Impacts of quark and lepton flavor signals in LHC era

w/ T. Goto (YITP), Y. Okada (KEK), and M. Tanaka(Osaka U)

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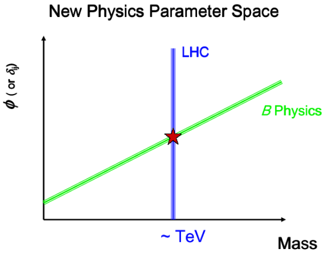
CERN Workshop “Flavor in the era of the LHC”

SUSY in the LHC era

- SUSY is one of the most attractive candidate of NP.
- LHC is the most promising way to discover SUSY.
- SUSY have rich sourse of flavor mixings and CP violations.
- Flavor structure depends on details of new physics.
- In general, correlations among various observables are important to figure out SUSY model.



J.Hewett and D. G. Hitlin (ed.), hep-ph/0503261

Sfermion mass matrices tells us ...

$m^2_{\tilde{f}} = (Y^\dagger Y)_{ij} v^2 + m^2_{ij}$ ← SUSY breaking terms

Squark/slepton mass matrices carry information on the SUSY breaking mechanism and interactions at the high energy scale.

Origin of SUSY breaking
(mSUGRA, AMSB, GMSB, FS, etc)

↓

RG running (SUSY GUT, Y_ν, etc)

↓

SUSY breaking terms at ∼TeV (sfermion mass matrix)

↑

LHC and flavor experiments

Sfermion mass matrices tells us ...

Then different assumption of SUSY flavor model give different structure of sfermion mass matrix

Several assumptions of SUSY breakings

1. minimal flavor violation (e.g. mSUGRA, CMSSM, ...)
   $V_{\tilde{q}} \to V_{\text{CKM}}$
2. SUSY GUT with seesaw mechanism
   $(m^2_{\tilde{f}})_{ij} \to (Y_\nu^\dagger Y_\nu)$
3. Flavor symmetry (e.g. U(2) model)
   Same symmetry controls Y_f and $m^2_{\tilde{f}}$
4. ....

Content of this talk

1. SU(5) SUSY GUT with righthanded neutrinos (RN) as a benchmark model
   - What is a possible deviation from SM ?
2. Benchmark point for SU(5) SUSY GUT with RN
   - What flavor signal can be obtained when SUSY is discovered at LHC ?

SU(5) SUSY GUT w/ RN

S. Baek, T. Goto, Y. Okada, K. Okumura, PRD63, 051701;PRD64, 095001;
T. Moroi, PLB493, 366; N. Akama, Y. Kiyo, S. Komine, T. Moroi, PRD64,095012;
D. Chang, A. Masiero, H. Murayama, PRD67,075013; J. Hisano, Y. Shimizu, PLB565,183 ...

L_i and D_i are embedded in same multiplet

$\Downarrow$

Large flavor mixing in the neutrino sector can be a source of flavor mixing in the d_R sector

ν-mixing	$\longrightarrow$	$\tilde{l}_L$-mixing	$\longrightarrow$	LFV
	$\longrightarrow$	$\tilde{d}_R$-mixing	$\longrightarrow$	FCNC

- Correlation btwn LFV and FCNC is important
- New CP phases in the GUT model (GUT phase)
  $10_i = \{Q_i, (V^\dagger U)_i, e^{i\phi_i^L} E_i\}, \quad 5_i = \{D_i, e^{-i\phi_i^L} L_i\}$

The LFVs give strong constraints !

LFV depends on $Y_\nu^\dagger Y_\nu$.
$m_\nu = v_u^2 Y_\nu^T M_R^{-1} Y_\nu \rightarrow$ undetermined 9 d.o.f. Y_ν
These d.o.f. affect LFV

e.g. J.R. Ellis, et al. EPJC14,319; S. Lavignac, I. Massina, C.A. Savoy, PLB520,269; J.A. Casas, A. Ibarra, NPB618,171; J. Ellis, J. Hisano, M. Raidal, Y. Shimizu, PRD66, 115013; A. Masiero, S.K. Vempati, O. Vives, NPB649,189; S.T. Petcov, W. Rodejohann, T. S, Y. Takanishi, hep-ph/0510404 ...

Hereafter, we consider two typical examples ♡

- Degenerate M_R case: $M_R = \mu_R \mathbf{1}$, $Y_\nu \propto \sqrt{m_\nu^{\text{diag}}} U^\dagger$
  large 1–2 and 2–3 mixing $\Rightarrow$ severe $\mu \rightarrow e\gamma$ constraint
- Non-degenerate M_R case

$$Y_\nu^\dagger Y_\nu = \begin{pmatrix} * & 0 & 0 \\ 0 & * & * \\ 0 & * & * \end{pmatrix}$$

$\mu \rightarrow e\gamma$ is significantly suppressed
2–3 mixing can be large

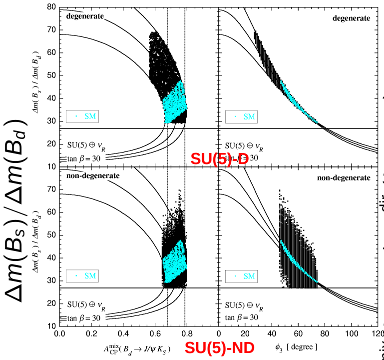
J.A. Casas and A. Ibarra, NPB618,171;
J. Ellis, J. Hisano, M. Raidal, Y. Shimizu, PRD66, 115013

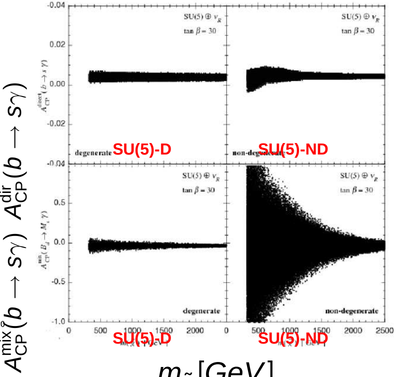
What we do

- We assume mSUGRA type boundary conditions at Planck scale.
- Possible SUSY parameters are scaned.
- We treat ϕ_3 and $|V_{ub}|$(within $\pm 10\%$) as a free parameter.
- GUT phase ϕ_L is included
- M_R scale is taken as $\mu_R^3 = \det M_R$
- Constraints
  - SUSY mass and Higgs mass (LEP etc)
  - $2 \times 10^{-4} < \mathrm{B}(b \to s\gamma) < 4.5 \times 10^{-4}$
  - For SUSY GUT, $\mathrm{B}(\mu \to e\gamma) < 1.2 \times 10^{-11}$
  - EDMs: $|d_n| < 6.3 \times 10^{-26} ecm$, $|d_e| < 4.0 \times 10^{-27} ecm$
  - K–$\bar{K}$: $1.08 \times 10^{-3} < \epsilon_K < 4.42 \times 10^{-3}$
  - B–$\bar{B}$: $0.465 ps^{-1} < \Delta m_{B_d} < 0.513 ps^{-1}$, $\Delta m_{B_s} > 13.1 ps^{-1}$
  - $A(B \to J/\psi K_S)$ and related results in B-factory

Numerical Result

T. Goto, Y. Okada, Y. Shimizu, T.S. and M. Tanaka,PRD66,035009;PRD70, 035012





$A(B \to J/\psi K_S)$ ϕ_3[degree] $m_{\tilde{g}}$[GeV]

A significant contribution to ϵ_K in SU(5)-D
$\Rightarrow$ deviation in ϕ_3

A large 2–3 mixing (CPV) in SU(5)-ND

Pattern of the deviation from SM

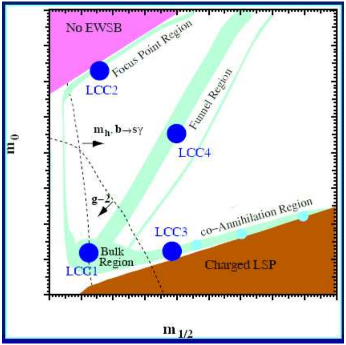
	mSUGRA	SU(5)+ν_R (De-generate)	SU(5)+ν_R (non-deg)	U(2) FS
B_d-UT	closed	closed	closed	$++$
ϕ_3	$-$	$++$	$-$	$++$
Δm_{B_s}	$-$	$-$	$++$	$++$
$A_{\rm mix}(B\to\phi K_S)$	$-$	$-$	$++$	$++$
$A_{\rm mix}(B\to M_s\gamma)$	$-$	$+$	$++$	$++$
$A_{\rm dir}(b\to s\gamma)$	$+$	$+$	$+$	$++$

In SU(5) SUSY GUT,
large SUSY contributions to B observables
$\Leftrightarrow$ large contributions to LFV $\rightarrow$ significantly constrained !

Benchmark point in SUSY GUT

In order to figure out impact of flavor physics in era of LHC, we consider a benchmark point.

- If we consider the DM constraint, much of the parameter space is excluded.
- Some benchmark points are proposed for detailed LHC/ILC studies $\rightarrow$ mass spectrum and signals
- How about flavor signals on such points?



M. Battaglia, talk at Snowmass 2005

We focus on focus point in the SUSY SU(5) GUT with RN

- LSP is $\tilde{\chi}_1^0$ ($\tilde{h}$ like)
- Annihilate to W^+W^- through $\tilde{\chi}^\pm$ exchange

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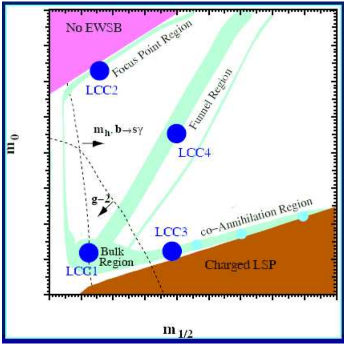

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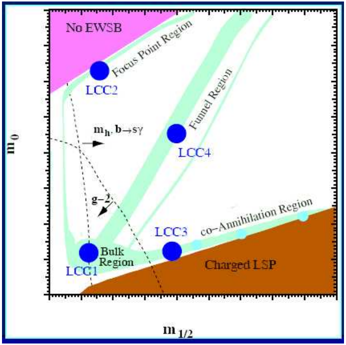


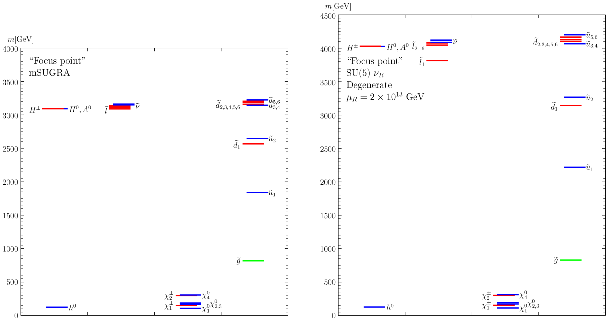
M. Battaglia, talk at Snowmass 2005

We focus on focus point in the SUSY SU(5) GUT with RN

- LSP is $\tilde{\chi}^0_1$ ($\tilde{h}$ like) $\to \mu < M_1(\simeq 0.4 m_{1/2}) \ll m_0$
- Annihilate to W^+W^- through $\tilde{\chi}^\pm$ exchange

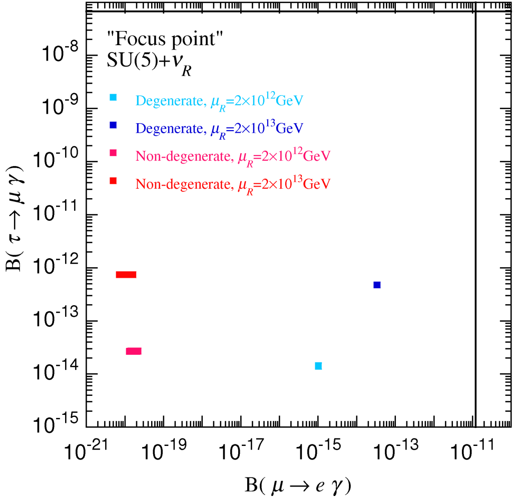
Our definition of focus point in SU(5) SUSY GUT

We choose the SUSY parameters s.t. the spectrum of $\tilde{\chi}^0$ and $\tilde{\chi}^{\pm}$ are similar to focus point in mSUGRA

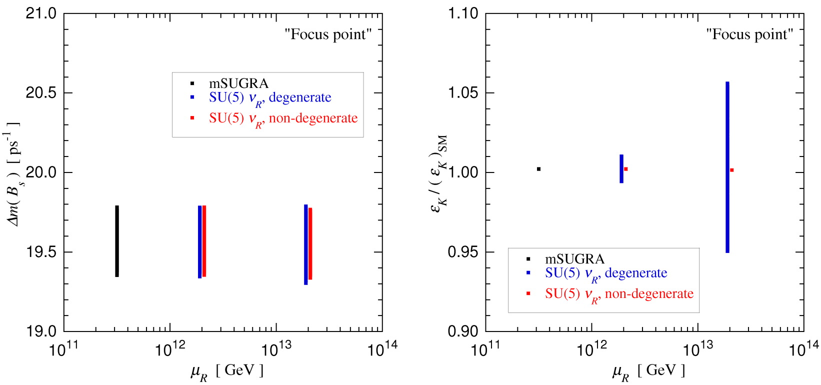


Sfermion masses in SU(5) SUSY GUT are much larger than mSUGRA case ♡

Lepton flavor violation



Unitarity triangle test

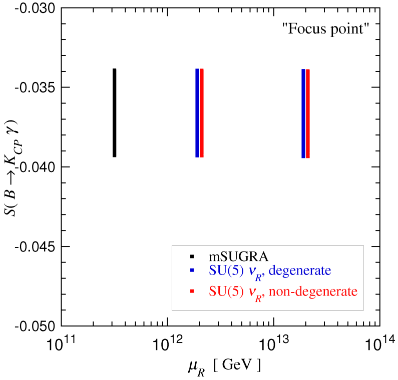


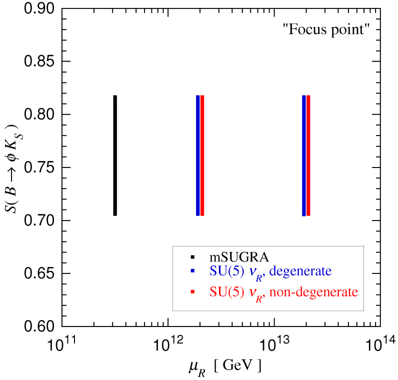
$\sim$ 5% SUSY contribution to ϵ_K is possible

$\Downarrow$

$\sim$ 5% deviation in ϕ_3 is possible

Time dependent CP asymmetry of B decay





SUSY contributions on flavor signals (Focus point)

Models	$\mu \to e\gamma$	$\tau \to \mu\gamma$	ϕ_3	B signal
mSUGRA	—	—	small	small
SU(5)-D	10^{-13}	10^{-12}	5%	small
SU(5)-ND	small	10^{-12}	small	small

Summary

- If SUSY at ∼TeV is realized in nature, LHC is likely to provide some evidence. Then, determining the SUSY breaking scenario becomes one of the most important works.
- The flavor structure of the SUSY breaking terms should be the largest hint for determining the SUSY breaking scenario.
- There are a variety of ways to look for SUSY effects in flavor processes, LFV, B decays, etc.
- In order to distinguish different SUSY models, we need to see pattern of deviations from the SM predictions in various processes.
- On focus point in SUSY GUT, 5% deviation in ϕ_3 is possible and LFVs are hopeful to be observed. scenario.

Thank you

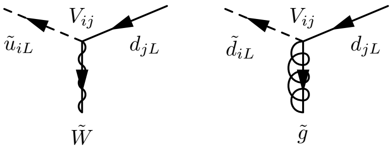
mSUGRA (CMSSM)

S. Bertolini, F. Borzumati, A. Masiero, and G. Ridolfi, NPB353:591

- All squarks and sleptons are degenerate at M_P.
- Flavor mixings and mass-splittings are induced by running
- Flavor mixings in d_L sector (because of CKM mixing)
- No mixing in slepton sector

The CKM matrix is the only source of flavor mixing. SUSY CP phases (in A- and μ-term) are constrained by EDM exp.

$$(V_{\tilde{q}})_{ij} \simeq (V_{\rm CKM})_{ij}$$



MSSM with U(2) FS

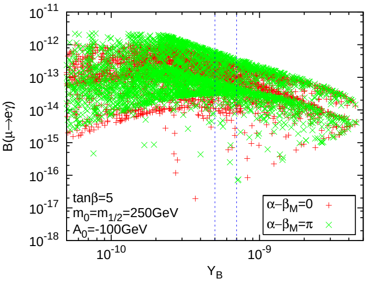
A. Pomarol, D. Tommasini, NPB466,3; R. Barbieri, G. Dvarli, L. Hall, PLB377, 76;
R. Barbieri, L. Hall, NCA110, 1; R. Barbieri, L. Hall, S. Raby, A. Romanino, NPB493, 3;
R. Barbier, L. Hall, A. Romanino, PLB401,47;
A. Masiero, M. Piai, A. Romanino,L. Silverstrini, PRD64, 075005 ...

Y_q and $m^2_{\tilde{q}}$ terms are controlled by the same flavor symmetry, U(2)

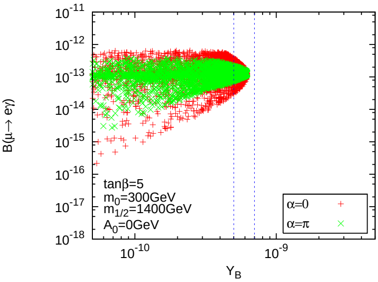
- 1st and 2nd generation $\rightarrow$ U(2) doublet
- 3rd generation $\rightarrow$ U(2) singlet
- Symmetry is broken as:

$$\text{U(2)} \xrightarrow{\epsilon} \text{U(1)} \xrightarrow{\epsilon'} \text{No symmetry} \quad 1 \gg \epsilon \gg \epsilon'$$

$$(Y)_{ij} \simeq y \begin{pmatrix} 0 & \mathcal{O}(\epsilon') & 0 \\ \mathcal{O}(\epsilon') & \mathcal{O}(\epsilon) & \mathcal{O}(\epsilon) \\ 0 & \mathcal{O}(\epsilon) & 1 \end{pmatrix}, \; m^2_{\tilde{Q}} = (m^2_0) \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1+\mathcal{O}(\epsilon^2) & \mathcal{O}(\epsilon) \\ 0 & \mathcal{O}(\epsilon) & \mathcal{O}(1) \end{pmatrix}$$

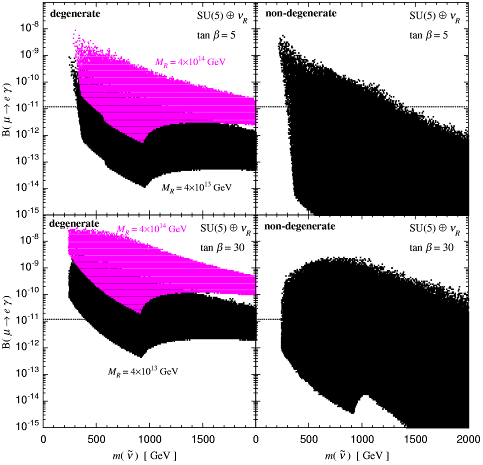


$m_1 \ll m_2 \ll m_3$



$m_1 \sim m_2 \gg m_3$

Constraint from LFV



Deg:

$M_R = 4.0 \times 10^{14}$GeV

$M_R = 4.0 \times 10^{13}$GeV

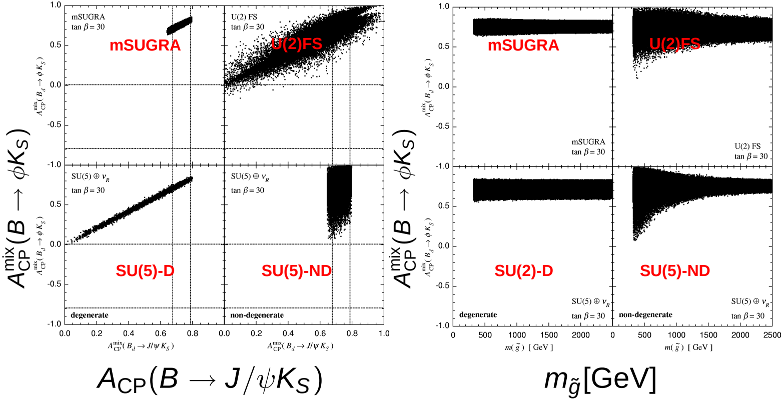
ND:

$M_R = 4.0 \times 10^{14}$GeV

Deg: $Y_\nu \rightarrow$small

ND: Y_ν can be large

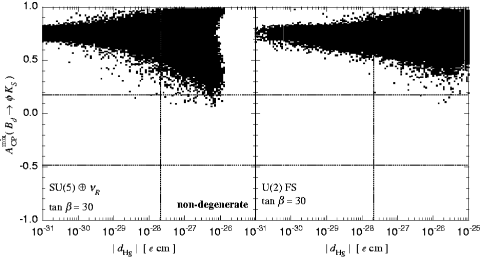
$A_{\rm mix}(B \to \phi K_S)$



Large deviation can be observed in U(2) model and SU(5)+ν_R(non-deg)

EDM and $B \to \phi K_S$

A correlation between $A(B \to \phi K_S)$ and the s-quark EDM is pointed out (J. Hisano, Y. Shimizu, PRD70,093001; PLB581,224).



μ in m_0 — $m_{1/2}$ plane

Y_ν accelerate the EWSB $\to$ m_0 should be larger