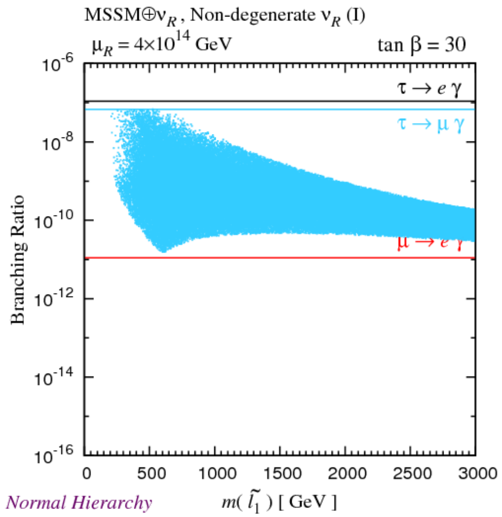
$D\nu_R$-NH



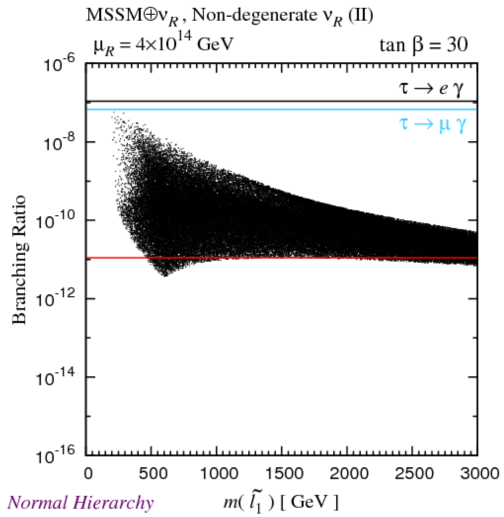
$D\nu_R$-IH



$D\nu_R$-D



$ND\nu_R$(I)-NH



$ND\nu_R$(II)-NH

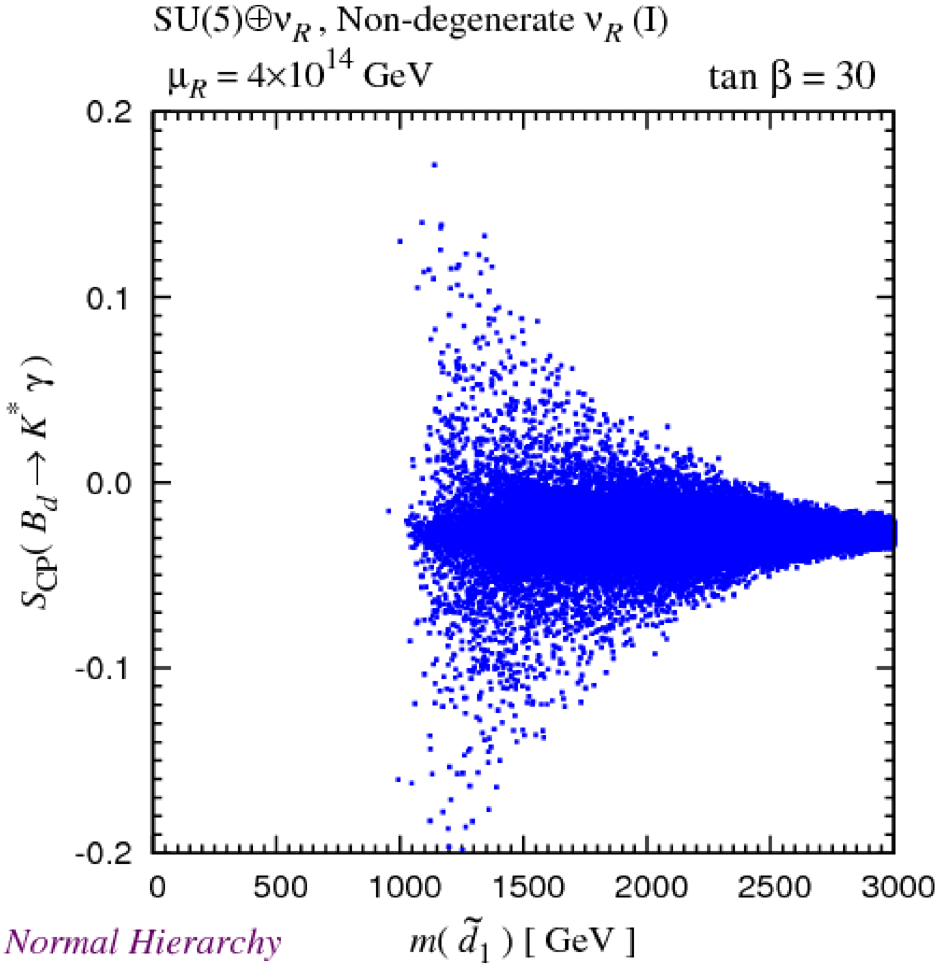
Time-dependent CP asymmetries in $b \to s/b \to d$ decays

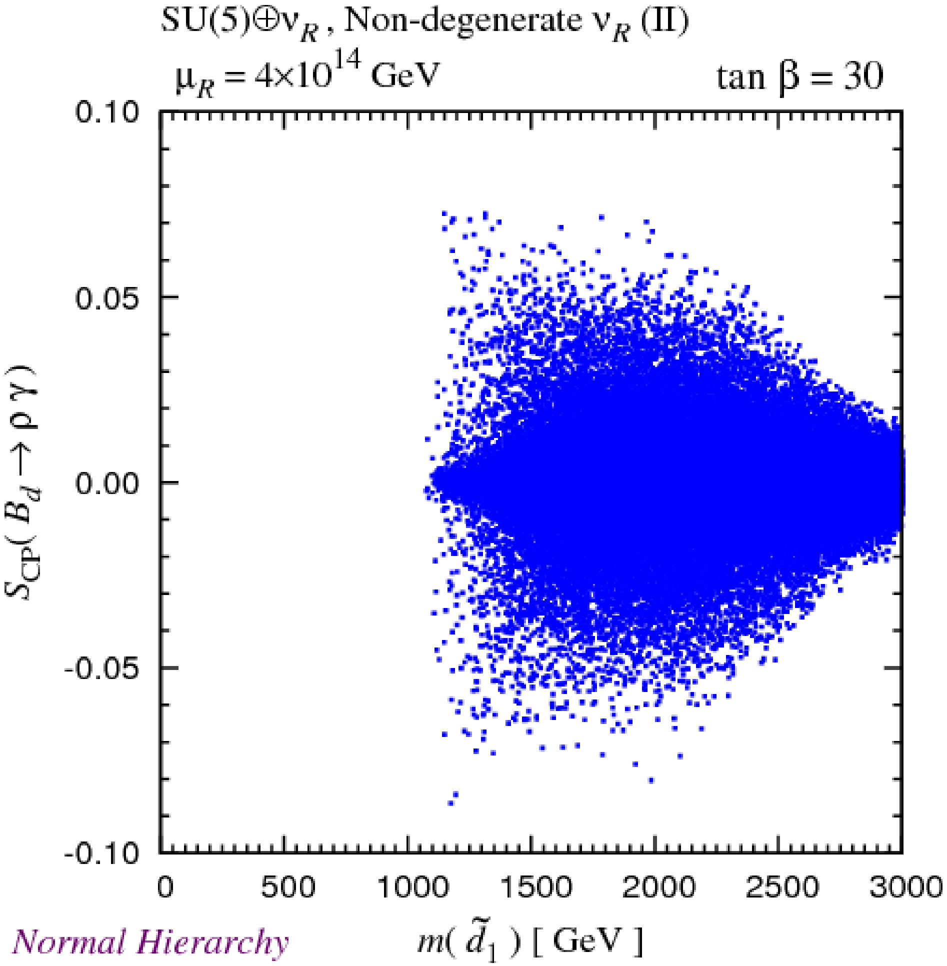
- $S_{\mathrm{CP}}(B_d \to K^* \gamma)$, $S_{\mathrm{CP}}(B_d \to \rho \gamma)$
  - ▷ $B_d - \overline{B}_d$ mixing $\otimes$ $b \to s(d)\gamma$ decay.
  - ▷ Interference between $b_R \to s(d)_L \gamma_L$ and $\overline{(b_L)} \to \overline{(s(d)_R)} \gamma_L$; suppressed by $m_{s,d}/m_b$ in SM (Atwood-Gronau-Soni).
- $S_{\mathrm{CP}}(B_d \to \phi K_S)$
  - ▷ $B_d - \overline{B}_d$ mixing $\otimes$ $b \to s s \overline{s}$ decay.
  - ▷ Differs from $S_{\mathrm{CP}}(B_d \to J/\psi K_S)$ if new phase exists in $b \to s$ penguin amplitude.
- $S_{\mathrm{CP}}(B_s \to J/\psi \phi)$
  - ▷ $B_s - \overline{B}_s$ mixing $\otimes$ $b \to s c \overline{c}$ decay.
  - ▷ Small in SM; enhanced if new phase exists in $B_s - \overline{B}_s$ mixing.

$\Longrightarrow$ $\tilde{d}_R$ mixing can contribute to all.

- Significant in SU(5) SUSY-GUT$\oplus\nu_R$ and U(2)FS.

$S_{\mathrm{CP}}(B_d \to K^*\gamma)$ [$b \to s$], $S_{\mathrm{CP}}(B_d \to \rho\gamma)$ [$b \to d$]

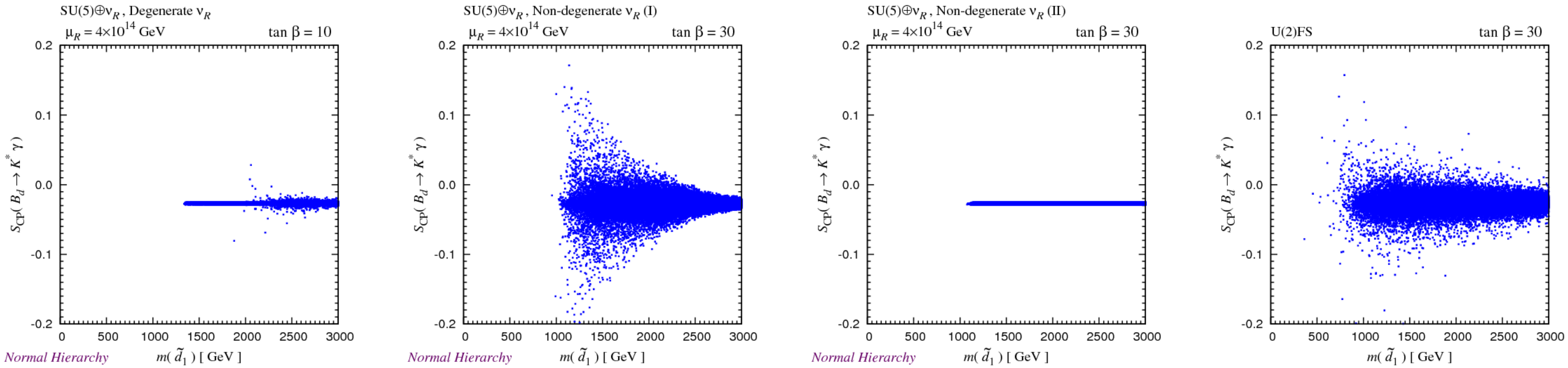




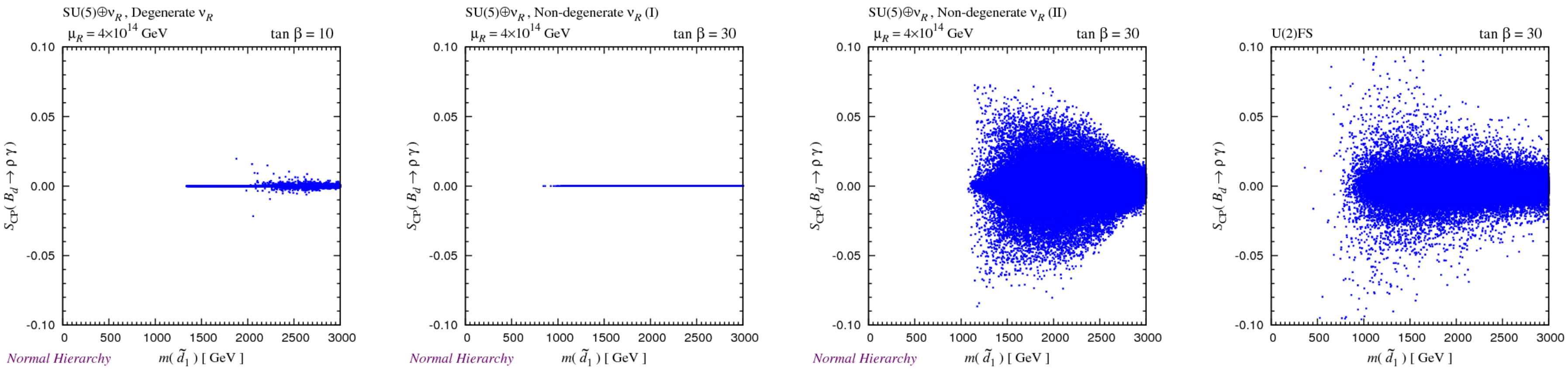
$S_{\mathrm{CP}}(B_d \to K^*\gamma)$ $[b \to s]$, $S_{\mathrm{CP}}(B_d \to \rho\gamma)$ $[b \to d]$

Significant in SU(5)$\oplus\nu_R$, U(2)FS; small in mSUGRA, MSSM$\oplus\nu_R$.

$S_{\mathrm{CP}}(B_d \to K^*\gamma)$ vs. $m(\tilde{d}_1)$



$D\nu_R$-NH　　$ND\nu_R$(I)-NH　　$ND\nu_R$(II)-NH　　U(2)FS

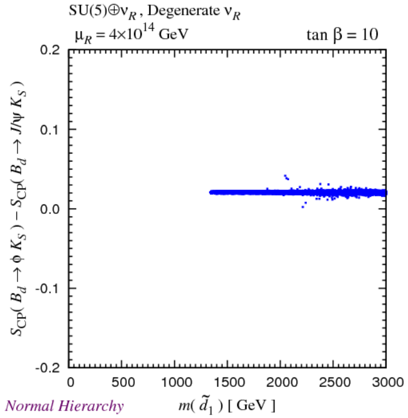


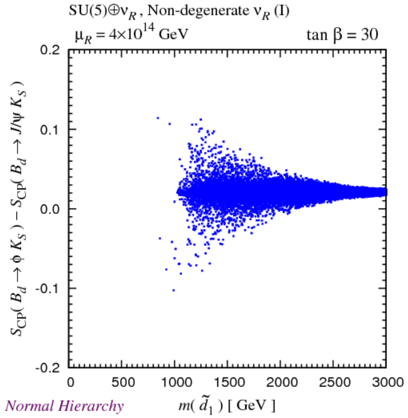
$S_{\mathrm{CP}}(B_d \to \rho\gamma)$ vs. $m(\tilde{d}_1)$

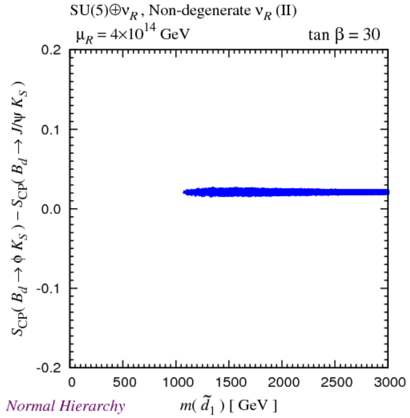
$S_{\mathrm{CP}}(B_d \to \phi K_S)$, $S_{\mathrm{CP}}(B_s \to J/\psi\phi)$ $[b \to s]$

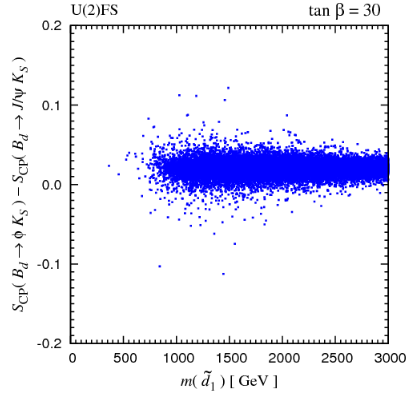
Significant in SU(5)$\oplus\nu_R$, U(2)FS; small in mSUGRA, MSSM$\oplus\nu_R$.

$S_{\mathrm{CP}}(B_d \to \phi K_S) - S_{\mathrm{CP}}(B_d \to J/\psi K_S)$ vs. $m(\tilde{d}_1)$

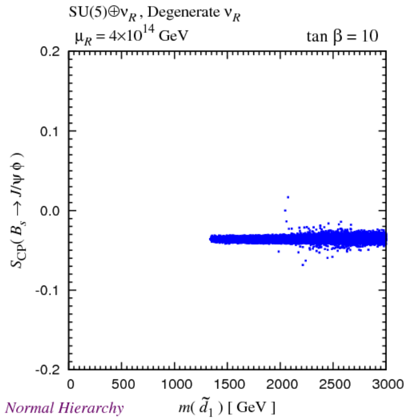


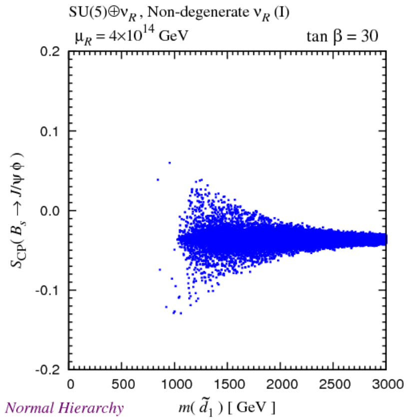


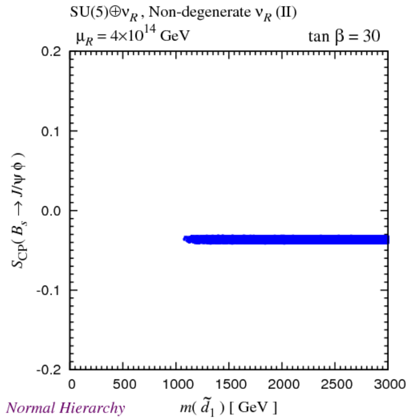


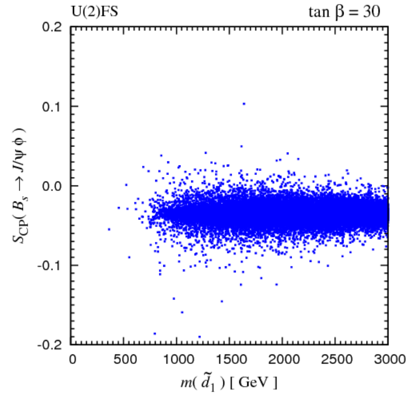


Dν_R-NH　　NDν_R(I)-NH　　NDν_R(II)-NH　　U(2)FS









$S_{\mathrm{CP}}(B_s \to J/\psi\phi)$ vs. $m(\tilde{d}_1)$

Summary: LFV

Model	$\mu \to e\gamma$	$\tau \to \mu\gamma$	$\tau \to e\gamma$
MSSM$\oplus\nu_R$			
Degenerate ν_R, NH	$\surd$		
Degenerate ν_R, IH	$\surd$	$\surd$	
Degenerate ν_R, D	$\surd$	$\surd$	
Non-degen. ν_R (I), NH		$\surd$	
Non-degen. ν_R (II), NH			$\surd$
SU(5)$\oplus\nu_R$			
Degenerate ν_R, NH	$\surd$		
Degenerate ν_R, IH	$\surd$	$\surd$	
Degenerate ν_R, D	$\surd$	$\surd$	
Non-degen. ν_R (I), NH	$\surd$	$\surd$	
Non-degen. ν_R (II), NH	$\surd$		$\surd$
Exp. sensitivity	10^{-13}	$2-8\times10^{-9}$	
	MEG	SuperB@$50-75$ab^{-1}	

$\surd$: B$(\mu \to e\,\gamma) \sim 10^{-11}$, B$(\tau \to \mu(e)\gamma) \sim 10^{-8}$ possible.

Summary: Time-dependent CPV in $b \to s(d)$

	$S_{\text{CP}}(K^*\gamma)$	$S_{\text{CP}}(\rho\gamma)$	$\Delta S_{\text{CP}}(\phi K_S)$	$S_{\text{CP}}(B_s \to J/\psi\phi)$
SU(5)$\oplus\nu_R$				
Dν_R, NH	~ 0.01	~ 0.01	~ 0.01	~ 0.01
Dν_R, IH	~ 0.2	~ 0.02	~ 0.2	~ 0.1
Dν_R, D	~ 0.01	~ 0.01	~ 0.01	~ 0.01
NDν_R(I), NH	~ 0.2		~ 0.1	~ 0.1
NDν_R(II), NH		~ 0.1		
U(2)FS	~ 0.2	~ 0.1	~ 0.1	~ 0.1
Exp. precision	$0.02-0.03$	$0.08-0.12$	$0.02-0.03$	~ 0.01
	SuperB@$50-75$ab^{-1}			LHCb@10fb^{-1}

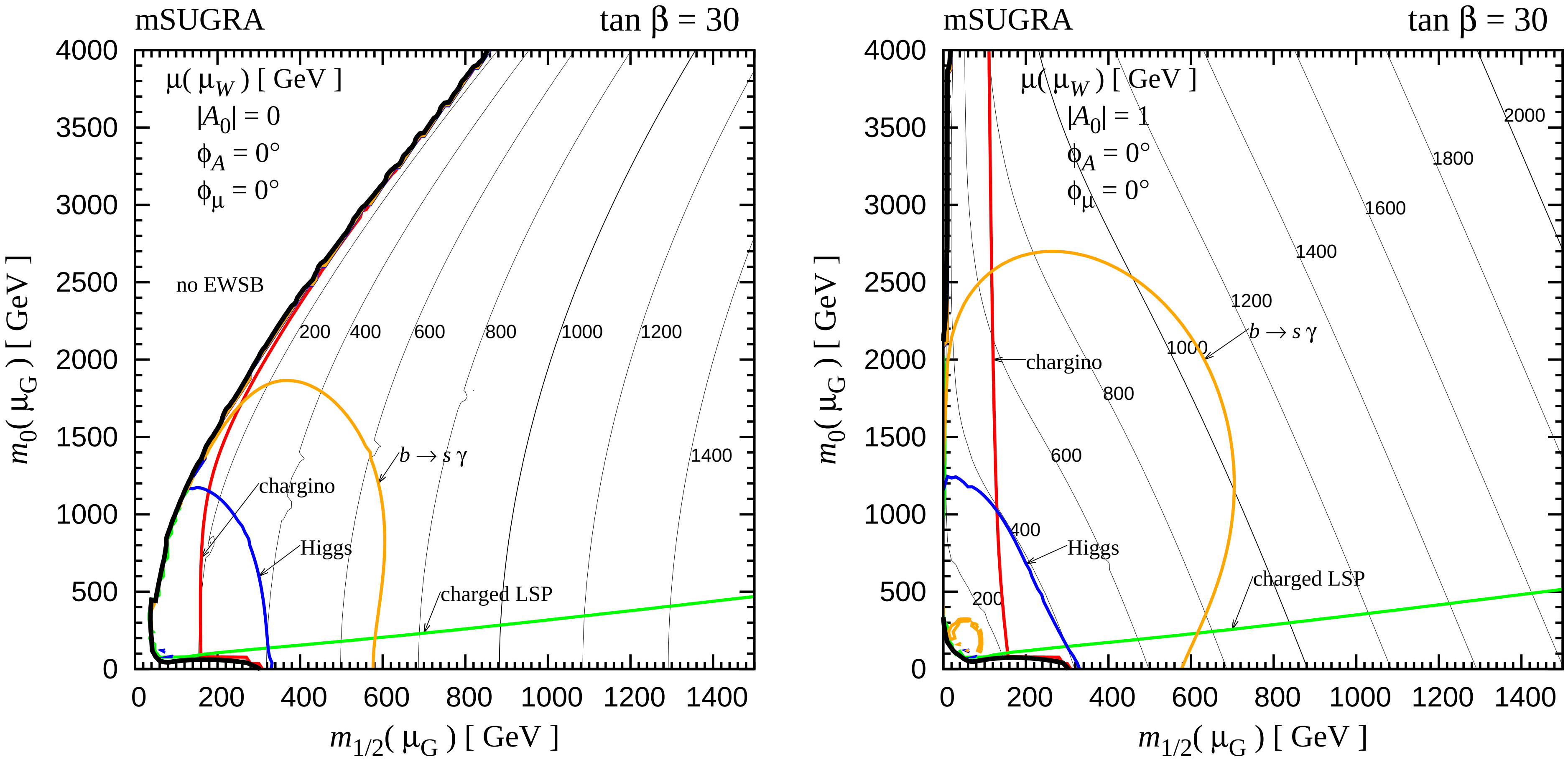
- Small in mSUGRA, MSSM$\oplus\nu_R$.

Conclusion

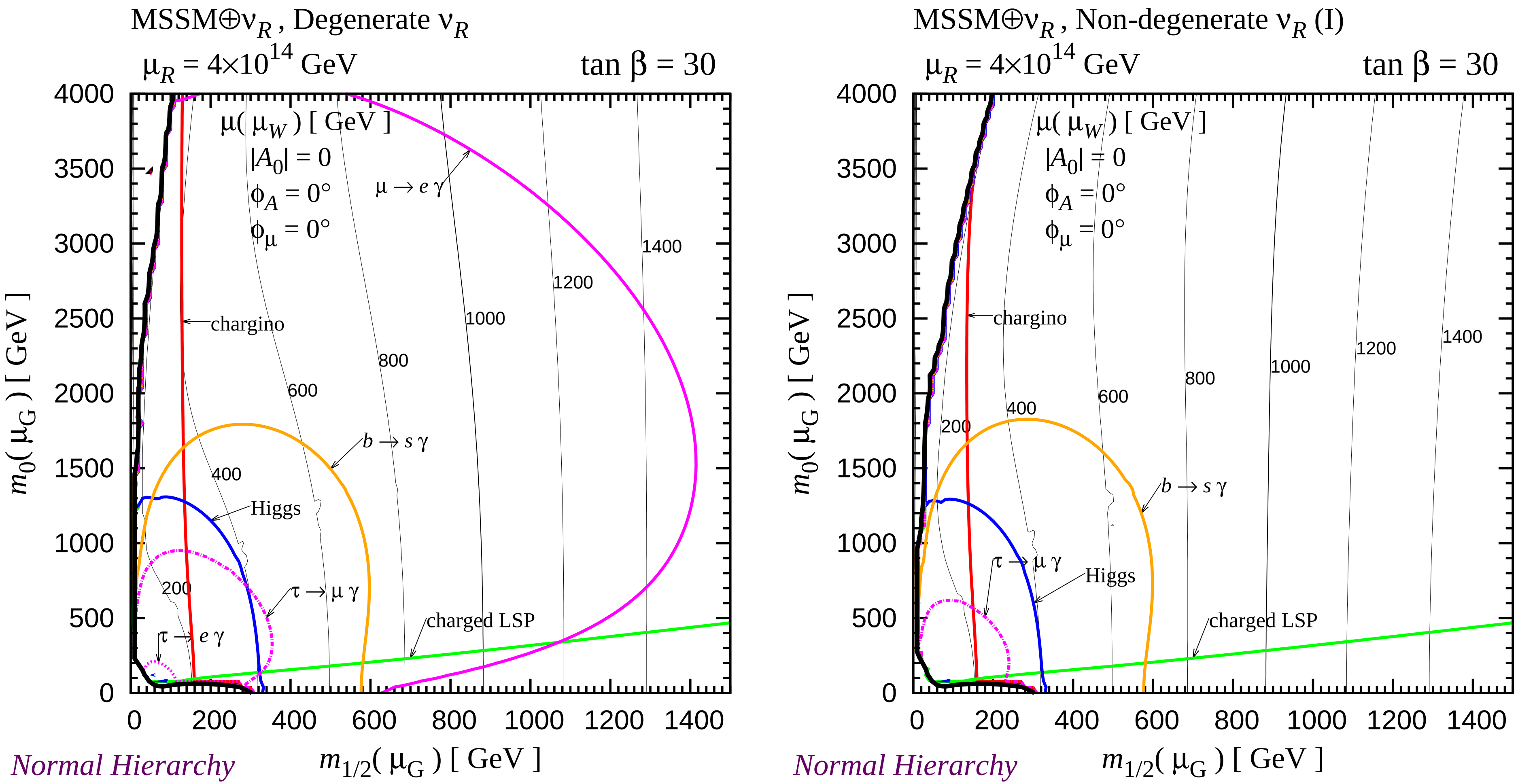
- Quark and lepton flavor signals are studied for SUSY models with various flavor structures.
- Each model gives different pattern of signals in $b \to s$, $b \to d$ and LFV processes.
- Measuring many processes is important to explore flavor structure of new physics beyond the SM.
- Reducing theoretical (hadronic) uncertainties in SM predictions to $O(\%)$ level is important.

Backups

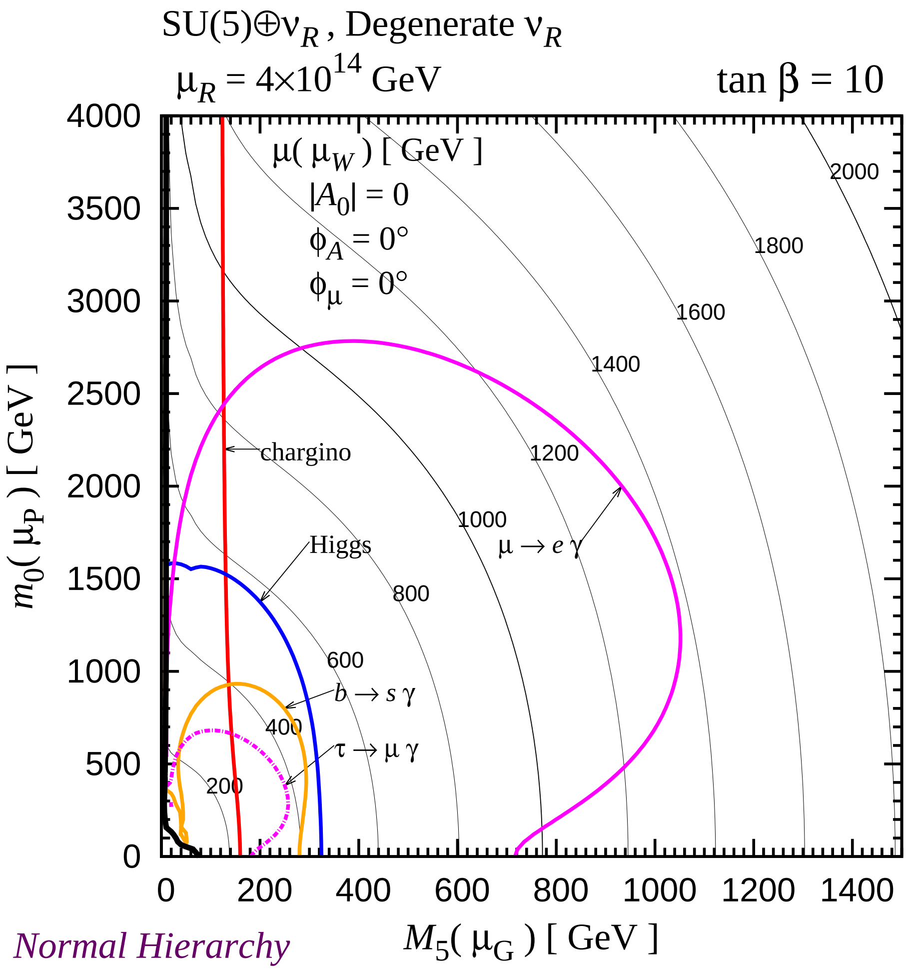
Allowed parameter space: mSUGRA

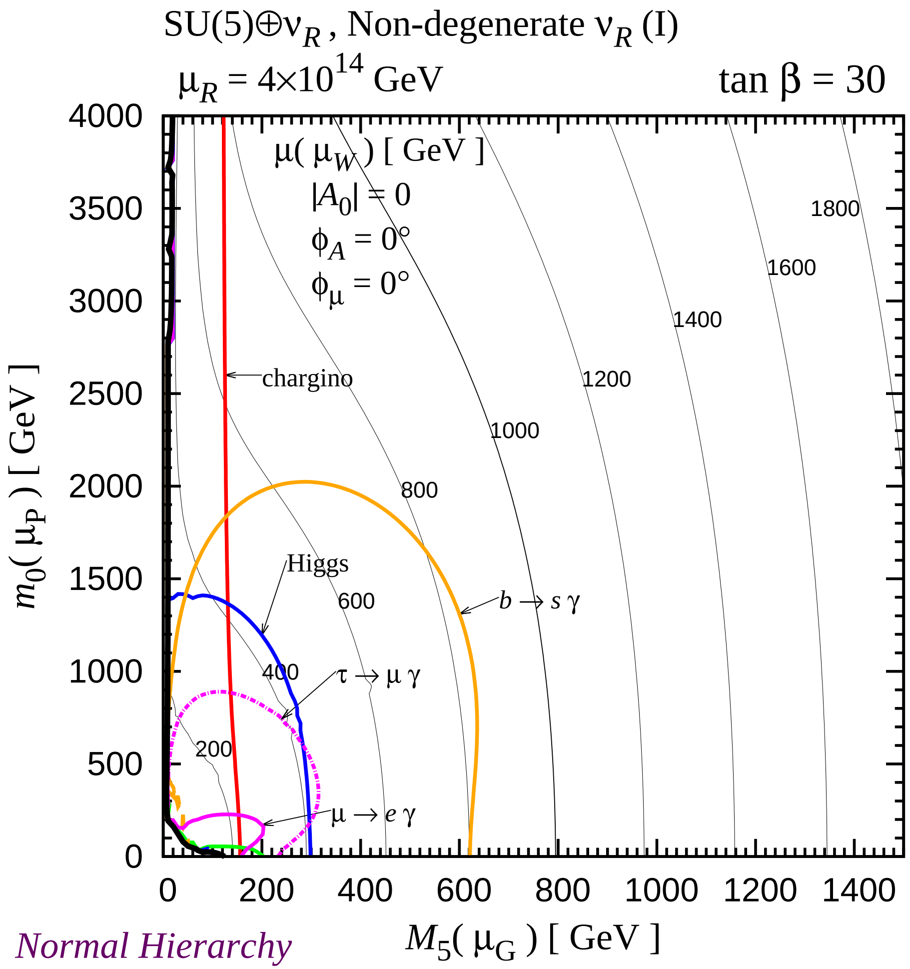


Allowed parameter space: MSSM$\otimes\nu_R$



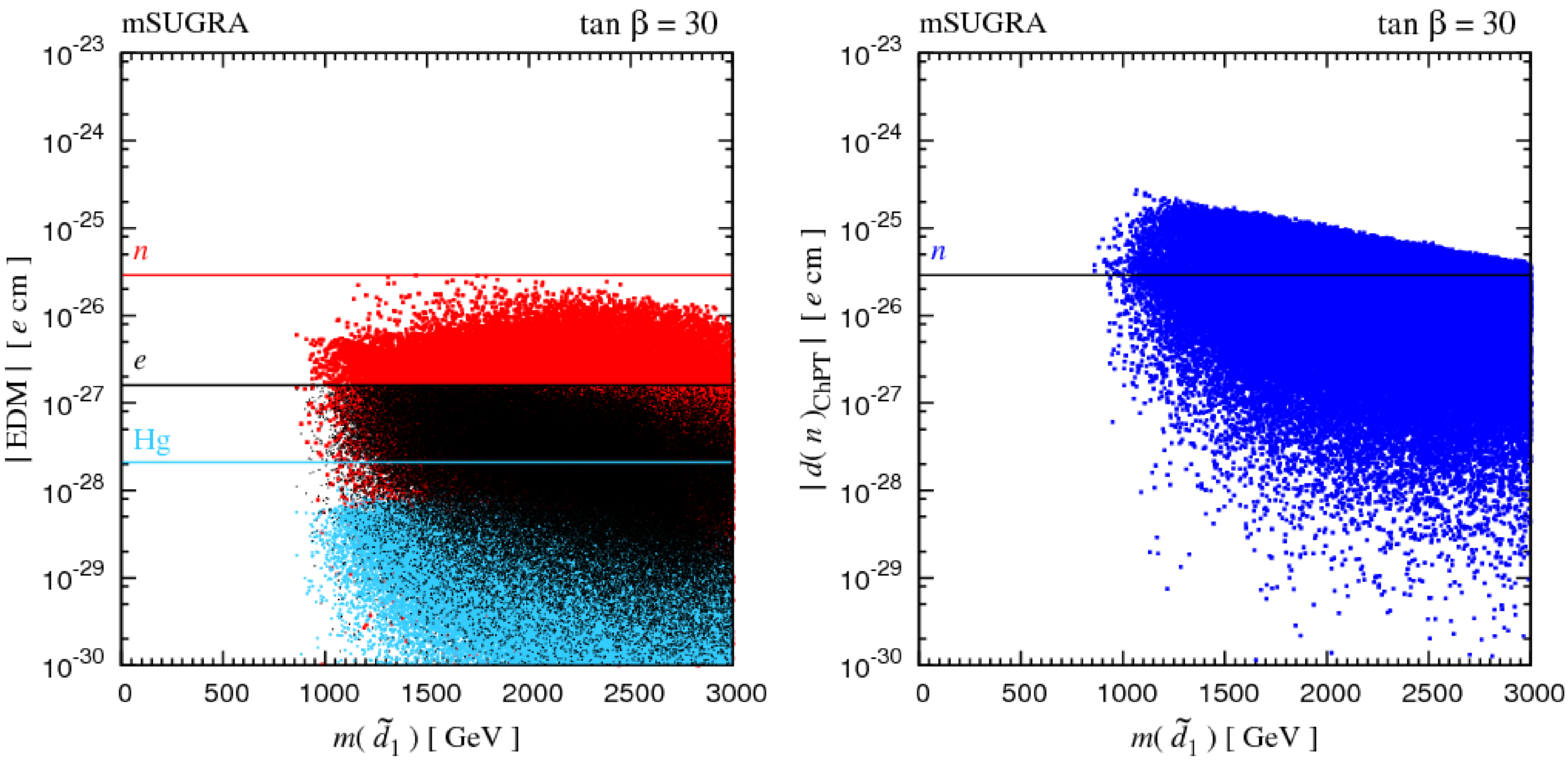
Allowed parameter space: SU(5)$\otimes\nu_R$





Normal Hierarchy *Normal Hierarchy*

Neutron EDM: naive quark model vs. chiral perturbation theory



- Source: ϕ_A.
- Large uncertainty in s quark contributions.