Non-MFV and Non-SUSY models

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“Flavour as a Window to New Physics at the LHC “

Flavor in the LHC era

- LHC will give a first look at the TeV scale physics.

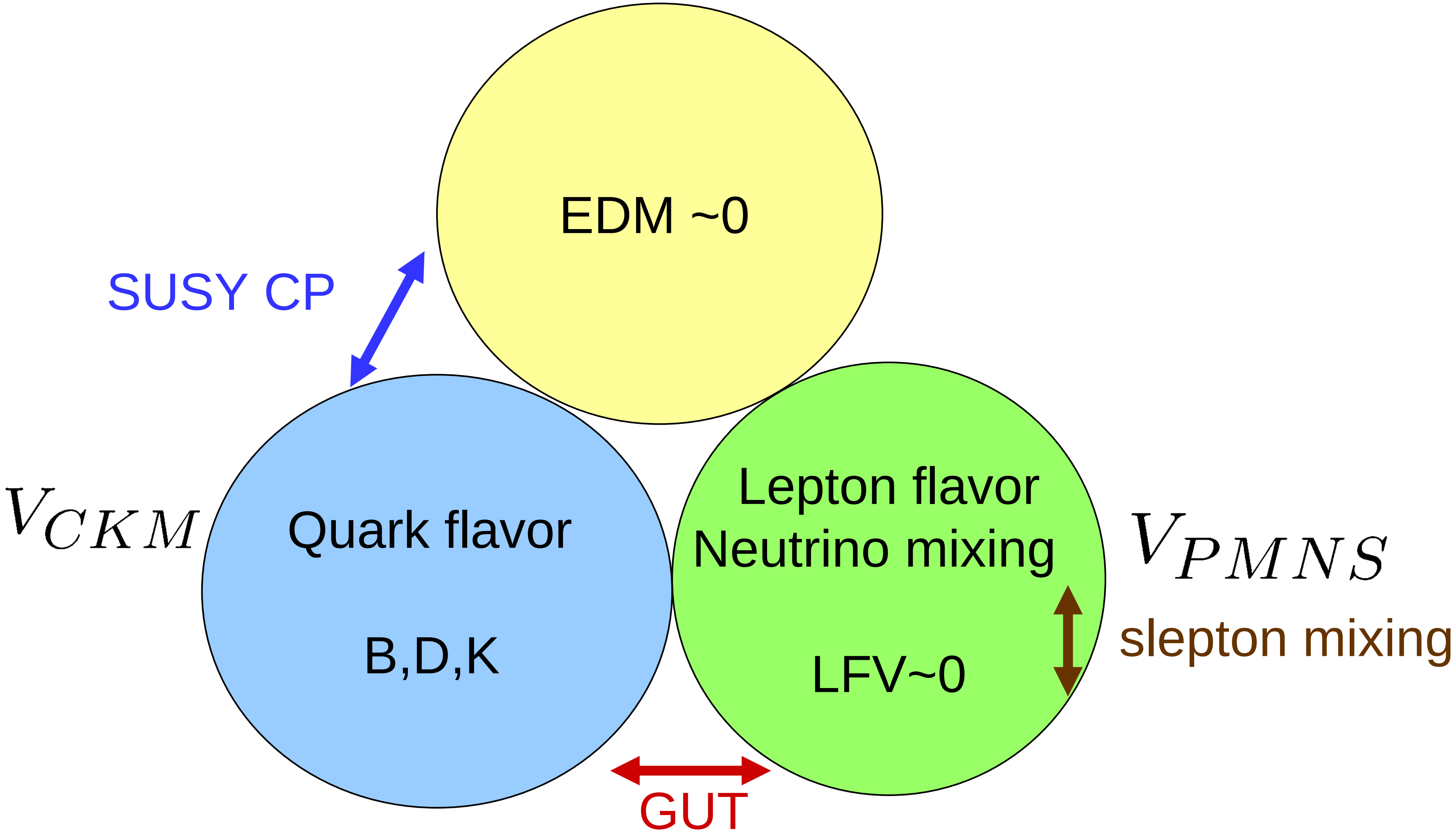
  The mass of the Higgs boson alone is an important hint for possible new physics scenarios.

- Flavor structure of the TeV scale physics is largely unknown.

  Patterns of the deviations from the SM predictions are a key to distinguish new physics models.

- New flavor experiments are coming. LHCb, B physics at ATLAS and CMS, MEG, Super B, etc.

SM has a characteristic feature among various flavor and CP signals.



EDM ~0

SUSY CP

V_{CKM}

Quark flavor

B,D,K

Lepton flavor

Neutrino mixing

LFV~0

V_{PMNS}

slepton mixing

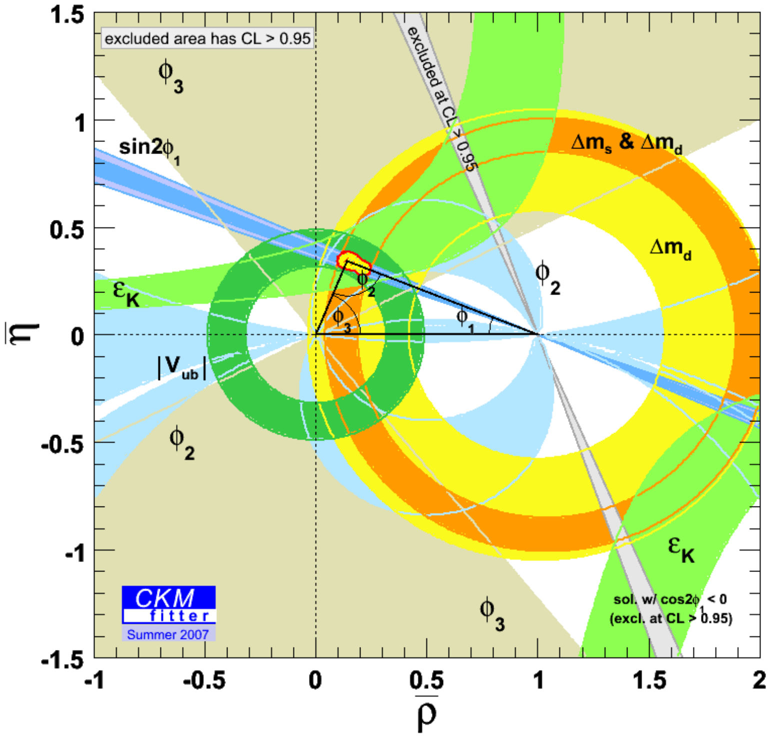
GUT

Relationship may be quite different for new physics contributions.

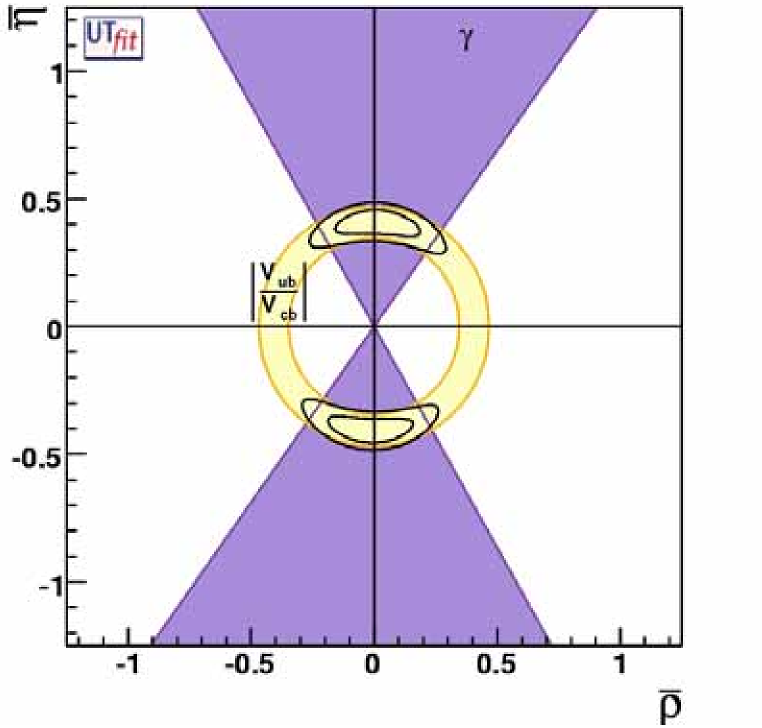
CKM looks perfect

Even if CKM looks perfect, there are still room for new physics contributions of at least a few 10’s %.

SM global fit



Fit by tree level processes



Minimal Flavor Violation

D.G'Ambrosio, G.F.Giudice, G.Isidori, A.Strumia, 2002

New physics contributions to flavor changing amplitudes are essentially governed by the CKM matrix.

$$M_{ij}(New) \sim (V^*_{3i}V_{3j})X(m_{new})$$

LHC, new particle

Flavor physics amplitudes

There are definite relations among different flavor transitions, for instance, Bd, Bs, K flavor signals.

New physics studies for Super B factory.

- There are series of studies to clarify the physics potential of a super B factory, including B, D and tau physics.

Super KEKB study (2001-)

SLAC Super B WS (2003)

CERN WS on Flavour in the era of the LHC (2005-2007)

SuperB CDR (2007)

- Various new physics models are taken to compare patterns of new physics signals.

Super B, experimental prospects

50-75 ab^{-1}

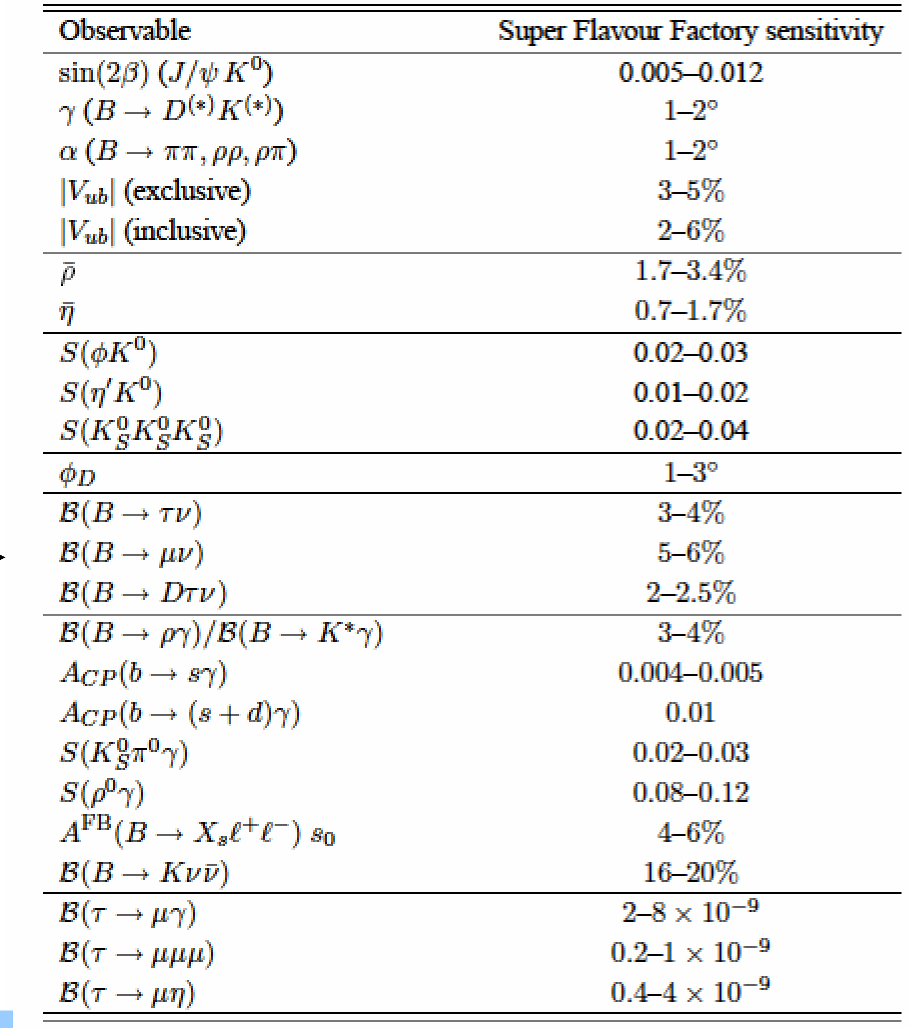
CKM parameters

b-s transition

B-> (D) τν

EW penguin

tau LFV



Observable	Super Flavour Factory sensitivity
$\sin(2\beta)$ $(J/\psi\, K^0)$	0.005–0.012
γ $(B \to D^{(*)} K^{(*)})$	1–2°
α $(B \to \pi\pi, \rho\rho, \rho\pi)$	1–2°
$\lvert V_{ub}\rvert$ (exclusive)	3–5%
$\lvert V_{ub}\rvert$ (inclusive)	2–6%
$\bar{\rho}$	1.7–3.4%
$\bar{\eta}$	0.7–1.7%
$S(\phi K^0)$	0.02–0.03
$S(\eta' K^0)$	0.01–0.02
$S(K^0_S K^0_S K^0_S)$	0.02–0.04
ϕ_D	1–3°
$\mathcal{B}(B \to \tau\nu)$	3–4%
$\mathcal{B}(B \to \mu\nu)$	5–6%
$\mathcal{B}(B \to D\tau\nu)$	2–2.5%
$\mathcal{B}(B \to \rho\gamma)/\mathcal{B}(B \to K^*\gamma)$	3–4%
$A_{CP}(b \to s\gamma)$	0.004–0.005
$A_{CP}(b \to (s+d)\gamma)$	0.01
$S(K^0_S \pi^0 \gamma)$	0.02–0.03
$S(\rho^0 \gamma)$	0.08–0.12
$A^{\mathrm{FB}}(B \to X_s \ell^+ \ell^-)$ s_0	4–6%
$\mathcal{B}(B \to K\nu\bar{\nu})$	16–20%
$\mathcal{B}(\tau \to \mu\gamma)$	$2\text{–}8 \times 10^{-9}$
$\mathcal{B}(\tau \to \mu\mu\mu)$	$0.2\text{–}1 \times 10^{-9}$
$\mathcal{B}(\tau \to \mu\eta)$	$0.4\text{–}4 \times 10^{-9}$

0(10%) physics (Now)
=> 0(1%) physics (Future)

CERN Flavour WS report: **arXiv:0801.1833**

Conclusions

LHCb is a heavy flavour precision experiment searching for New Physics in **CP Violation** and **Rare Decays**

A program to do this has been developed and the methods, including calibrations and systematic studies, are being worked out..

CP Violation: 2 fb^{-1} (1 year)*

- γ from trees: 5° - 10°
- γ from penguins: ≈10°
- B_s mixing phase: 0.023
- β_s^{eff} from penguins: 0.11

Rare Decays: 2 fb^{-1} (1 year)*

- $Bs \to K^*\mu\mu$ s_0 : 0.5 GeV^2
- $B \to s\gamma$ A_{dir}, A_{mix} : 0.11
  A_{Δ} : 0.22
- $B_s \to \mu\mu$ BR.: 6 x 10^{-9} at 5σ

We appreciate the collaboration with the theory community to continue developing new strategies.

We are excitingly looking forward to the data from the LHC.

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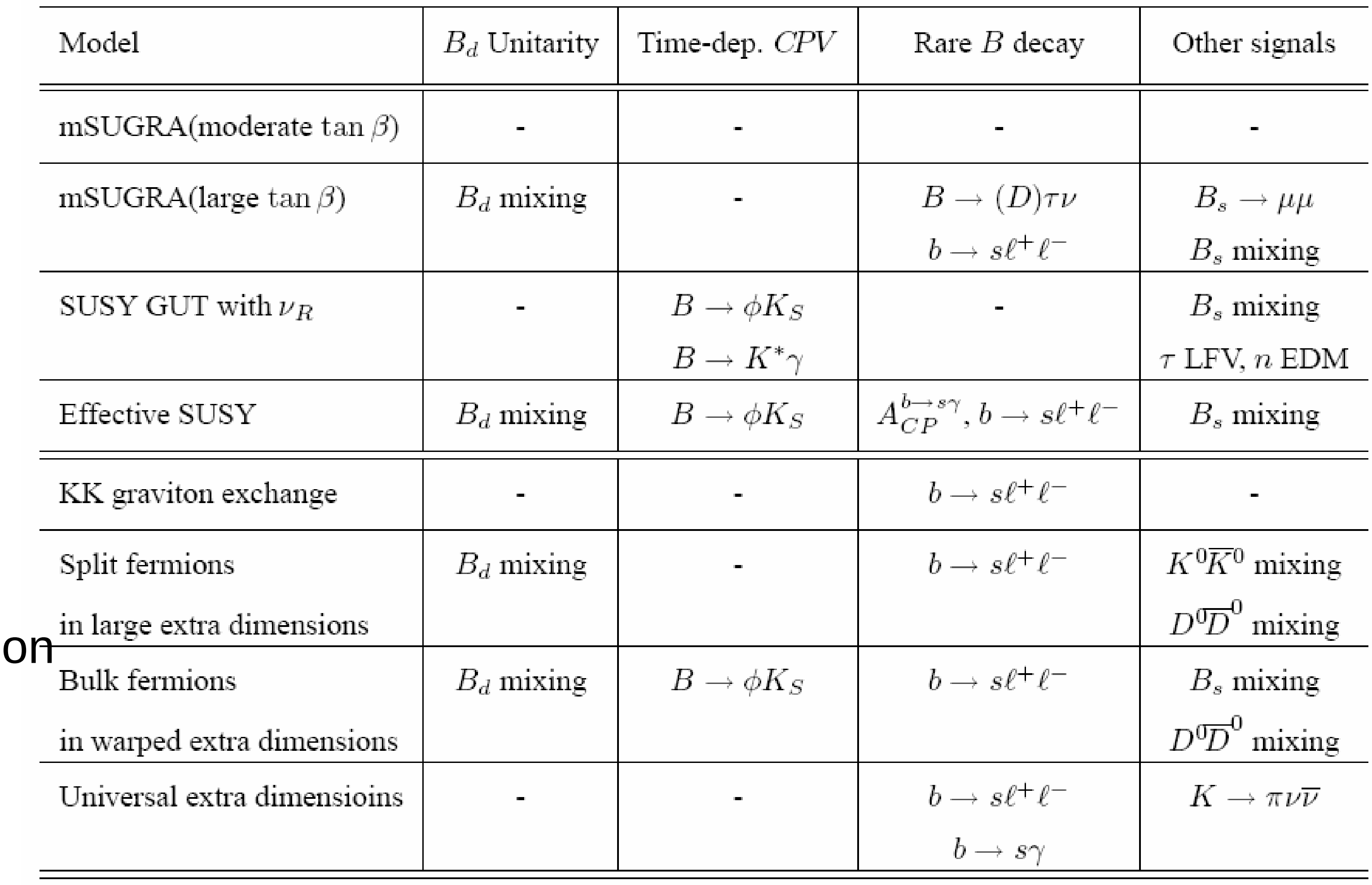
* Expect uncertainty to scale statistically to 10 fb^{-1}. Beyond: see Jim Libby's talk on Upgrade

Examples of New Physics Models and flavor signals

2003 SLAC WS Proceedings, hep-ph/0503261



	Model	B_d Unitarity	Time-dep. CPV	Rare B decay	Other signals	
SUSY	mSUGRA(moderate $\tan\beta$)	-	-	-	-	**MFV**
	mSUGRA(large $\tan\beta$)	B_d mixing	-	$B \to (D)\tau\nu$ $b \to s\ell^+\ell^-$	$B_s \to \mu\mu$ B_s mixing	**MFV**
	SUSY GUT with ν_R	-	$B \to \phi K_S$ $B \to K^*\gamma$	-	B_s mixing τ LFV, n EDM	
	Effective SUSY	B_d mixing	$B \to \phi K_S$	$A_{CP}^{b\to s\gamma}$, $b \to s\ell^+\ell^-$	B_s mixing	
Extra Dimension models	KK graviton exchange	-	-	$b \to s\ell^+\ell^-$	-	
	Split fermions in large extra dimensions	B_d mixing	-	$b \to s\ell^+\ell^-$	$K^0\overline{K}^0$ mixing $D^0\overline{D}^0$ mixing	
	Bulk fermions in warped extra dimensions	B_d mixing	$B \to \phi K_S$	$b \to s\ell^+\ell^-$	B_s mixing $D^0\overline{D}^0$ mixing	
	Universal extra dimensioins	-	-	$b \to s\ell^+\ell^-$ $b \to s\gamma$	$K \to \pi\nu\overline{\nu}$	**MFV**

Different pattern of the deviations from the SM prediction.

New physics examples

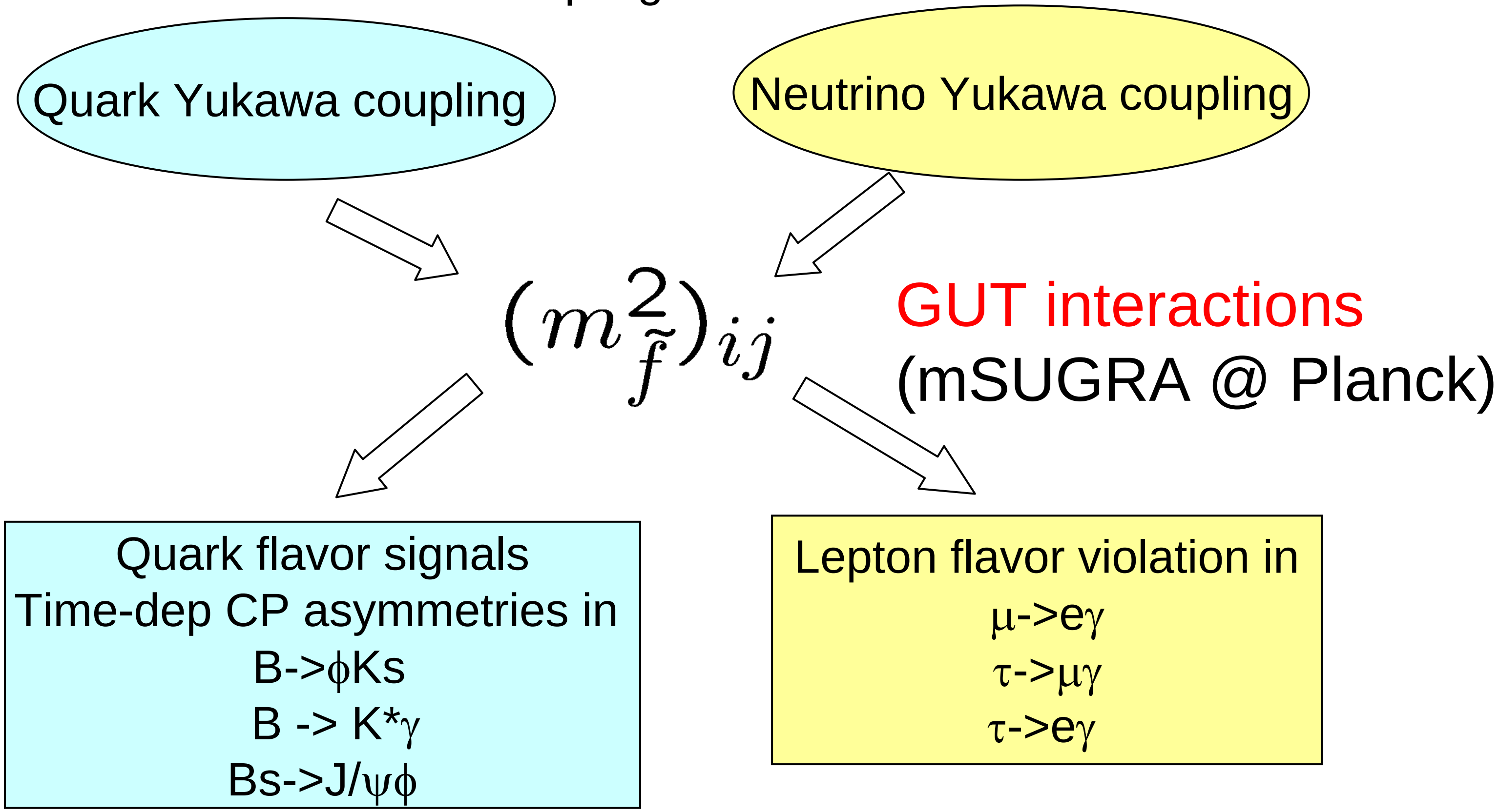
- SUSY GUT with right-handed neutrinos

(Recent update, T.Goto,Y.O., T.Shindou,M.Tanaka, arXiv:0711.2935)

- Little Higgs Model with T-parity
- Models with extra-dimensions.

[1] SUSY GUT with right-handed neutrinos

Yukawa interactions at the GUT scales induce quark and lepton flavor signals. In the SU(5) setup, the right-handed sdown sector can receive flavor mixing due to the neutrino Yukawa couplings.



Quark Yukawa coupling

Neutrino Yukawa coupling

$$(m^2_{\tilde{f}})_{ij}$$

GUT interactions
(mSUGRA @ Planck)

Quark flavor signals
Time-dep CP asymmetries in
B->ϕKs
B -> K*γ
Bs->J/$\psi\phi$

Lepton flavor violation in
μ->eγ
τ->$\mu\gamma$
τ->eγ

L.J.Hall,V.Kostelecky,S.Raby,1986;A.Masiero, F.Borzumati, 1986, R.Barbieri,L.Hall,1994, R.Barbieri,L.Hall.A.Strumia, 1995, S.Baek,T.Goto,Y.O, K.Okumura, 2001;T.Moroi,2000; A.Masiero, M.Piai,A Romanino, L.Silvestrini,2001 D.Chang, A.Masiero, H.Murayama,2003 J.Hisano,and Y.Shimizu, 2003, M.Ciuchini, et.al, 2004, 2007…

Effects of the neutrino Yukawa coupling

$$\mathcal{W}_{\mathrm{MSSM}\nu_R} = \mathcal{W}_{\mathrm{MSSM}} + (y_N)^{ij}\bar{N}_i L_j H_2 + \frac{1}{2}(M_N)^{ij}\bar{N}_i\bar{N}_j,$$

Neutrino mass matrix (in the basis where y_l is diagonal).

$$\boxed{(m_\nu)_{ij} = (y_N^T \frac{1}{M_N} y_N)_{ij} < H_2 >^2}$$

LFV mass terms for slepton (and sdown).

$$\boxed{(m_L^2)_{ij} \sim -(y_N^\dagger y_N)_{ij} \frac{m_0^2(3+|A_0|^2)}{8\pi^2} ln(\frac{M_p}{M_R})}$$

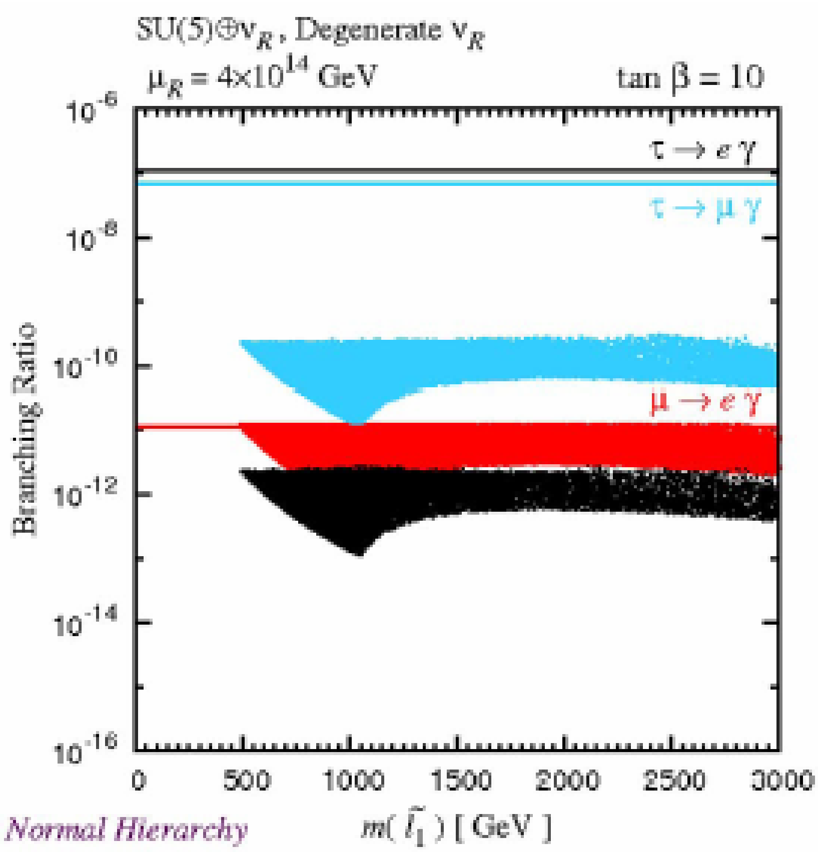
LFV mass terms and V_{PMNS} is directly related when

$(M_N)_{ij} \propto \delta_{ij}$ and y_N: real. (Minimal LFV)

In the case of Degenerate M_N and “Normal hierarchy” for light neutrinos :

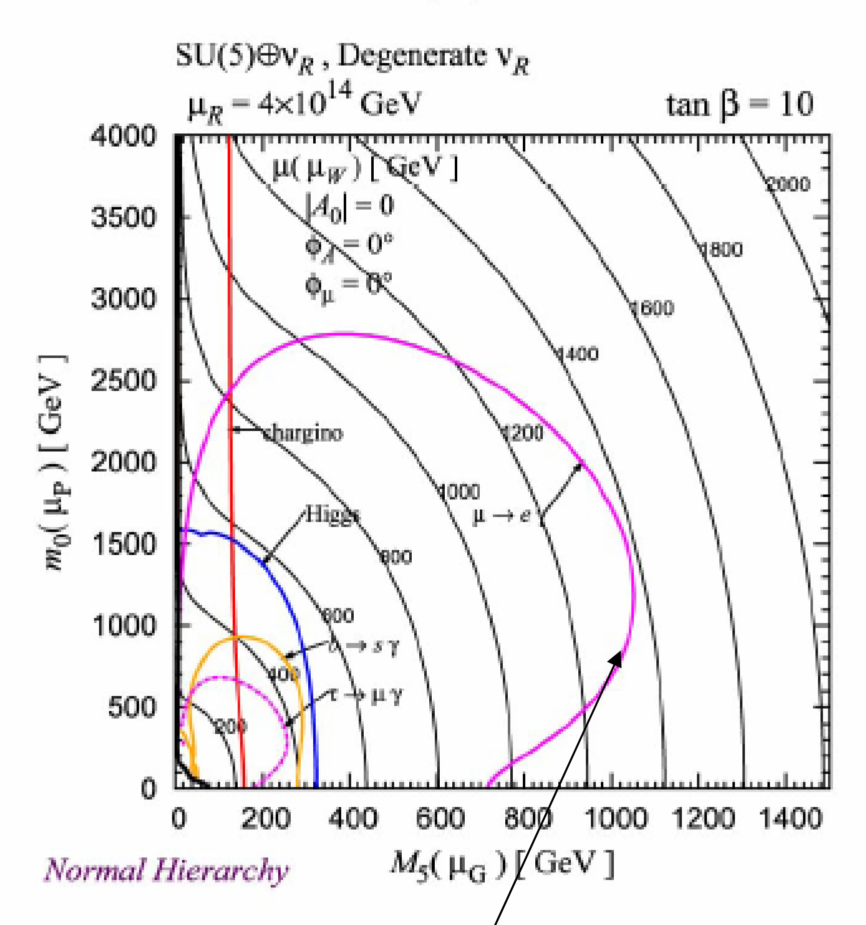
B(μ–>eγ) can be close to the present bound even if the slepton mass is 3 TeV.

μ–>eγ, τ–>$\mu\gamma$, τ–>eγ branching ratios



T.Goto,Y.O., T.Shindou,M.Tanaka, 2007

Contour in the m_0 -$M_{1/2}$ plane



μ–>eγ bound

If $(y_N^\dagger y_N)_{12}$ is somewhat suppressed, the B(μ->eγ) constraint becomes weaker, and a variety of flavor signals are possible.

- Non-degenerate M_N

$$y_N \sim \begin{pmatrix} y_{11} & 0 & 0 \\ 0 & y_{22} & y_{23} \\ 0 & y_{32} & y_{33} \end{pmatrix} \qquad (M_N)_{ij} \not\propto \delta_{ij}$$

J.Casas, A.Ibarra2001; J.Ellis,J.Hisano,M.Raidal,Y.Shimizu, 2002

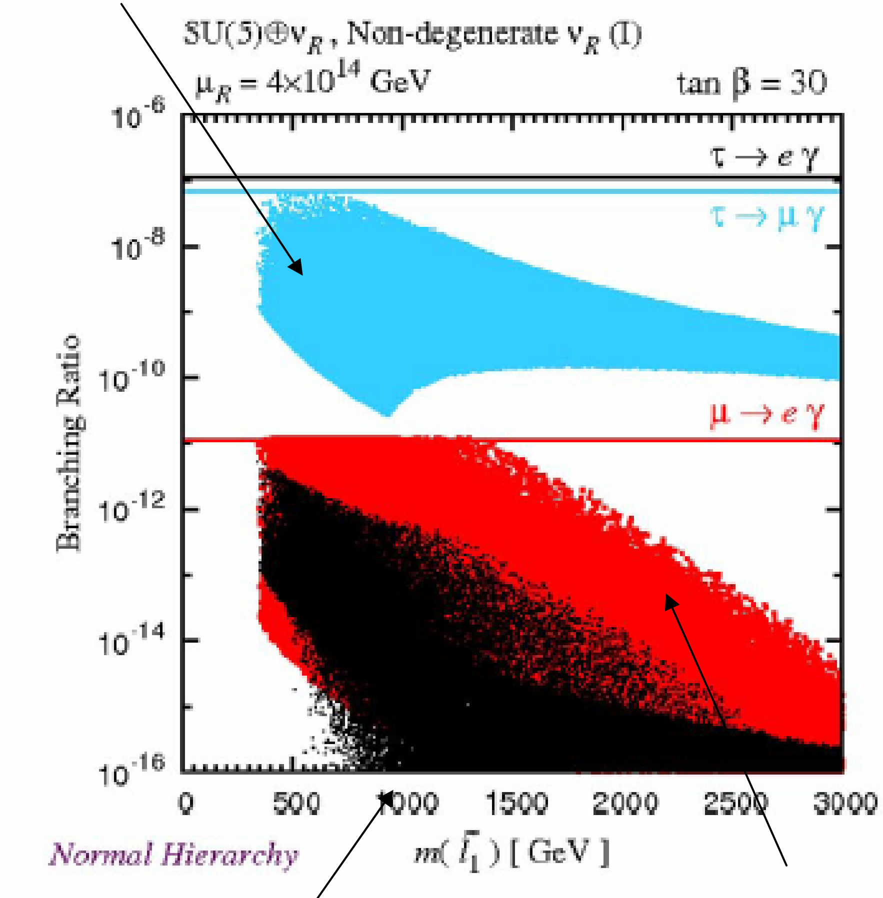
- Degenerate M_N, but inverse hierarchy or degenerate light neutrino with θ_{13}~0.

$$(y_N^\dagger y_N)_{12} = \frac{\hat{M}_N}{\langle h_2 \rangle^2} c_\odot s_\odot c_{\text{atm}} \frac{m_{\nu_2}^2 - m_{\nu_1}^2}{m_{\nu_2} + m_{\nu_1}}$$

$$V_{\text{PMNS}} = \begin{pmatrix} c_\odot c_{13} & s_\odot c_{13} & s_{13} \\ -s_\odot c_{\text{atm}} - c_\odot s_{\text{atm}} s_{13} & c_\odot c_{\text{atm}} - s_\odot s_{\text{atm}} s_{13} & s_{\text{atm}} c_{13} \\ s_\odot s_{\text{atm}} - c_\odot c_{\text{atm}} s_{13} & -c_\odot s_{\text{atm}} - s_\odot c_{\text{atm}} s_{13} & c_{\text{atm}} c_{13} \end{pmatrix}$$

Lepton Flavor Violation $\tau \to \mu\gamma$, $\tau \to e\gamma$ vs. $\mu \to e\gamma$

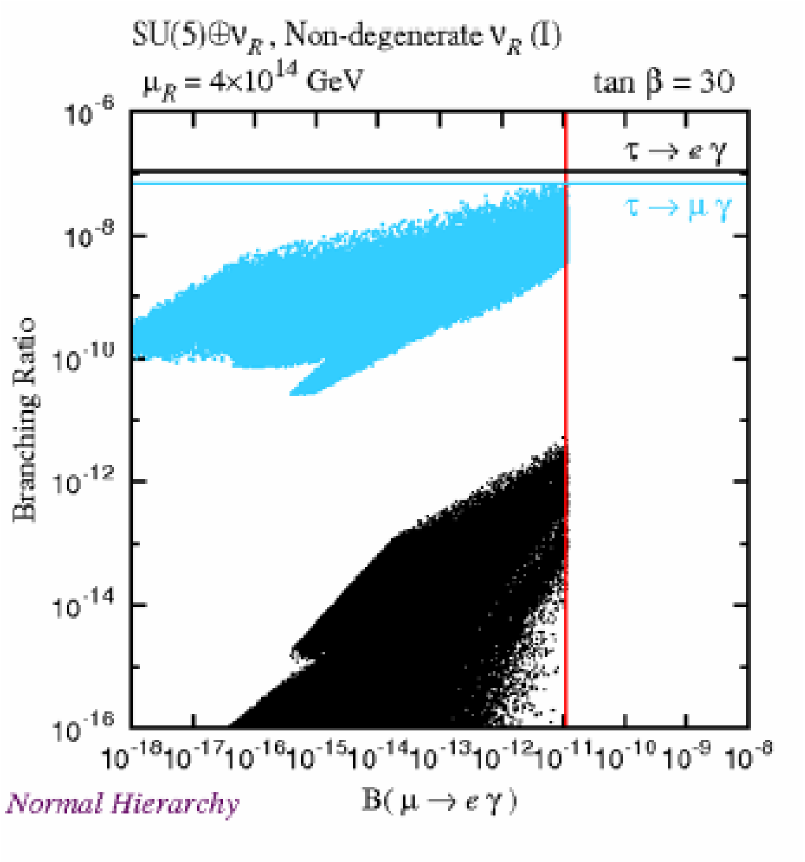
$\tau \to \mu\gamma$



$\tau \to e\gamma$

$\mu \to e\gamma$

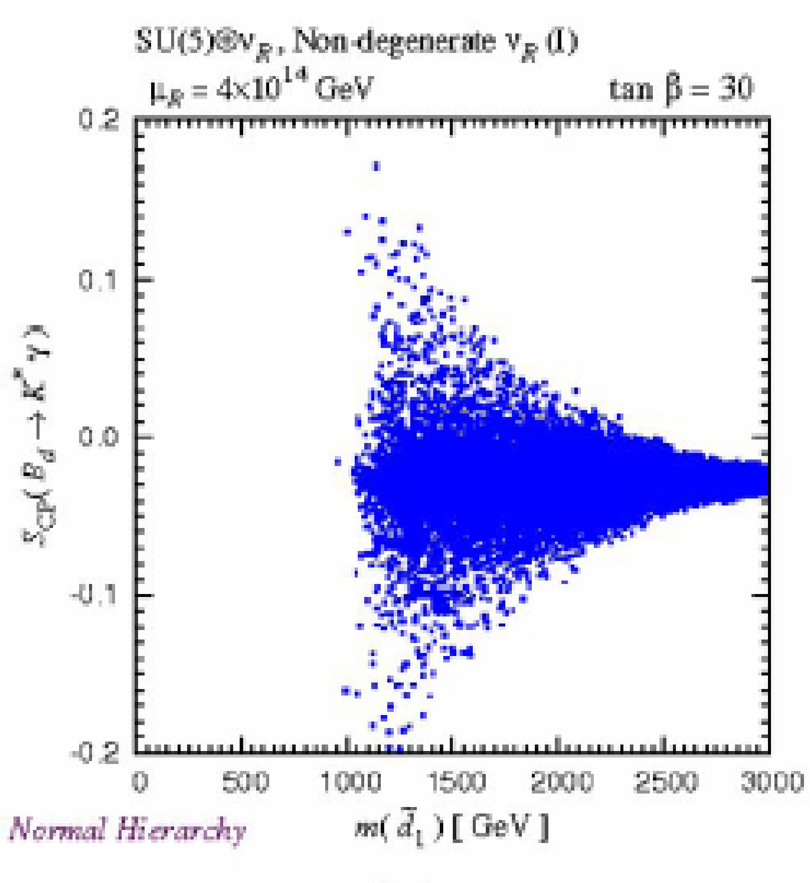
$B(\tau \to \mu\gamma)$



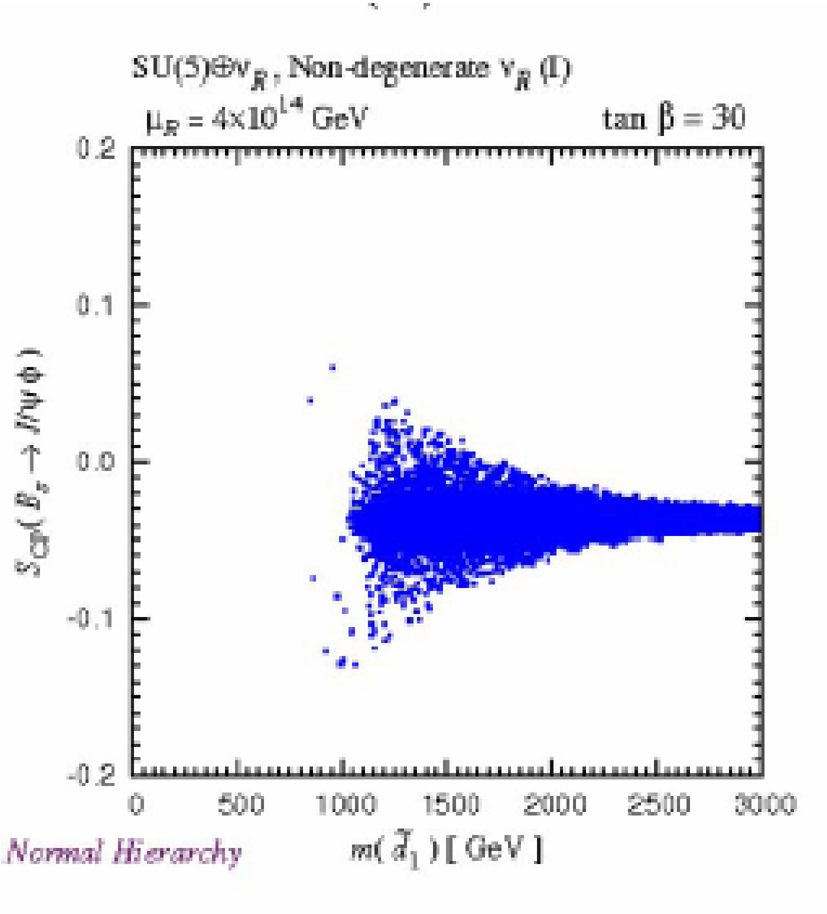
B($\mu \to e\gamma$)

T.Goto,Y.O., T.Shindou,M.Tanaka, 2007

Time-dependent CP asymmetry in Bd->K*γ



Time-dependent CP asymmetry in Bs->J/ψϕ



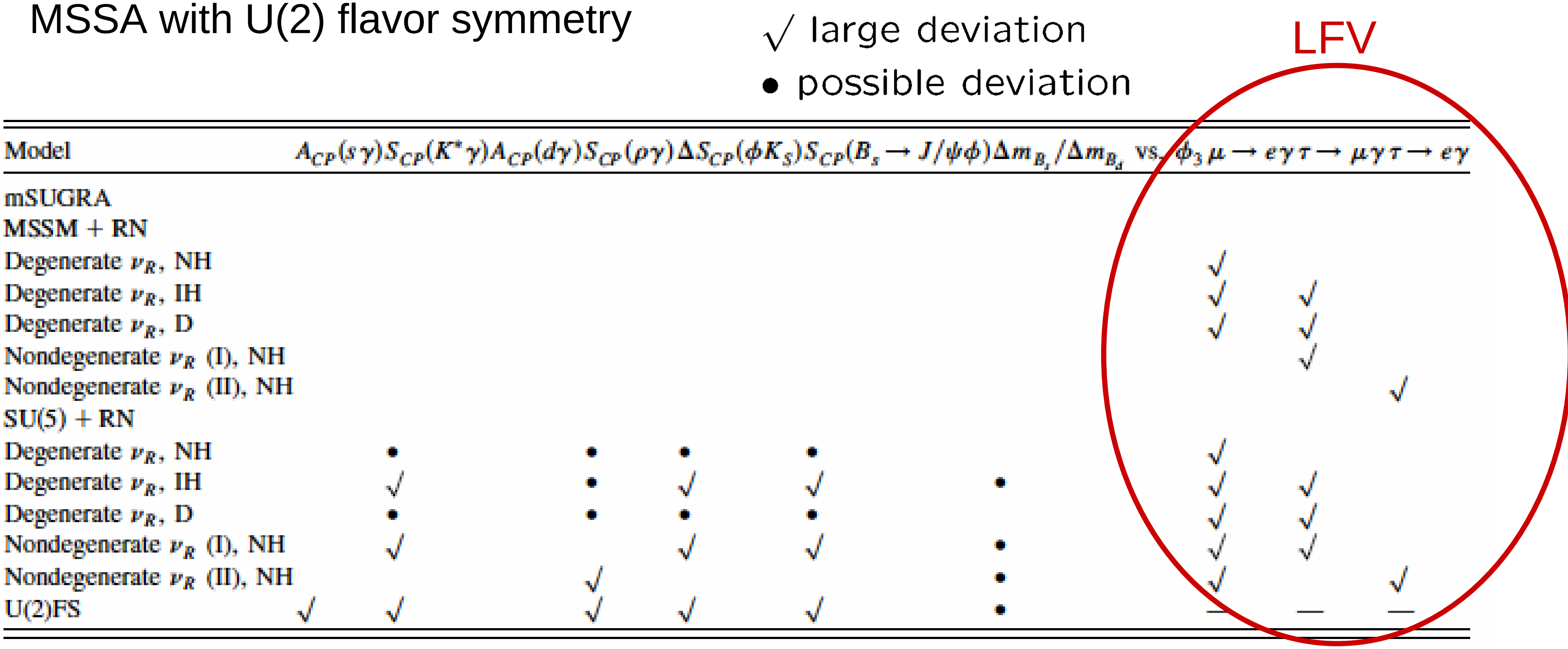
These asymmetries can be sizable if the squarks are within the LHC reach.

T.Goto,Y.O., T.Shindou,M.Tanaka, 2007

Summary table of flavor signals for mSUGRA, SUSY seesaw, SUSY GUT, MSSA with U(2) flavor symmetry

√ large deviation

● possible deviation



Model	$A_{CP}(s\gamma)$	$S_{CP}(K^*\gamma)$	$A_{CP}(d\gamma)$	$S_{CP}(\rho\gamma)$	$\Delta S_{CP}(\phi K_S)$	$S_{CP}(B_s\to J/\psi\phi)$	$\Delta m_{B_s}/\Delta m_{B_d}$ vs. ϕ_3	$\mu\to e\gamma$	$\tau\to\mu\gamma$	$\tau\to e\gamma$
mSUGRA										
MSSM + RN										
Degenerate ν_R, NH								√		
Degenerate ν_R, IH								√	√	
Degenerate ν_R, D								√	√	
Nondegenerate ν_R (I), NH									√	
Nondegenerate ν_R (II), NH										√
SU(5) + RN										
Degenerate ν_R, NH		●		●	●	●		√		
Degenerate ν_R, IH		√		●	√	√	●	√	√	
Degenerate ν_R, D		●		●	●	●		√	√	
Nondegenerate ν_R (I), NH		√			√	√	●	√	√	
Nondegenerate ν_R (II), NH				√			●	√		√
U(2)FS	√	√		√	√	√	●	—	—	—

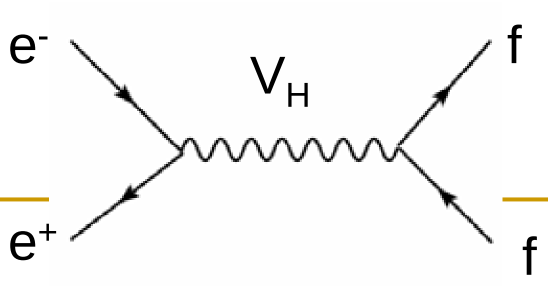
Large LFV signals=> possible slepton mixing signals at LHC

$$\chi_2^0 \to \chi_1^0 + l + l'$$

K.Aagshe, M.Graesser, 2000; I.Hinchliffe,F.E.Paige, 2001;
J.Hisano,R.Kitano,M.M.Nojiri,2002,
D.F.Carvallo, J.Ellis,M.E.Gomez,S.Lola, J.C.Romao,2005
J.Feng,C.G.Lester, Y.Nir, Y.Shadmi, 2007 …

[2] Little Higgs model with T parity

- An effective theory describing the electroweak symmetry breaking where the Higgs boson is a pseudo Nambu-Goldstone boson below the cutoff scale (~4πf ~10TeV).
- The quadratic divergence of the Higgs boson mass renormalization is absent at one loop by “collective symmetry breaking”. N.Arkani-Hamed,A.G.Cohen, E.Katz,and A.E.Nelson,2002
- New gauge bosons, top-partners, extra scalar fields are introduced (masses ~ O(f)) .
- In order to satisfy the electroweak precision constraints, new particle mass should be multi-TeV, reintroducing the little hierarchy problem.
- The new particle can be below 1 TeV, if the little Higgs model is extended to have T-parity. C.H.Cheng and I.Low,2003



The littlest Higgs model with T parity

SU(5)/S0(5) non-linear sigma model

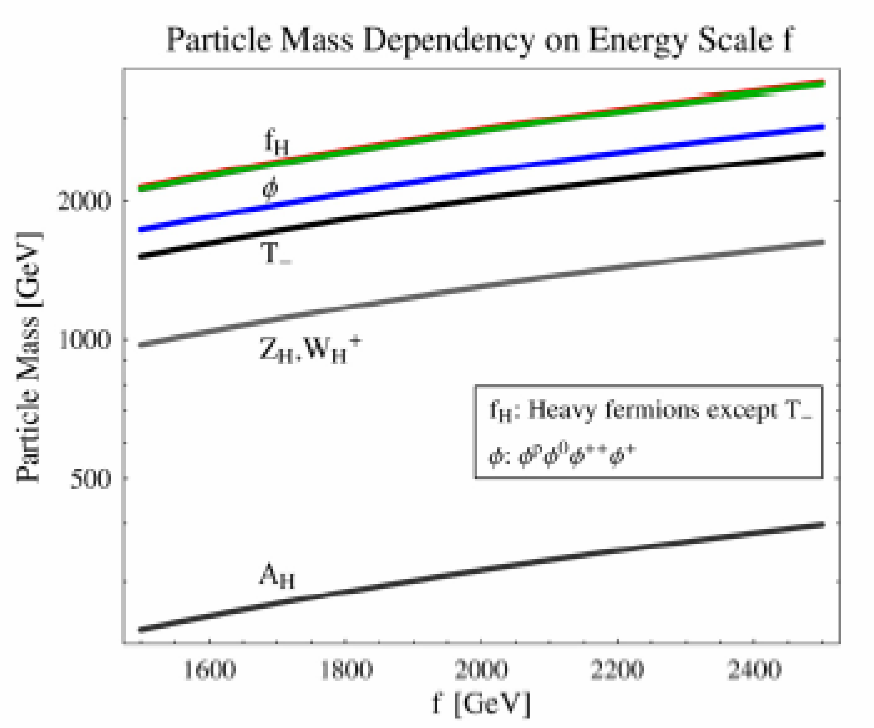
$$[SU(2) \times U(1)]^2 \rightarrow SU(2)_L \times U(1)_Y \text{ at } f$$

$$SU(2)_L \times U(1)_Y \rightarrow U(1)_{em} \text{ at v=246 GeV}$$

At ~10 TeV, UV completion theory

At f ~ O(1) TeV
T-odd bosons: W_H, Z_H, ϕ_{ij},
T-odd fermions: $u_{H,}d_H,l_H$
Top partners T_+, T_-

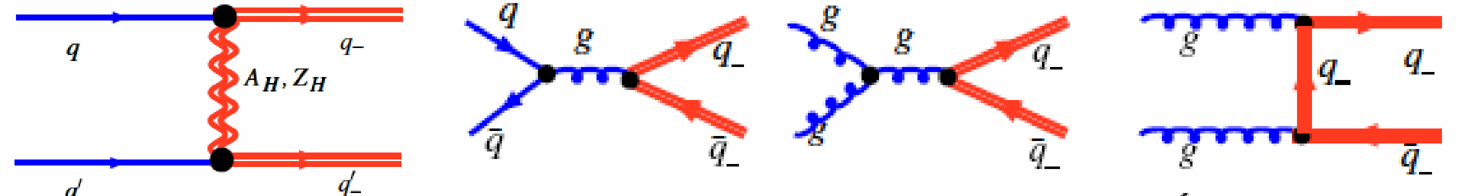
Less than ~200 GeV
T-odd heavy photon A_H
SM particles

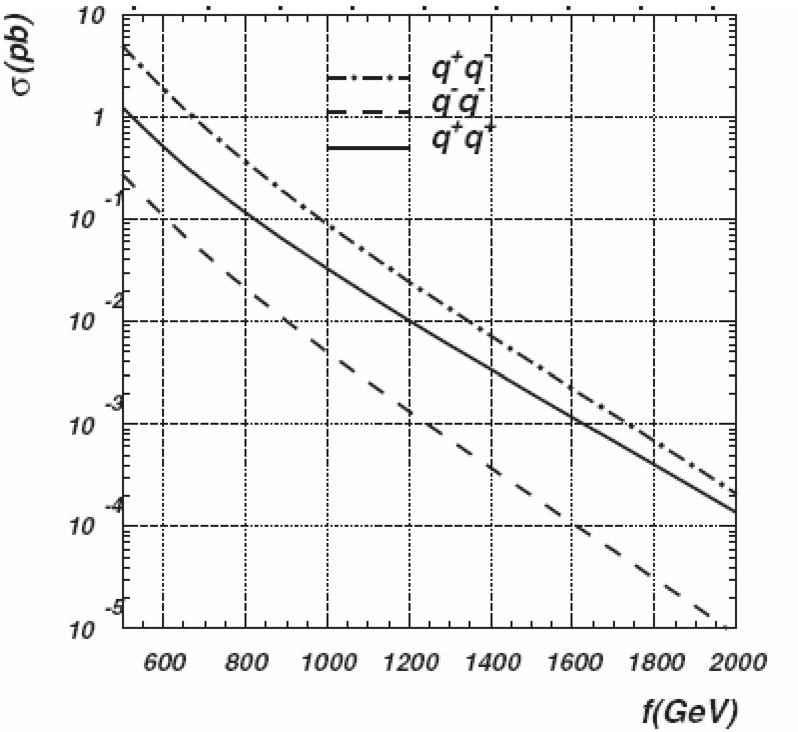


V.Barger,Y.Gao, W.-Y.Keung 2007

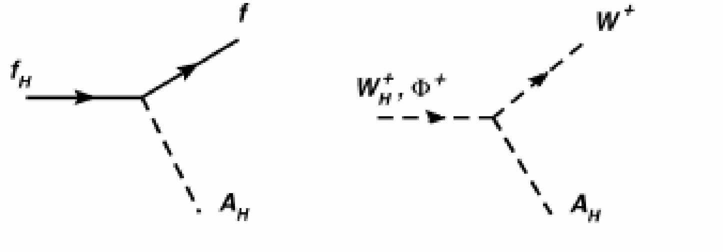
New particle production at LHC

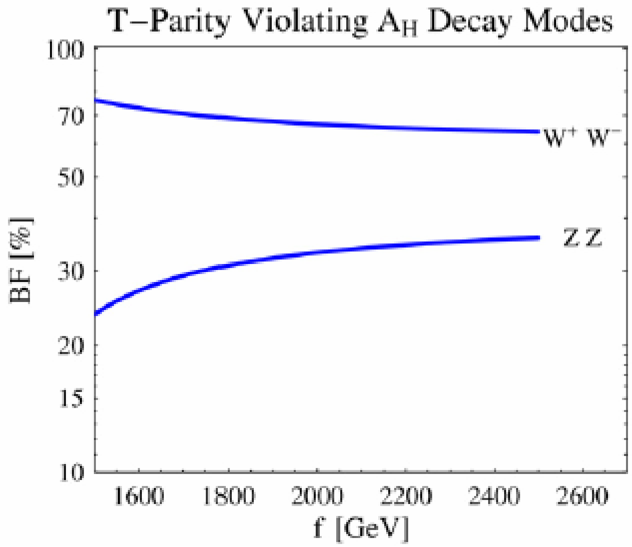
New particles (except for T+) are pair-produced.
T-parity is likely to be violated by anomaly. (C.Hill and R.Hill,2007)
T-odd particles decay to A_H, and A_H decays to WW or ZZ through the WZW term.





A.Belyaev,C-R.Chen,K.Tobe,C.P.Yuan2006



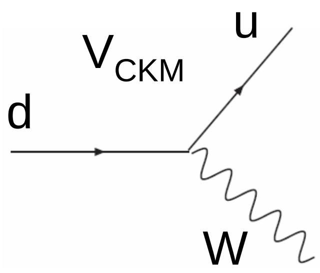


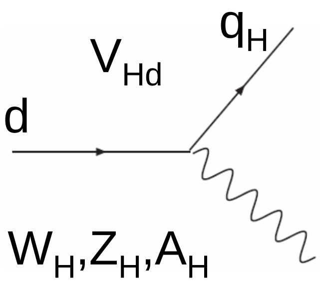
V.Barger,Y.Gao, W.-Y.Keung 2007

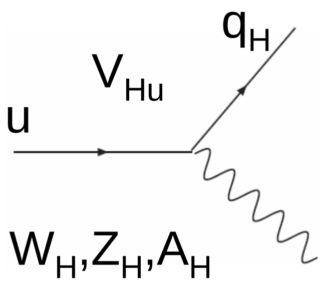
Flavor Physics in the Little Higgs model with T-parity

J.Hubisz,S.J.Lee,G.Paz, 2005

New flavor mixing from T-odd quark and lepton sectors.







Out of three mixing matrixes, two are independent.

$$\boxed{V_{Hu}^{\dagger} V_{Hd} = V_{CKM}}$$

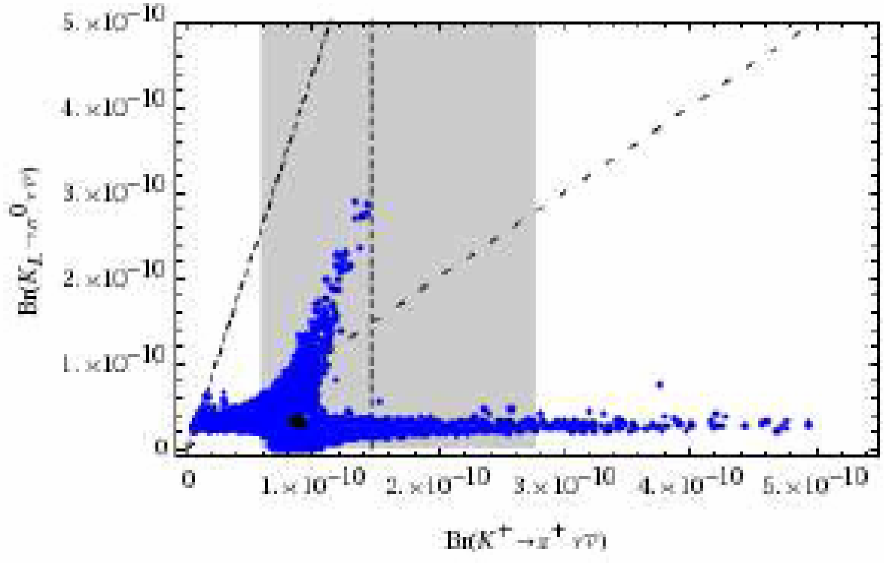
Similarly, in the lepton sector,

$$\boxed{V_{H\nu}^{\dagger} V_{Hl} = V_{PMNS}^{\dagger}}$$

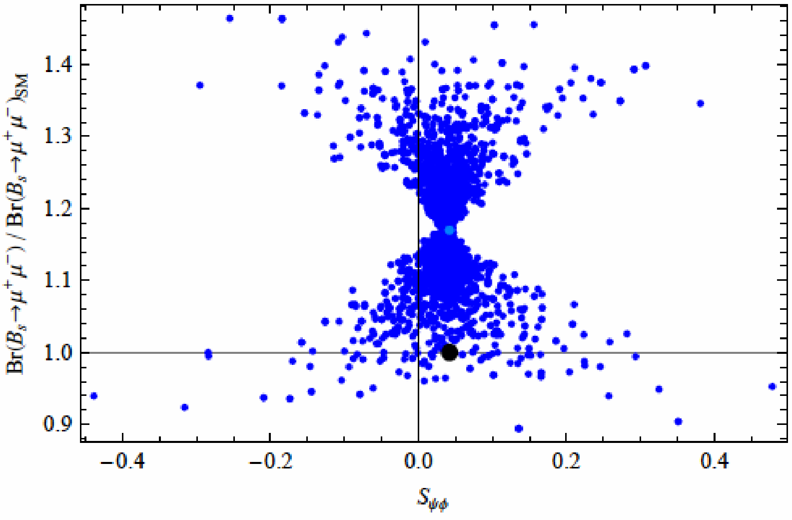
These matrixes can induce a large contributions to FCNC and LFV processes. (Non-MFV in general)

Examples of flavor signals in Little Higgs model with T -parity

KL->$\pi^0\nu\nu$ vs. K^+->$\pi^+\nu\nu$

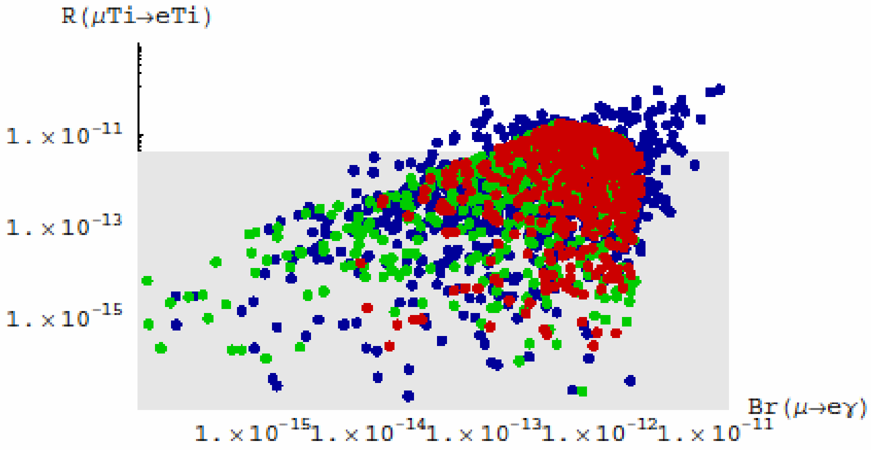


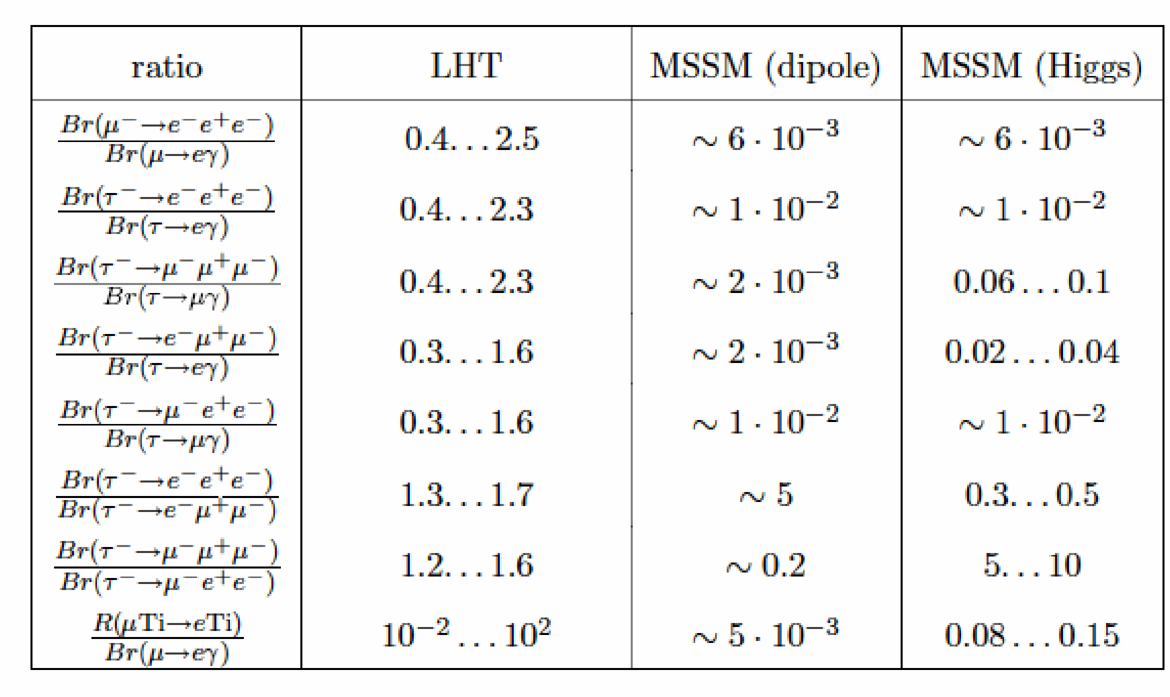
Bs->$\mu\mu$ vs. S (J/$\psi\phi$)



M.Blanke,A.Buras.S.Recksiegel,C.Tarantino, 2008

Lepton flavor violation





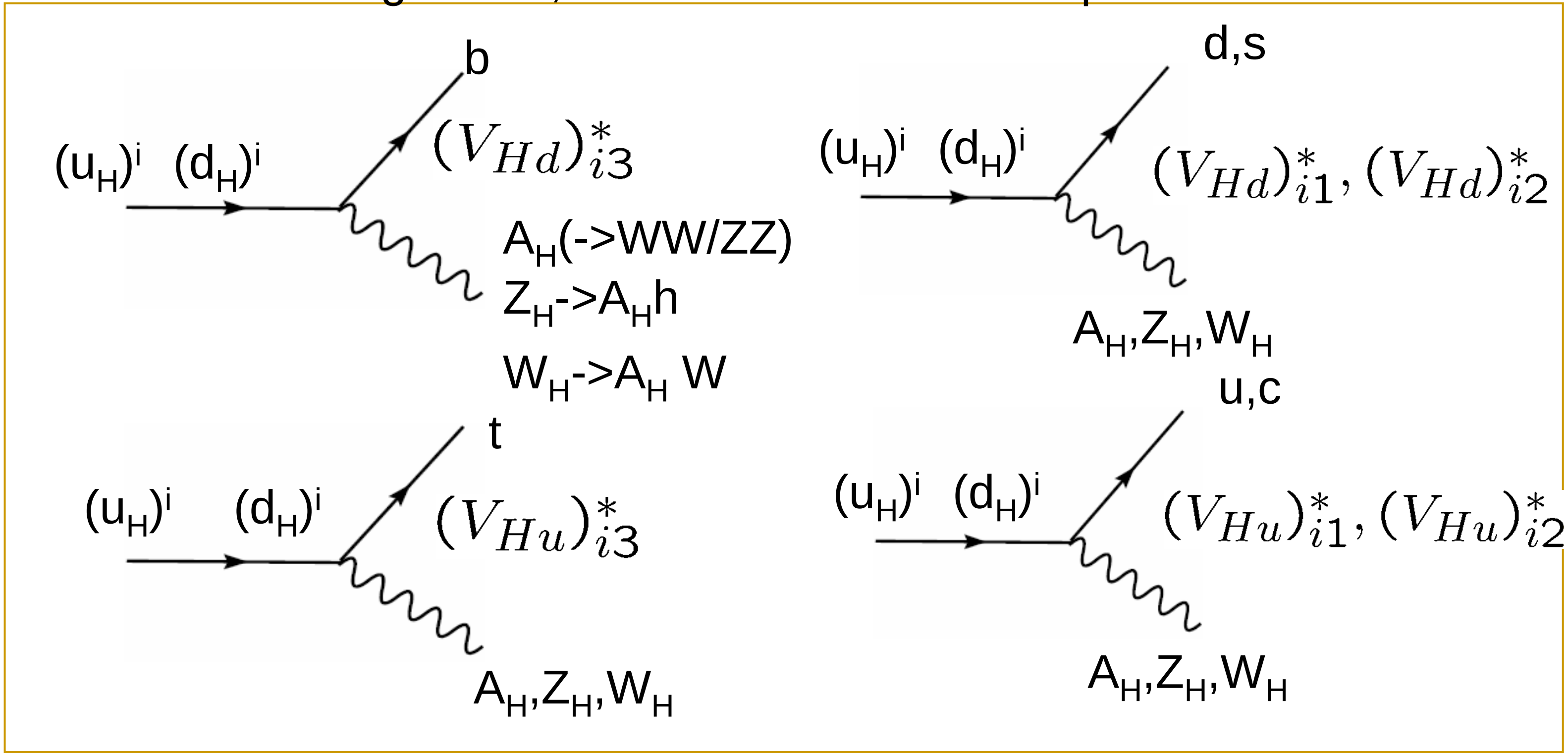
ratio	LHT	MSSM (dipole)	MSSM (Higgs)
$\frac{Br(\mu^-\to e^-e^+e^-)}{Br(\mu\to e\gamma)}$	$0.4\dots2.5$	$\sim 6\cdot10^{-3}$	$\sim 6\cdot10^{-3}$
$\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau\to e\gamma)}$	$0.4\dots2.3$	$\sim 1\cdot10^{-2}$	$\sim 1\cdot10^{-2}$
$\frac{Br(\tau^-\to \mu^-\mu^+\mu^-)}{Br(\tau\to \mu\gamma)}$	$0.4\dots2.3$	$\sim 2\cdot10^{-3}$	$0.06\dots0.1$
$\frac{Br(\tau^-\to e^-\mu^+\mu^-)}{Br(\tau\to e\gamma)}$	$0.3\dots1.6$	$\sim 2\cdot10^{-3}$	$0.02\dots0.04$
$\frac{Br(\tau^-\to \mu^-e^+e^-)}{Br(\tau\to \mu\gamma)}$	$0.3\dots1.6$	$\sim 1\cdot10^{-2}$	$\sim 1\cdot10^{-2}$
$\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau^-\to e^-\mu^+\mu^-)}$	$1.3\dots1.7$	~ 5	$0.3\dots0.5$
$\frac{Br(\tau^-\to \mu^-\mu^+\mu^-)}{Br(\tau^-\to \mu^-e^+e^-)}$	$1.2\dots1.6$	~ 0.2	$5\dots10$
$\frac{R(\mu\mathrm{Ti}\to e\mathrm{Ti})}{Br(\mu\to e\gamma)}$	$10^{-2}\dots10^{2}$	$\sim 5\cdot10^{-3}$	$0.08\dots0.15$

Clear distinction from the MSSM case.

M.Blanke, A.Buras, B.Duling. A.Poschenreider, C.Yarantino, 2007

Possible flavor connection to LHC physics

Heavy T-odd quark decays with and without b and t provide information on the new mixing matrix, which determine FCNC processes.



b

$(u_H)^i$ $(d_H)^i$

$(V_{Hd})^*_{i3}$

A_H(->WW/ZZ)

Z_H->A_Hh

W_H->A_H W

d,s

$(u_H)^i$ $(d_H)^i$

$(V_{Hd})^*_{i1}, (V_{Hd})^*_{i2}$

A_H,Z_H,W_H

t

$(u_H)^i$ $(d_H)^i$

$(V_{Hu})^*_{i3}$

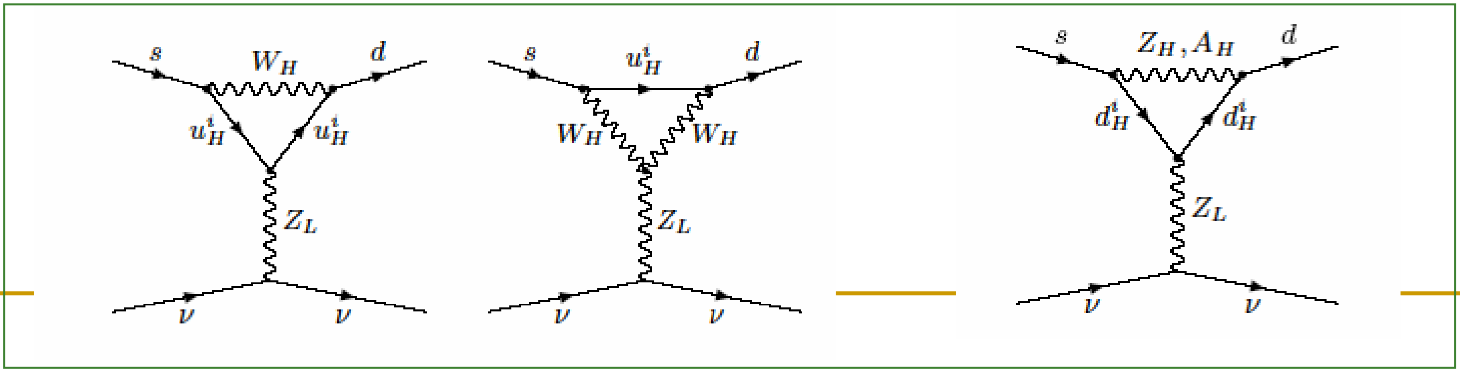
A_H,Z_H,W_H

u,c

$(u_H)^i$ $(d_H)^i$

$(V_{Hu})^*_{i1}, (V_{Hu})^*_{i2}$

A_H,Z_H,W_H



[3] Models with extra dim.

- Models with extra dimensions were proposed as an alternative scenario for a solution to the hierarchy problem.
- Various types of models:

Flat extra dim vs. Curved extra dim.

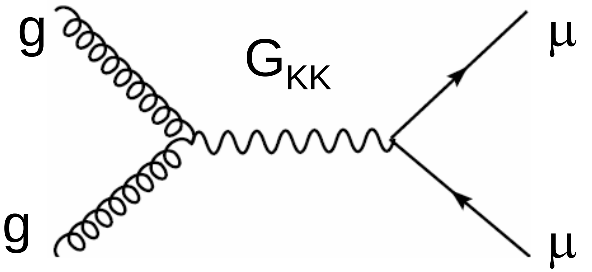
Various particles are allowed to propagate in the bulk.

- Geometrical construction of the fermion mass hierarchy

  => non-universality of KK graviton/gauge boson couplings

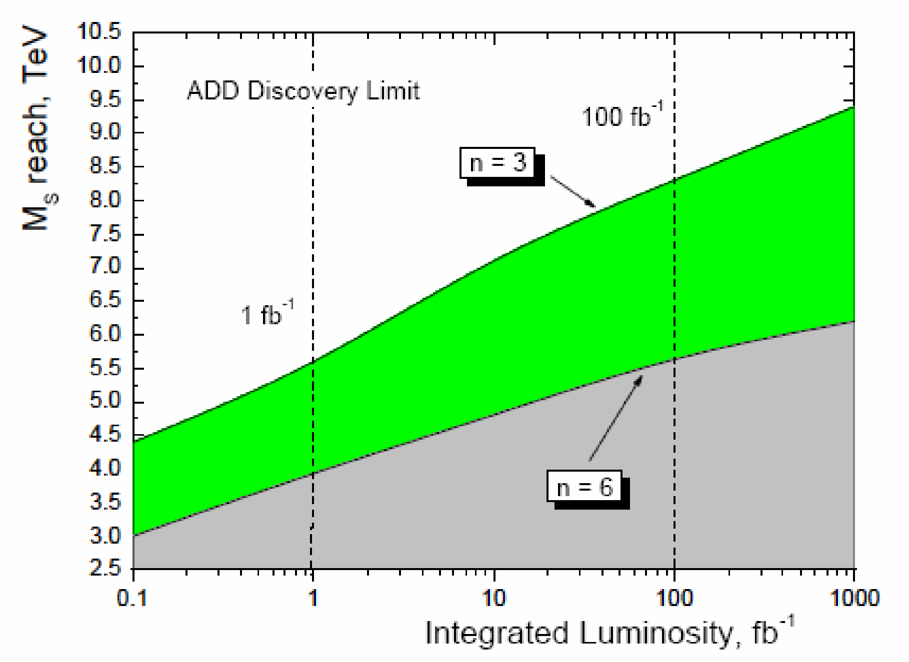
Split fermions in the flat extra dim.
Fermion mass hierarchy in the warped extra dim.

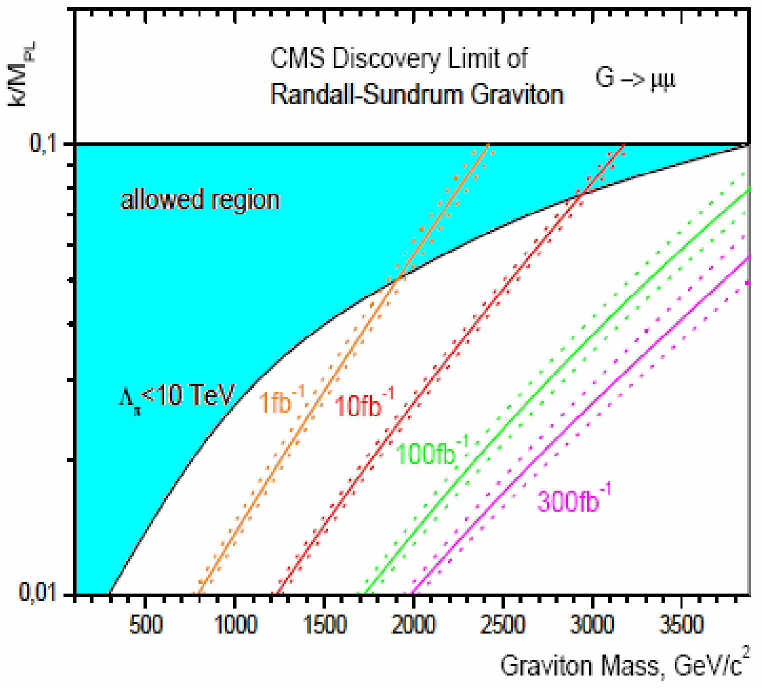
LHC reach on extra-dim models



Flat extra dim,
KK graviton exchange to μμ

Warped extra dim,
G_{KK}-> μμ





CMS TDR 2006

KK graviton exchange

T.Rizzo in SLAC WS Proc.

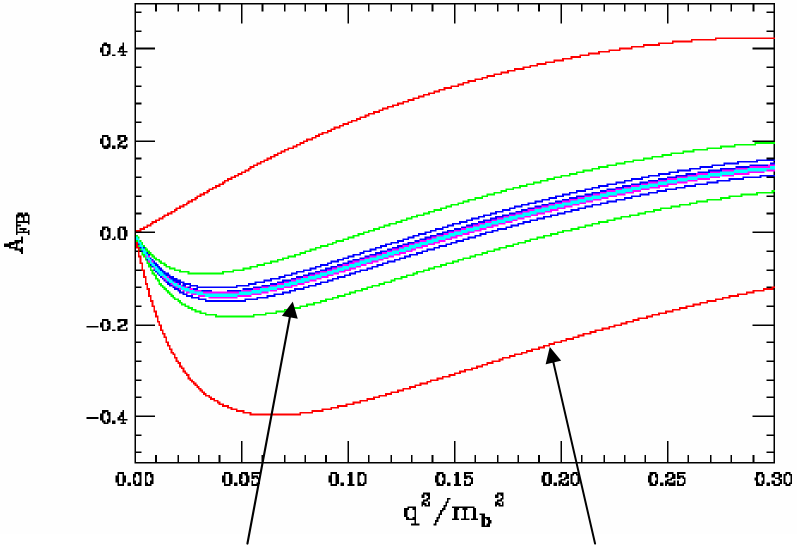
KK graviton exchange can induce tree-level FCNC coupling.

$$O_{grav} = \frac{X}{M^4} T_{\mu\nu} T^{\mu\nu}$$

Differential branching ratio of b->sll processes

Lepton FB asymmetry: $A_{FB}(s)$

Flat Extra Dim



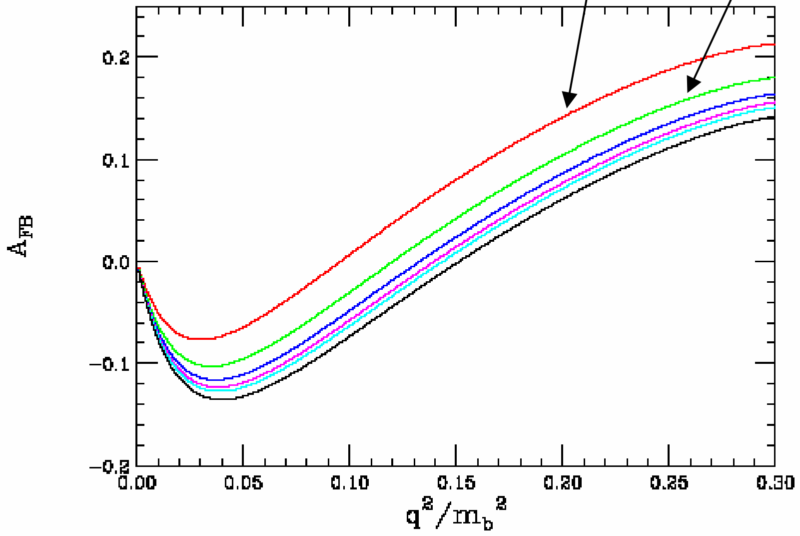
M=1.5 TeV

M=1TeV

Warped extra dim

m_{KK1}=600 GeV

m_{KK1}=700 GeV

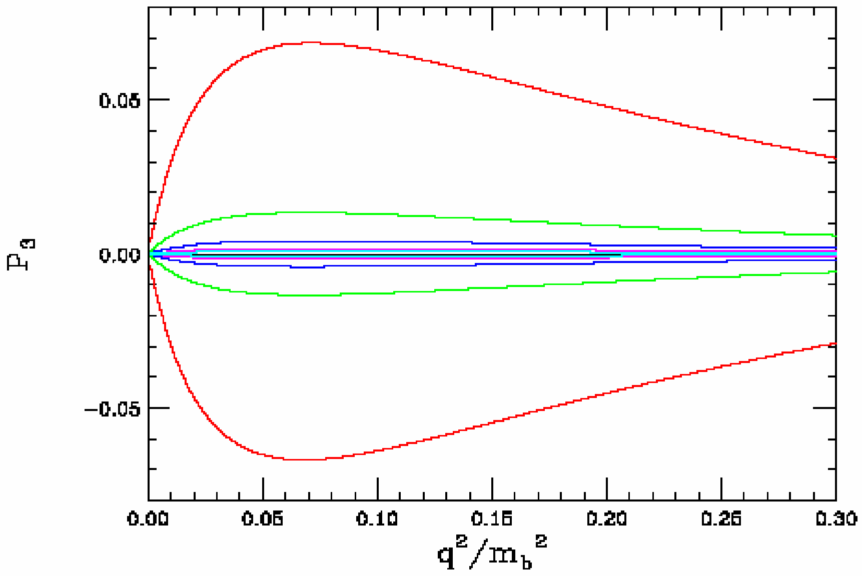


3^{rd} Legendre polynomial moment

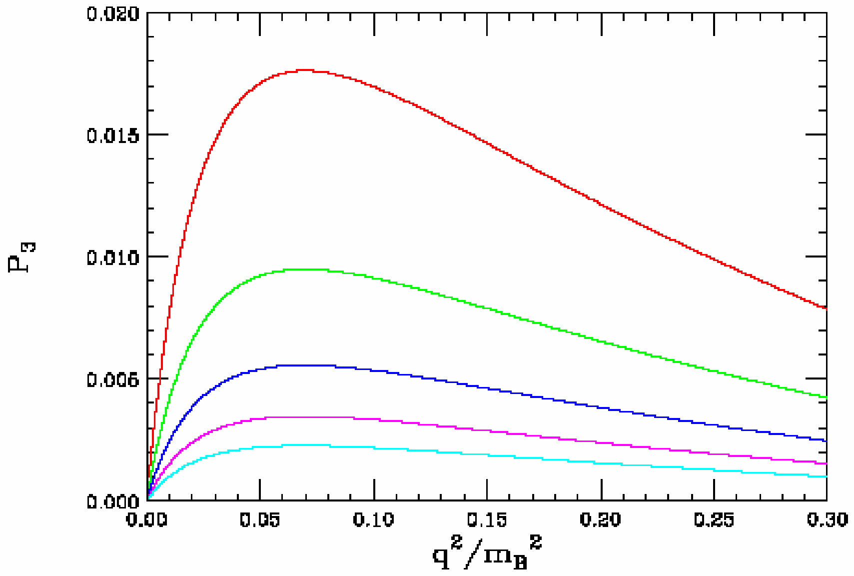
$$< P_3(s) > = \frac{\int \frac{d^2\Gamma}{ds\,dz} P_3(z)\, dz}{\frac{d\Gamma}{ds}}$$

=> pick up $(\cos\theta)^3$ terms due to spin2 graviton exchange

Flat Extra Dim

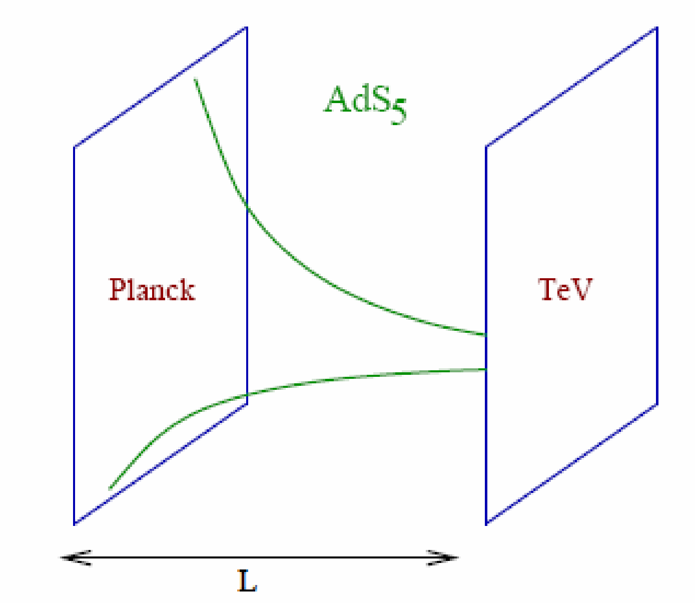


Warped extra dim



SM particle propagations in warped extra dim.

In the warped extra dimension with
bulk fermion/gauge boson propagation



In order for the fermion mass hierarchy, we put

Light fermion -> localized toward Planck brane
Top and left-handed bottom -> localized toward the TeV brane.

⇒Generate tree level FCNC in KK gluon and Z boson exchange.

Various interesting signals.
B-B mixing, b-> sll, K->$\pi\nu\nu$, t->cZ, LFV processes

Flavor changing processes are closely related to physics of fermion mass generation

=> A.Soni's talk

Summary

- There are many possibilities in the TeV scale physics, and it may contain new sources of flavor. Role of flavor physics depends on a correct physics scenario.
- Flavor structure of new physics is unknown. We need to combine information from quark and lepton flavor experiments and flavor-dependent decay signals of high-Q2 physics. There are examples in SUSY, Little Higgs models as well as extra-dim models