Flavour Signals in SUSY GUT models

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Ref

- JHEP 1105:005, 2011 [arXiv:1011.4853]

Collaborated with:

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1. Introduction

LHC is on-going

- High Energy Frontier

ATLAS, CMS start to constrain new physics models

- High Statistics Frontier

- Key ingredients to understand the flavor structure of the New Physics (NP)

- Possible to probe high energy physics which can't be accessed directly by colliders

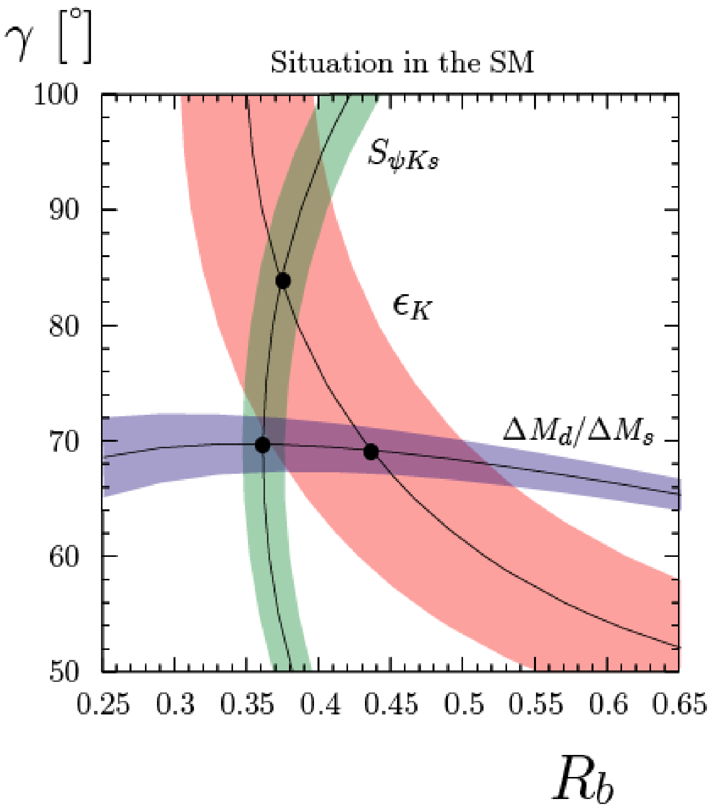
LHCb, MEG experiments are coming soon

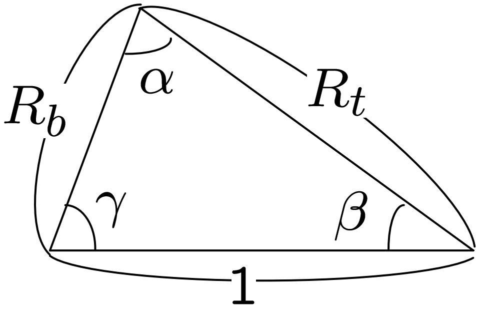
Some hints may be already presented:

UT tension, Bs mixing, muon g-2…

Tension in the Unitarity Triangle

Lunghi, Soni (‘08); Buras, Guadagnoli (’08, ’09)





Using only $S_{\psi K_S}$ and $\Delta M_d/\Delta M_s$ to construct the UT,

$$\epsilon_K^{\mathrm{SM}} = (1.90 \pm 0.26) \times 10^{-3}$$

$$\Updownarrow$$

$$\epsilon_K^{\mathrm{exp}} = (2.229 \pm 0.010) \times 10^{-3}$$

Possible 3 solutions :

New physics contributes

1) +20 % in ϵ_K

2) – 4.5 ° in B_d mixing phase

3) - 20 % in $\Delta M_d/\Delta M_s$

Tension in the Unitarity Triangle

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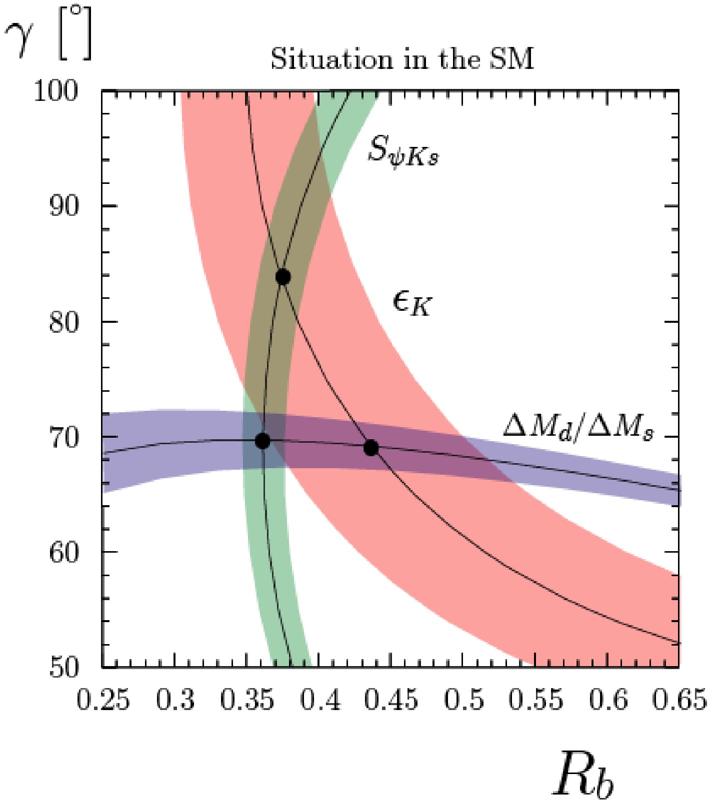
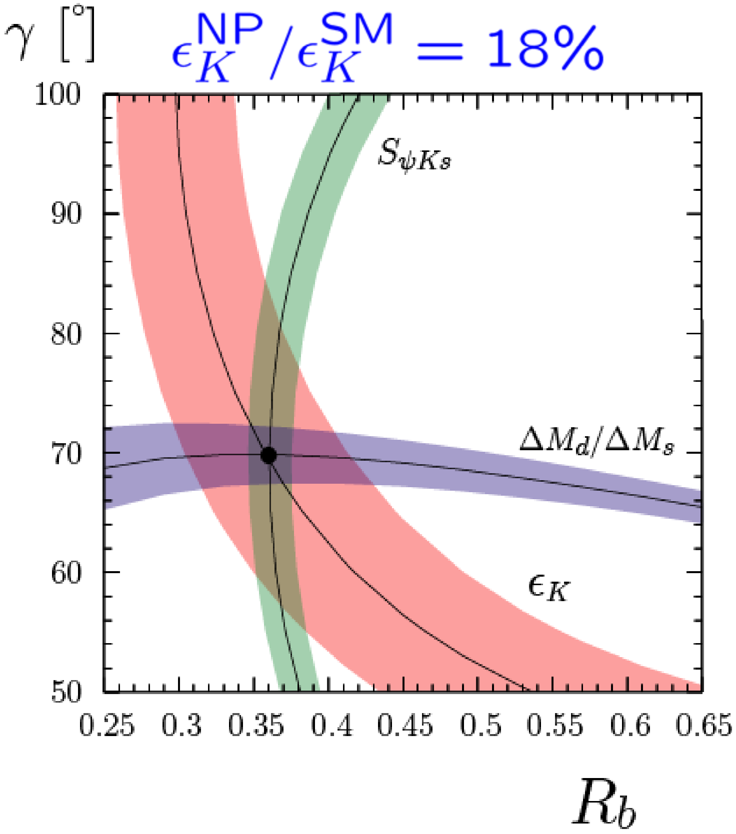
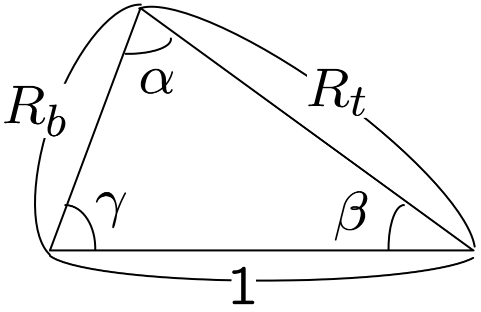


Situation in the SM



$\epsilon_K^{NP}/\epsilon_K^{SM} = 18\%$



Hint for New physics in Bs system?

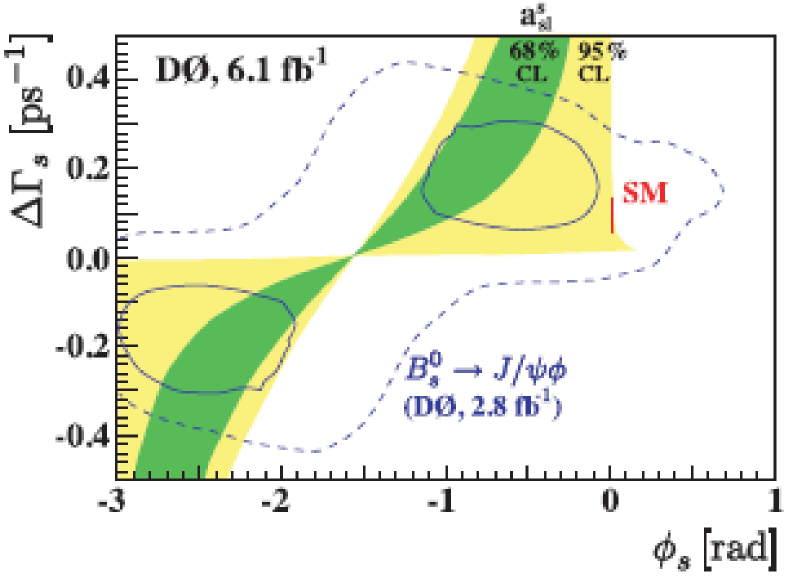
CP asymmetry in $B_s \to J/\psi\phi$ ⇨ Sensitive to the phase of bs-mixing

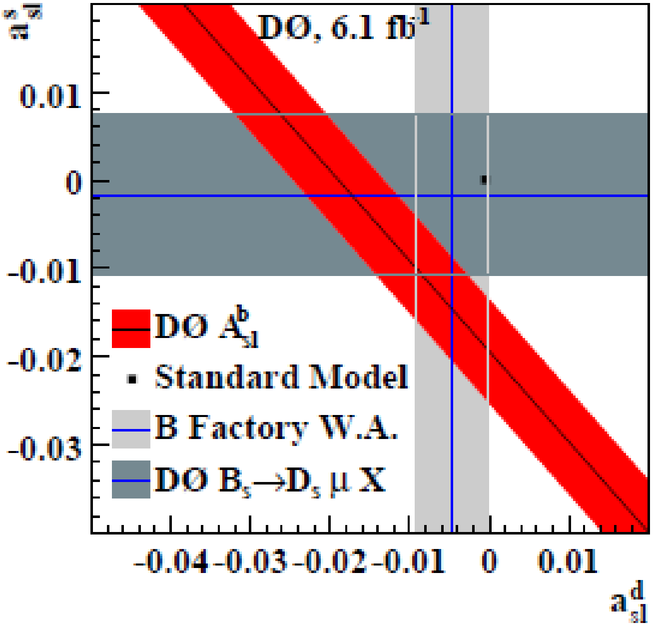
$$S_{\psi\phi} = \sin(2|\beta_s| + 2\phi_s^{\rm NP}) \qquad (S_{\psi\phi}^{\rm SM} = \sin|2\beta_s| \simeq 0)$$

Dimuon charge asymmetry (3.2 sigma deviation from the SM)

$$A_b^{\rm SL}({\rm D0}) = (-9.57 \pm 2.51 \pm 1.46) \times 10^{-3}$$

$$A_b^{\rm SL} \simeq 0.5 a_d^{\rm SL} + 0.5 a_s^{\rm SL}, \qquad a_s^{\rm SL} \simeq -10^{-3} S_{\psi\phi}/C_{bs}$$





Purpose of this talk

To clarify

- Implications of the currently available experimental hints
- Expected signals in up-coming experiments

in SUSY GUT models.

Outline

1. Introduction
2. Flavor Structure in SUSY GUTs
3. Numerical Results
4. Summary

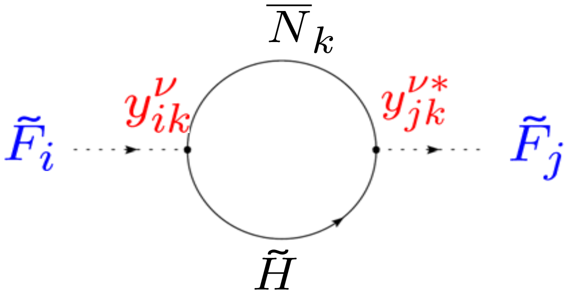
2. Flavour Structure in SUSY GUTs

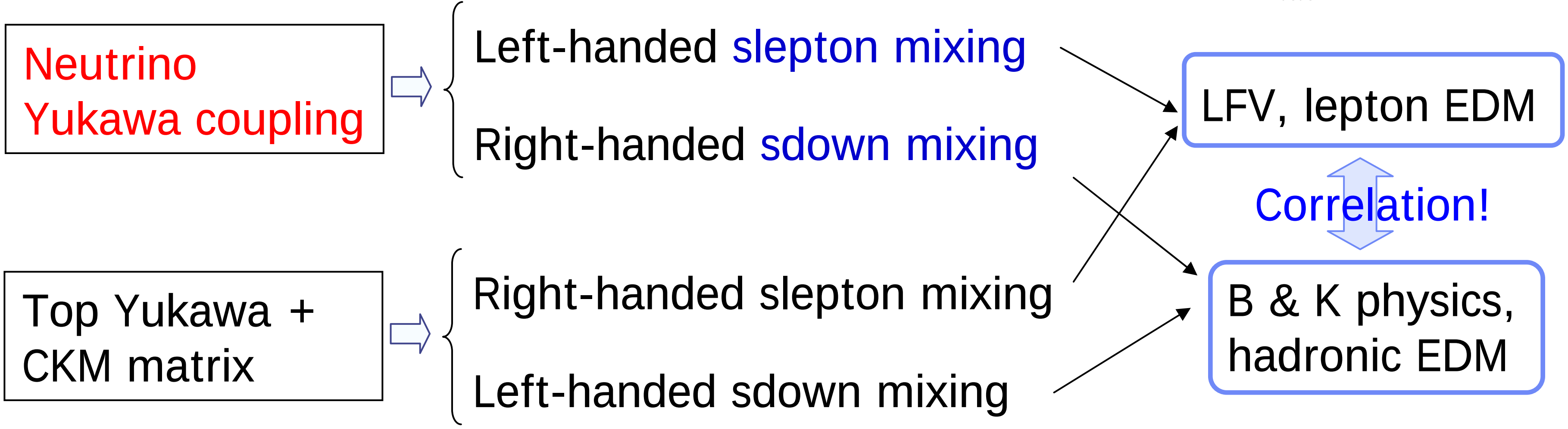
SUSY SU(5) GUT with right-handed neutrinos (SSU(5)$_{\text{RN}}$)

Matter multiplet : $T(U^c, Q, E^c)$, $F(D^c, L)$, N^c

Superpotential : $W = W_{\text{SU(5)}} + y_\nu N^c F H + M_N N^c N^c$

Neutrino Yukawa couplings induce flavor-violating soft masses both for quarks and leptons.





Neutrino Yukawa coupling

- Left-handed slepton mixing
- Right-handed sdown mixing

Top Yukawa + CKM matrix

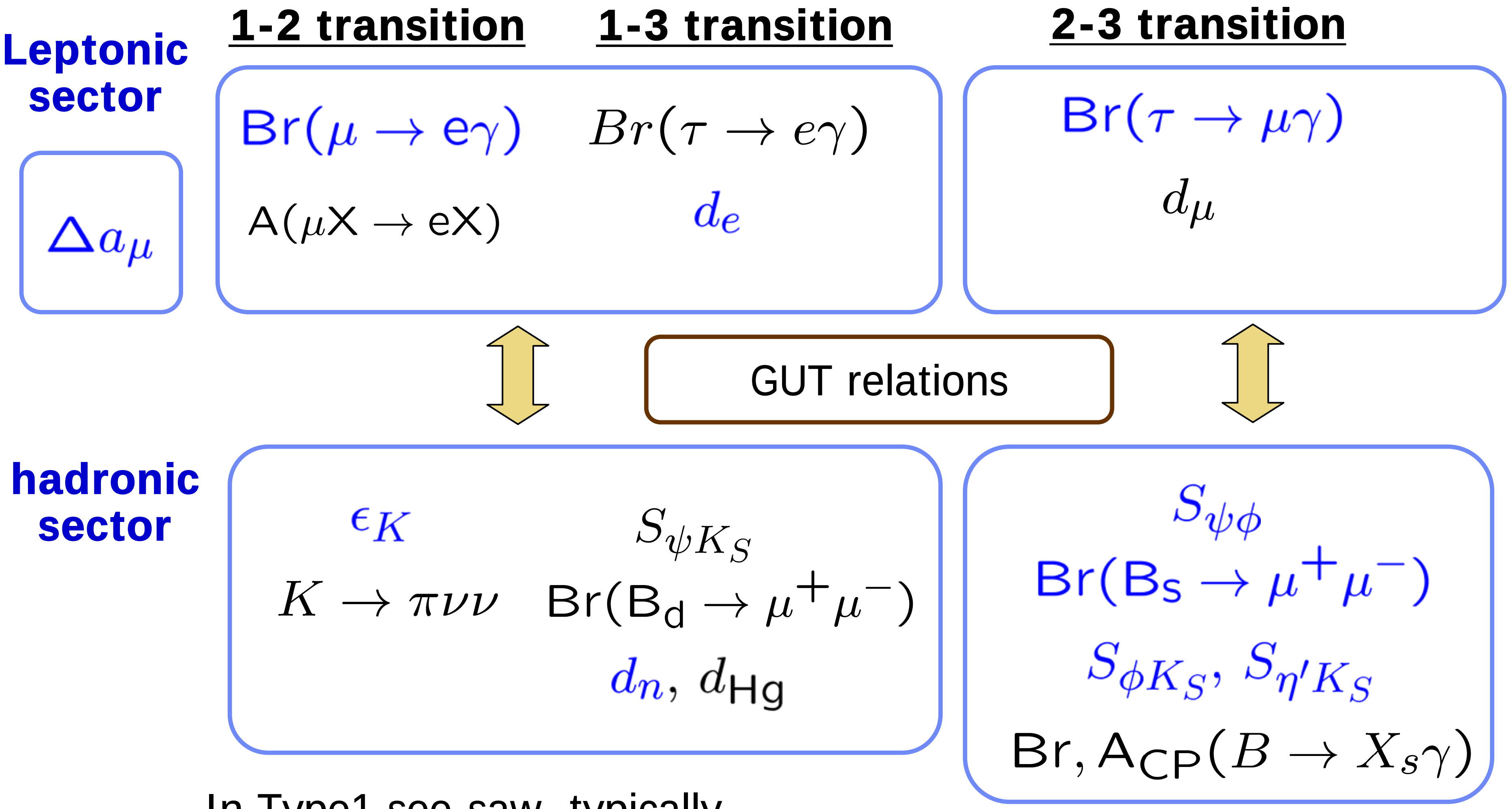
- Right-handed slepton mixing
- Left-handed sdown mixing

LFV, lepton EDM

Correlation!

B & K physics, hadronic EDM

Correlation between observables in SSU(5)$_{\mathrm{RN}}$



Leptonic sector

Δa_μ

1-2 transition

$\mathrm{Br}(\mu \to e\gamma)$

$\mathrm{A}(\mu X \to eX)$

1-3 transition

$Br(\tau \to e\gamma)$

d_e

2-3 transition

$\mathrm{Br}(\tau \to \mu\gamma)$

d_μ

GUT relations

hadronic sector

ϵ_K

$S_{\psi K_S}$

$K \to \pi\nu\nu$

$\mathrm{Br}(B_d \to \mu^+\mu^-)$

$d_n,\ d_{\mathrm{Hg}}$

$S_{\psi\phi}$

$\mathrm{Br}(B_s \to \mu^+\mu^-)$

$S_{\phi K_S},\ S_{\eta' K_S}$

$\mathrm{Br}, A_{CP}(B \to X_s\gamma)$

In Type1 see-saw, typically

$$(\delta^e_{LL})_{12} \sim (\delta^e_{LL})_{13} \Longleftarrow ??? \Longrightarrow (\delta^e_{LL})_{23}$$

Hisano, MN, Paradisi, Shimizu ('09)

Correlation between observables in SSU(5)$_{RN}$

Leptonic sector

Δa_μ

1-2 transition

1-3 transition

2-3 transition

Br($\mu \to$ eγ) $Br(\tau \to e\gamma)$

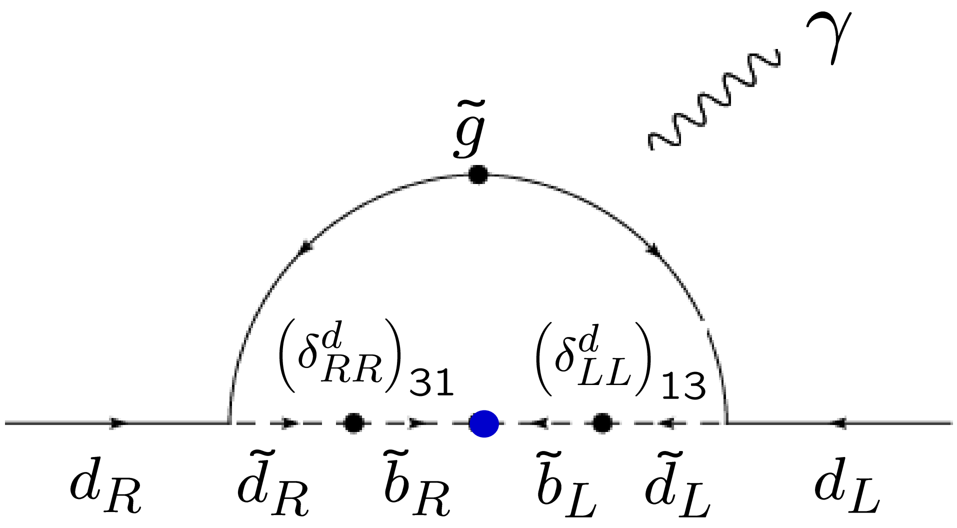
A(μX $\to$ eX)

Br($\tau \to \mu\gamma$)

hadronic sector

ϵ_K

$K \to \pi\nu\nu$ Br



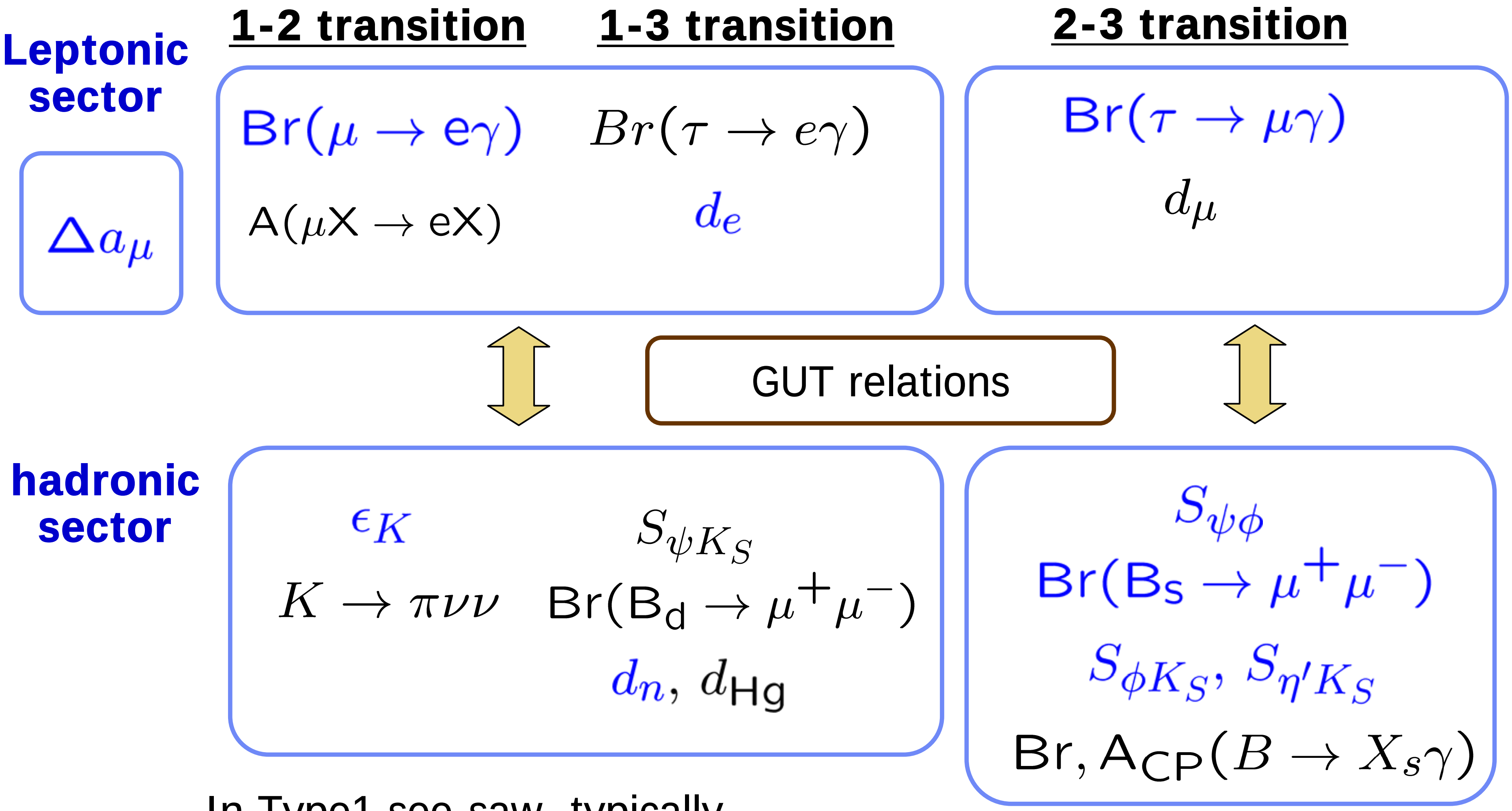
Enhanced by bottom Yukawa coupling

In Type1 see-saw, typically

$$(\delta^e_{LL})_{12} \sim (\delta^e_{LL})_{13} \Longleftarrow ??? \Longrightarrow (\delta^e_{LL})_{23}$$

Hisano, MN, Paradisi, Shimizu (‘09)

Correlation between observables in SSU(5)$_{\text{RN}}$



1-2 transition **1-3 transition** **2-3 transition**

Leptonic sector

Δa_μ

$\mathrm{Br}(\mu \to e\gamma)$ $Br(\tau \to e\gamma)$

$\mathrm{A}(\mu X \to eX)$ d_e

$\mathrm{Br}(\tau \to \mu\gamma)$

d_μ

GUT relations

hadronic sector

ϵ_K $S_{\psi K_S}$

$K \to \pi\nu\nu$ $\mathrm{Br}(B_d \to \mu^+\mu^-)$

$d_n,\ d_{\mathrm{Hg}}$

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$S_{\phi K_S},\ S_{\eta' K_S}$

$\mathrm{Br}, \mathrm{A}_{\mathrm{CP}}(B \to X_s\gamma)$

In Type1 see-saw, typically

$(\delta^e_{LL})_{12} \sim (\delta^e_{LL})_{13} \Leftarrow ??? \Rightarrow (\delta^e_{LL})_{23}$

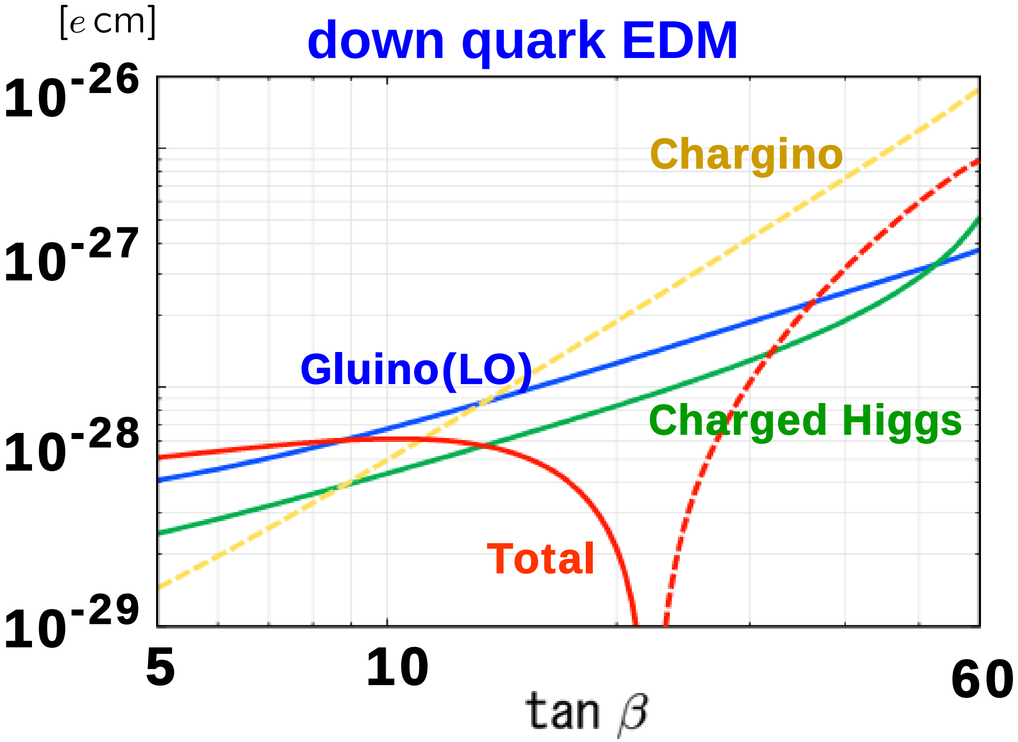
Hisano, MN, Paradisi, Shimizu (‘09)

What is NEW features in our analysis?

- The numbers of considered observables

  (Essential for the model discrimination!)
- Special focus on the UT tension and its implications
- $\tan\beta$ enhanced corrections are systematically included

  ⇨ Especially, unavoidable to calculate EDMs Hisano, MN, Paradisi (‘06, ‘08)



Not only $m_b \to \frac{m_b}{1+\epsilon t_\beta}$

But also, new Jarskog inv.

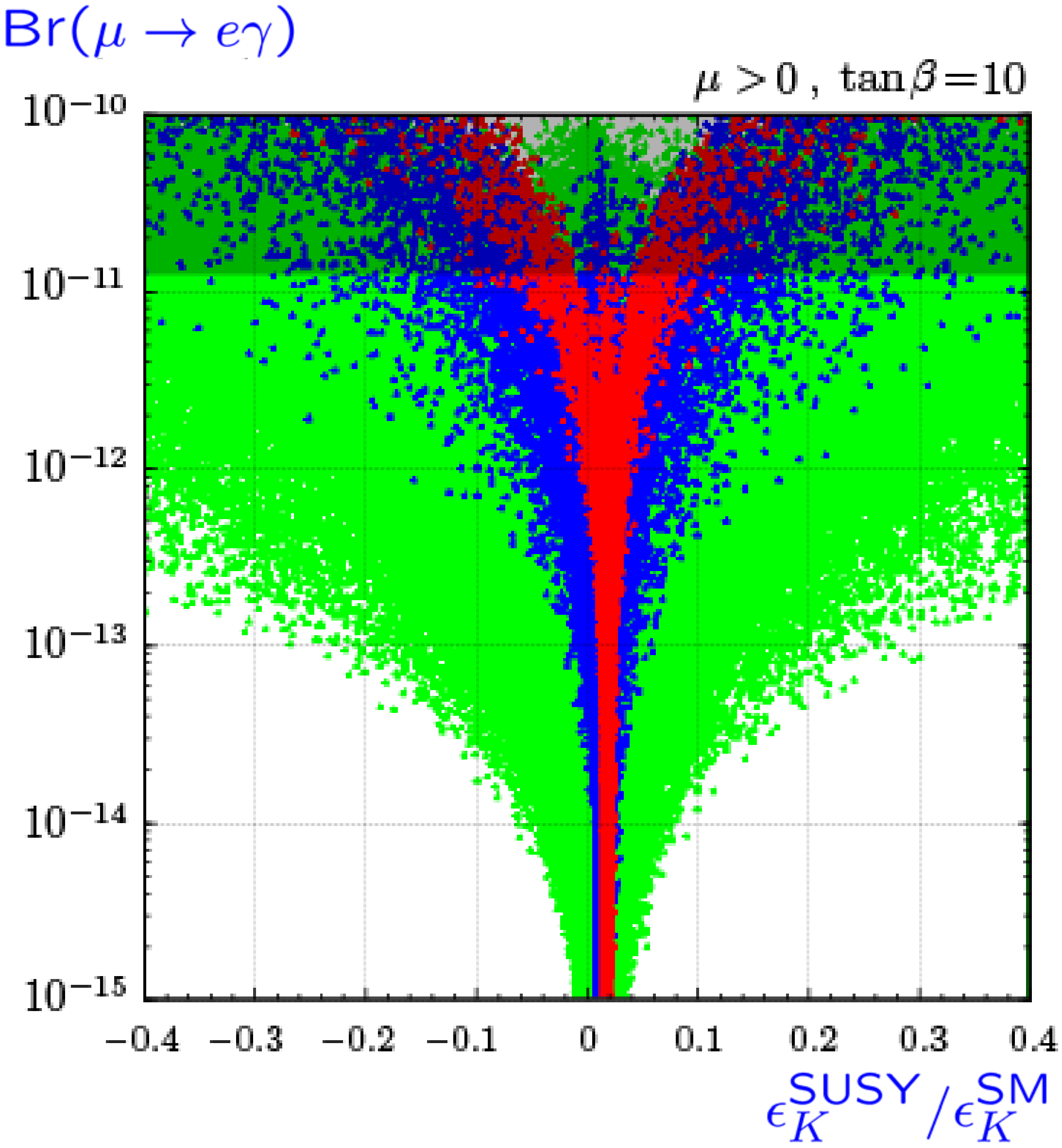
$$\mathrm{Im}[\delta_{LL}\delta_{RR}] + \epsilon t_\beta \mathrm{Im}[V_{CKM}\delta_{RR}]$$

$$\left(\begin{array}{r@{}l} M_{H_c} &= 2\times 10^{16}\mathrm{GeV} \\ M_{N_3} &= 10^{14}\mathrm{GeV} \\ m_{\nu_\tau} &= 0.05\mathrm{eV} \\ U_{e3} &= 0.01 \\ A_0 &= 0,\ \mu > 0 \\ m_0 &= 400\mathrm{GeV} \\ M_{1/2} &= 400\mathrm{GeV} \end{array}\right)$$

3. Numerical Results

Scan of parameters in the mSUGRA scenario

Correlation between Leptonic and Hadronic Sectors (1)

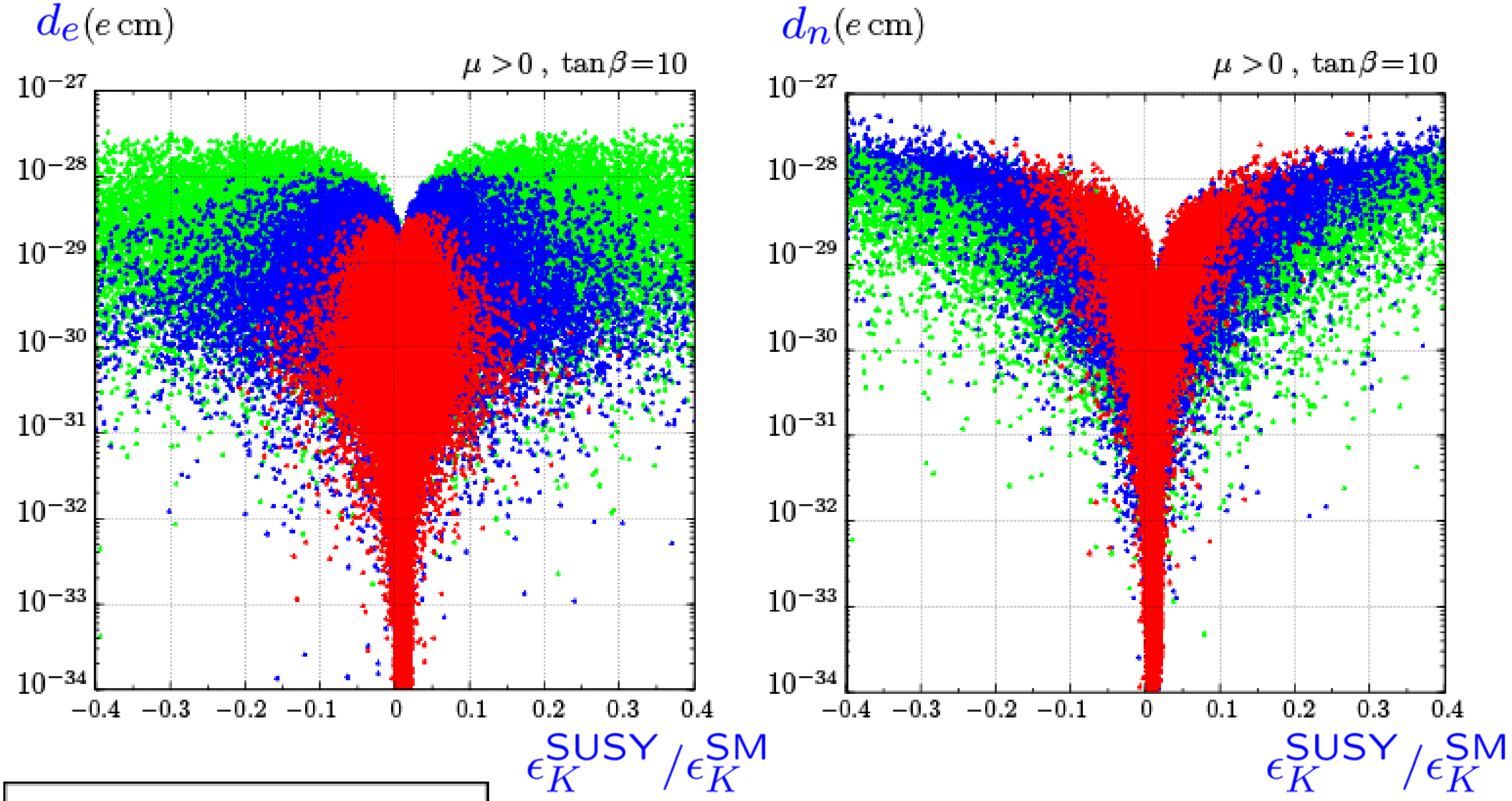


$\epsilon_K^{\text{SUSY}}/\epsilon_K^{\text{SM}} \sim 0.2$ is desirable to solve the UT tension

- Sizable SUSY effects in epsK imply a lower bound on $\text{Br}(\mu \to e\gamma)$
- Simultaneous explanation of $(g-2)_\mu$

$$\text{Br}(\mu \to e\gamma) > 10^{-12}$$

Predictions of EDMs



$BR(\mu\to e\gamma)<10^{-11}$ 🟢

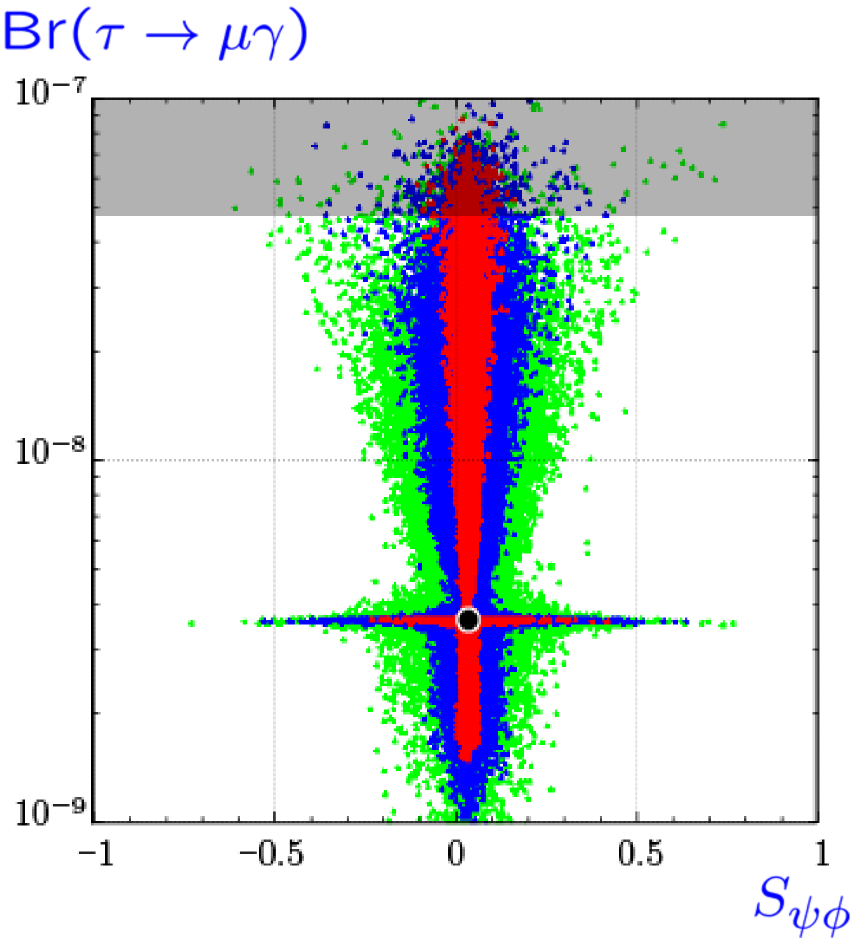
$BR(\mu\to e\gamma)<10^{-12}$ 🔵

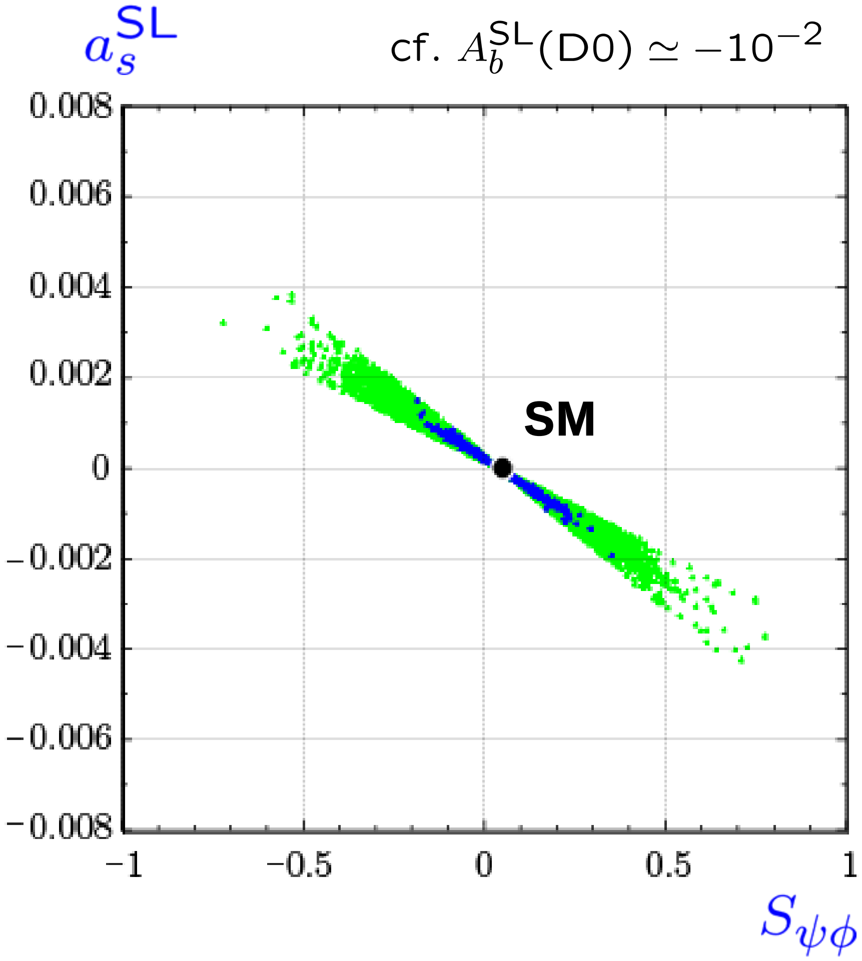
$BR(\mu\to e\gamma)<10^{-13}$ 🔴

Sizable SUSY effect in epsK

⇨ d_e & d_n in the reach of planned experiments

Correlation between Leptonic and Hadronic Sectors (2)





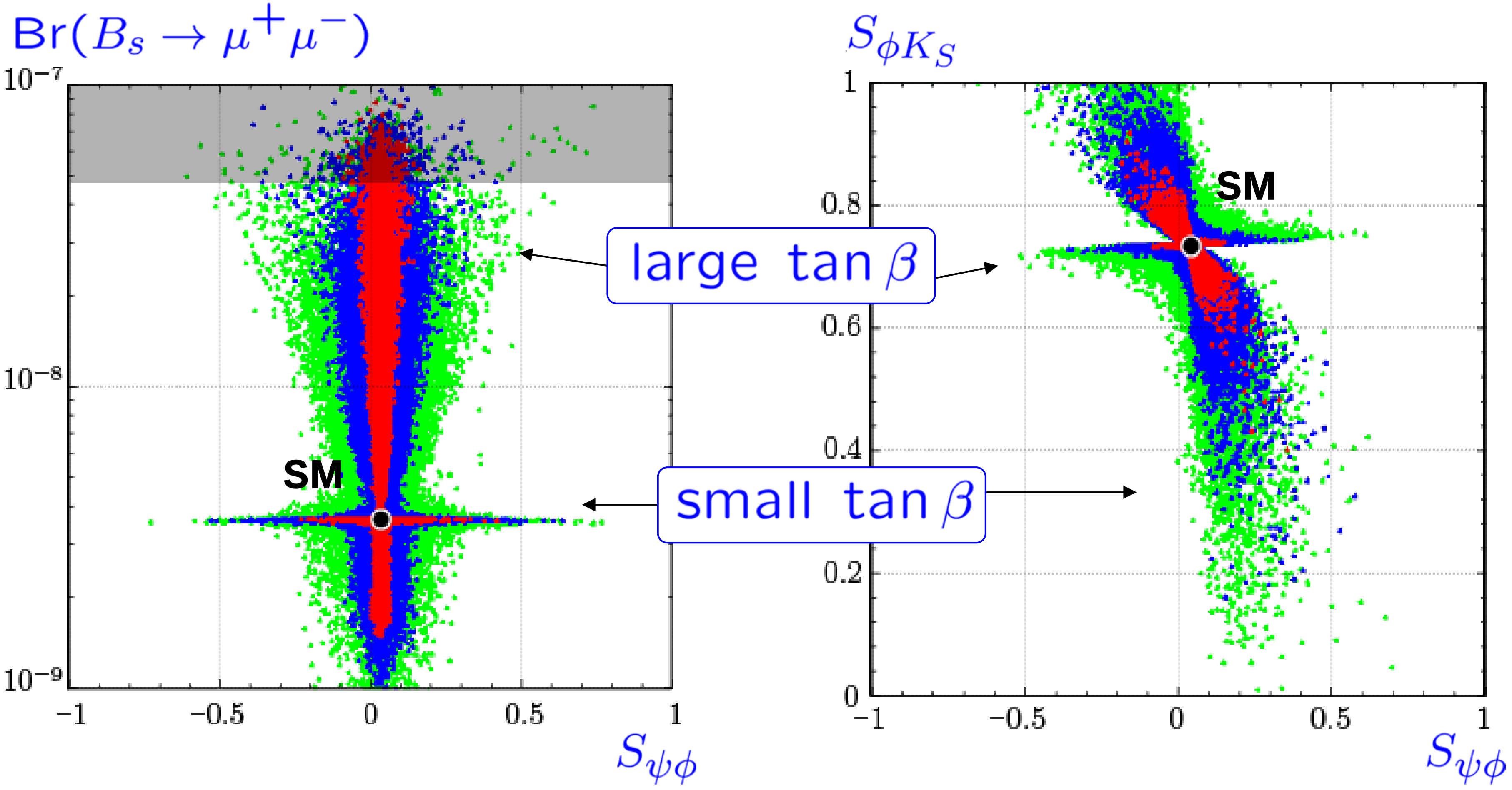
cf. $A_b^{\mathrm{SL}}(\mathrm{D0}) \simeq -10^{-2}$

$\Delta a_\mu < 10^{-9}$ 🟢

$\Delta a_\mu > 10^{-9}$ 🔵

- Sizable $S_{\psi\phi}$ is possible, giving lower limits on $\mathrm{Br}(\tau \to \mu\gamma)$
- $\Delta a_\mu > 10^{-9}$ ⇨ $|S_{\psi\phi}| < 0.2$ with large tanbeta

Correlations between B meson observables



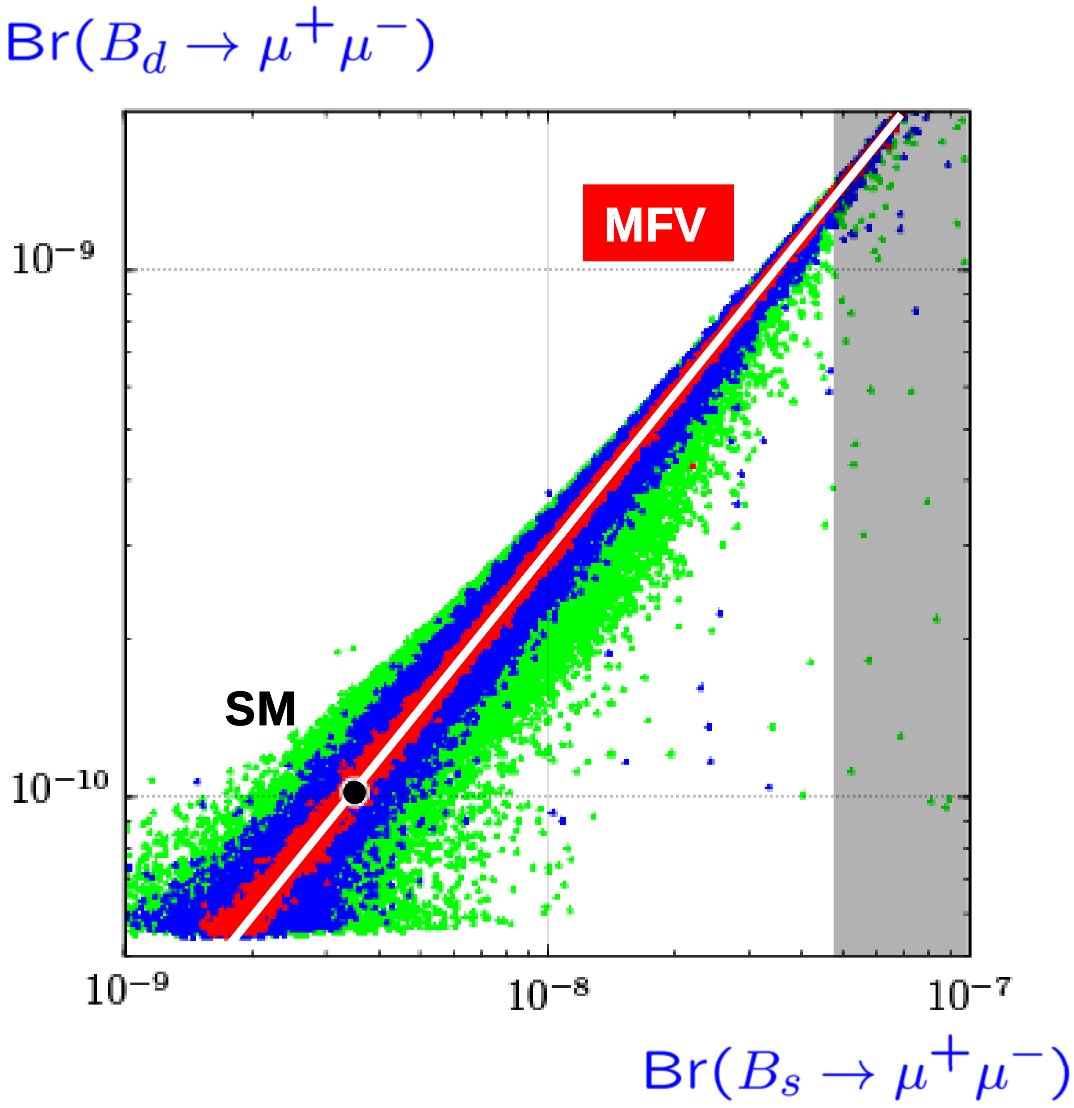
$BR(\tau \to \mu\gamma) > 10^{-8}$ 🟢

$BR(\tau \to \mu\gamma) < 10^{-8}$ 🔵

$BR(\tau \to \mu\gamma) < 10^{-9}$ 🔴

- Sizable departures from the SM predictions
- Simultaneous explanation of $S_{\psi\phi}$ and $S_{\phi K_S}$

MFV or not?



Sizable deviation from the MFV prediction implies large $\mathrm{Br}(\tau \to \mu\gamma)$, well within the reach of SuperB experiments.

4. Summary

We analyzed the flavour signals in the SUSY SU(5) GUT with right-handed neutrino model, motivated by recent experimental data.

- GUT relation is one of the most important features in the SUSY GUT models, leading Rich Flavour Phenomena both in leptonic and hadronic sectors.

- We found several important correlations between observables to probe or falsify the model.

$$\epsilon_K,\ \underset{\substack{\uparrow \\ \text{MEG}}}{\mathrm{Br}(\mu\to e\gamma)},\ \underbrace{S_{\psi\phi},\ \mathrm{Br}(B_s\to\mu^+\mu^-)}_{\text{LHCb}},\ \underset{\substack{\uparrow \\ \text{SuperB}}}{\mathrm{Br}(\tau\to\mu\gamma)}\cdots$$

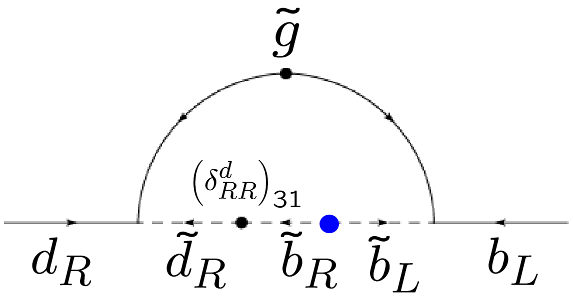
Back Up Slide

Higgs-mediated Two-loop Contribution

- Effective Higgs coupling

Threshold corrections to down quark mass :

$$(m_d)_{ij} \simeq m_{d_i}^{\rm tree}\delta_{ij} - \frac{\alpha_3}{9\pi}\tan\beta\; m_{d_i}^{\rm tree}(\delta^d_{RR})_{ij}$$



⇨

$$\mathcal{L}_{\rm eff} \simeq \frac{g\; m_d}{\sqrt{2}m_W}\tan\beta\left(V_{31} + \frac{\alpha_3\tan\beta}{9\pi}\frac{m_b}{m_d}\left(\delta^d_{RR}\right)_{31}\right)\bar{t}_L d_R H^+ + h.c.$$

Tree level 1-loop level

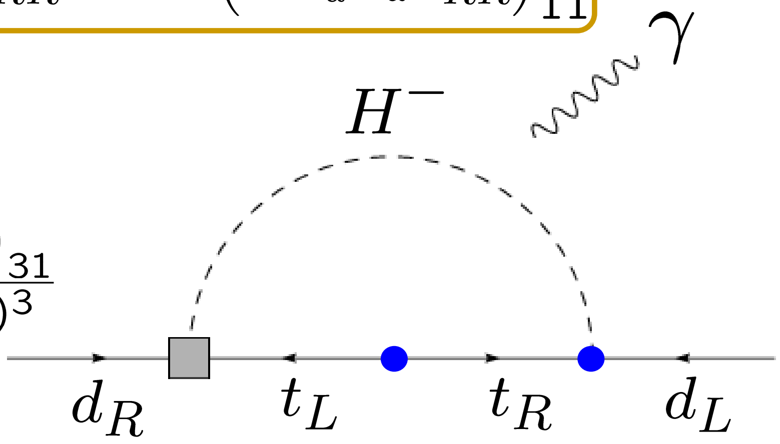
Non-decoupling at the large SUSY particle mass limit

- Charged Higgs contribution to EDMs

$$\boxed{J^d_{RR} = {\rm Im}\left(y_u y_u^\dagger\, y_d\, \delta^d_{RR}\right)_{11}}$$

$$d_d/e \;\sim\; \frac{\alpha_2}{4\pi}\frac{\alpha_3}{4\pi}\left(\frac{m_t^2}{m_W^2}\right)\frac{m_b\tan\beta}{M_{H+}^2}\,{\rm Im}\left[V_{31}^*\left(\delta^d_{RR}\right)_{31}\right]$$

$$\sim\; 1\times 10^{-26}\ {\rm cm}\left(\frac{M_{H+}}{300{\rm GeV}}\right)^{-2}\frac{\tan\beta}{10}\frac{\left(\delta^d_{RR}\right)_{31}}{(0.2)^3}$$



Hisano, MN, Paradisi (2006)

Flavor mixing in the SUSY see-saw model

$$(m_{\tilde{e}_L})_{ij} \simeq -\frac{3m_0^2 + A_0^2}{8\pi^2} \sum_{l,m} U_{il} U^*_{jm} H_{lm}$$

where

$$H_{ij} = \sum_k \frac{\sqrt{m_{\nu_i} m_{\nu_j}} M_{\nu_k}}{\langle H_u \rangle} \log\left(\frac{M_{pl}}{M_{\nu_k}}\right) R_{ik} R^*_{jk}$$

R: orthogonal complex matrix

U: PMNS matrix

cf. neutrino Yukawa coupling

Casas, Ibarra ('01)

$$y_\nu^\dagger = \sqrt{\widehat{M}_\nu} R \sqrt{\widehat{m}_\nu} U / \langle H_u \rangle$$

The structure of matrix H is not determined by the neutrino oscillation data. However, **the relative size of off-diagonal components is controlled by the PMNS matrix**. Especially,

$$U_{1l} U^*_{3m} \simeq U_{1l} U^*_{2m} \quad \text{for any } l, m$$

implies

$$(m_{\tilde{e}_L})_{13} \simeq (m_{\tilde{e}_L})_{12}$$

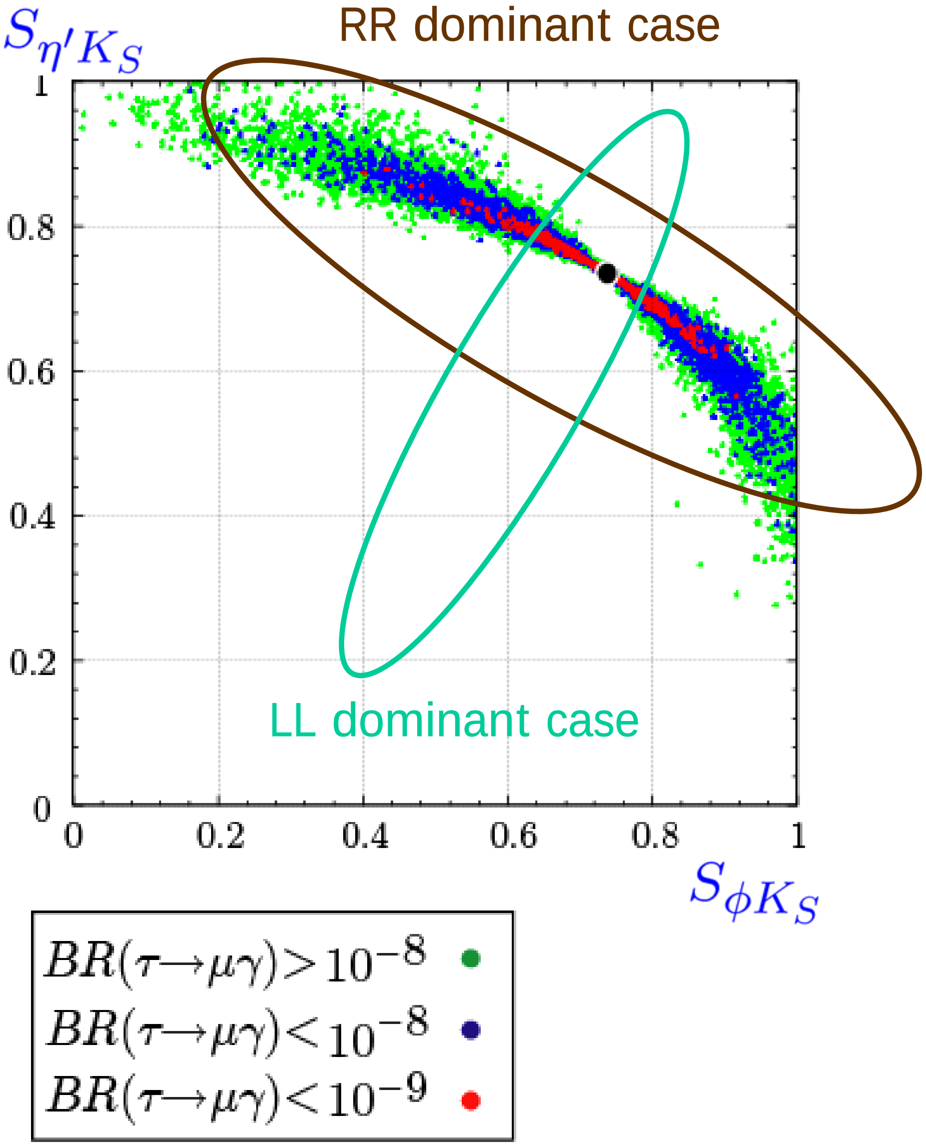
Because of observed two large mixing angle

as long as R, and then H, is given randomly.

Hisano, MN, Paradisi, Shimizu ('09)

Deviation from the above prediction may imply the existence of some specific flavor symmetries.

RR current



$$A^{\mathrm{NP}} \sim C_i^L + \zeta C_i^R$$

$\zeta = +1$ for ϕK_s

$\zeta = -1$ for $\eta' K_s$

Dependence on Final state Parity

In our case, RR current generated from neutrino Yukawa couplings is the dominant sources of flavor violation