LFV Higgs Decay in Extended Mirror Fermion Model

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Outline

- Introduction
- Extended Mirror Fermion Model
- LFV Higgs Boson Decay
- Numerical Analysis
- Conclusion

Introduction

- Lepton and baryon number are accidental Global symmetry in SM.
- Process like $\mu \to e\gamma$ and $p \to e\gamma$, is forbidden in SM.
- Recently CMS and ATLAS have reported that

$$\mathcal{B}(h \to \tau\mu) = \begin{cases} 0.84^{+0.39}_{-0.37}\,\%\ (2.4\sigma)\ [\mathrm{CMS}]\,, \\ 0.77 \pm 0.62\,\%\ (1.2\sigma)\ [\mathrm{ATLAS}] \end{cases}$$

Introduction

- At 95% CL, the following upper limit are obtained

- $$\mathcal{B}(h \to \tau\mu) = \begin{cases} < 1.85\,\%\ (95\,\%\,\mathrm{CL})\ [\mathrm{ATLAS}]\ , \\ < 1.51\,\%\ (95\,\%\,\mathrm{CL})\ [\mathrm{CMS}]\ . \end{cases}$$

- LFV constraints from BaBar at 90% CL

$$\mathcal{B}(\tau \to \mu\gamma) < 4.4 \times 10^{-8}$$

$$\mathcal{B}(\tau \to e\gamma) < 3.3 \times 10^{-8}$$

Introduction

- We also have the LFV limit from MEG experiment

$$B(\mu \to e\gamma) \leq 5.7 \times 10^{-13}\ (90\,\mathrm{C.L.})[\mathrm{MEG,\ 2013}]\ ,$$

$$B(\mu \to e\gamma) \sim 4 \times 10^{-14}\ [\mathrm{Projected\,Sensitivity}]\ .$$

- We motivated by Extended Mirror Fermion (EMF) Model with Mirror Fermion mass insertion in the loop diagrams.
- The calculation of Branching Ratio of Higgs LFV process is compatible with above constraints, but receive tension from low energy experiments.

Extended Mirror Fermion Model

- Model with the same gauge Group as the SM with more particles content.
- The Motivation : To obtain majorana right handed neutrino with the EW scale mass.
- Extended : Adding one scalar mirror doublet and one extra scalar triplet with horizontal A4 symmetry to the lepton sector.

Extended Mirror Fermion model

- Particles content in the original model :
- Leptons and Quarks doublet :

$$- \text{ SM: } l_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix};\ q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix}$$

$$- \text{ Mirror: } l_R^M = \begin{pmatrix} \nu_R^M \\ e_R^M \end{pmatrix};\ q_R^M = \begin{pmatrix} u_R^M \\ d_R^M \end{pmatrix}$$

Extended Mirror Fermion Model

- Leptons and Quarks Singlet :
  - SM: e_R; u_R, d_R
  - Mirror: e_L^M; u_L^M, d_L^M
- Scalar Sector :
- A singlet scalar Higgs ϕ_S with $\langle \phi_S \rangle = v_S$
- Doublet Higgses:

$$\Phi_2 = \begin{pmatrix} \phi_2^+ \\ \phi_2^0 \end{pmatrix} \text{ with } \langle \phi_2^0 \rangle = v_2/\sqrt{2}$$

Extended Mirror Fermion Model

- Scalar Triplets :

$-$ $\tilde{\chi}\ (Y/2 = 1) = \frac{1}{\sqrt{2}}\ \vec{\tau}.\vec{\chi} = \begin{pmatrix} \frac{1}{\sqrt{2}}\chi^{+} & \chi^{++} \\ \chi^{0} & -\frac{1}{\sqrt{2}}\chi^{+} \end{pmatrix}$ with $\langle \chi^0 \rangle = v_M$.

$-$ $\xi\ (Y/2 = 0)$ in order to restore Custodial Symmetry with $\langle \xi^0 \rangle = v_M$.

$-$ VEVs:

$$v_2^2 + v_{2M}^2 + 8\, v_M^2 = v^2 \approx (246\ \text{GeV})^2$$

Extended Mirror Fermion Model

- Extended particles content :
- To accommodate 125 GeV Higgs , we introduce one more Higgs doublet that couple to Mirror sectors only.

$$\Phi_{2\,M} = \begin{pmatrix} \phi^{+}{}_{2\,M} \\ \phi^{0}{}_{2\,M} \end{pmatrix}$$

- We also add the triplet scalar to accommodate A4 symmetry in lepton sector.

$$\phi_{0\,S} \to \{\phi_{0\,S}, \phi_{iS}\}$$

Extended Mirror Fermion Model

- **EW precision** ： V. Hoang, P. Q. Hung and A. S. Kamat, *Nucl. Phys. B 877, 190 (2013) [arXiv:1303.0428 [hep-ph]].*
- **Implications of the 125-GeV SM-like scalar:** Dr Jekyll

  (SM-like) and Mr Hyde (very different from SM) V. Hoang, P. Q. Hung and A. S. Kamat, *arXiv:1412.0343 [hep-ph] (To appear in Nuclear Physics B).*
- **On neutrino and charged lepton masses and mixings: A view from the electroweak-scale right- handed neutrino model** *P. Q. Hung and T. Le, arXiv:1501.02538 [hep-ph].*
- ***The Search for Mirror Quarks at the LHC :*** *S.Chakdar, K.Ghosh, V.Hoang, P.Q. Hung, and S. Nandi, arXiv : 1508.07318 [hep-ph].*

Relevant Interactions

- The relevant interactions in our calculations :
- Singlet scalar yukawa term :

$$\mathcal{L}_S = -\sum_{k=0}^{3}\sum_{i,m=1}^{3}\left(\bar{l}_{Li}\,\mathcal{U}^{L\,k}_{im}\,l^M_{Rm} + \bar{l}_{Ri}\,\mathcal{U}^{R\,k}_{im}\,l^M_{Lm}\right)\phi_{kS} + \text{H.c.}$$

with

$$\begin{aligned}\mathcal{U}^{L\,k}_{im} &\equiv \left(U^{\dagger}_{\text{PMNS}}\cdot M^k \cdot U^{l^M}_{\text{PMNS}}\right)_{im} \quad , \\ &= \sum_{j,n=1}^{3}\left(U^{\dagger}_{\text{PMNS}}\right)_{ij} M^k_{jn}\left(U^{M}_{\text{PMNS}}\right)_{nm} \quad ,\end{aligned}$$

Relevant Interactions

- And also

$$\mathcal{U}^{R\,k}_{im} \equiv \left(U'^{\dagger}_{\rm PMNS} \cdot M'^{\,k} \cdot U'^{\,l\,M}_{\rm PMNS}\right)_{im} \quad ,$$

$$= \sum_{j,n=1}^{3} \left(U'^{\dagger}_{\rm PMNS}\right)_{ij} M'^{\,k}_{jn} \left(U'^{\,M}_{\rm PMNS}\right)_{nm} \quad ,$$

- Where the matrices are defined as

$$U_{\rm PMNS} = U^{\dagger}_{\nu} U^{l}_{L}\,, \;\; U^{M}_{\rm PMNS} = U^{\dagger}_{\nu} U^{l^M}_{R}\;, \quad U'_{\rm PMNS} = U^{\dagger}_{\nu} U^{l}_{R}\,,$$

$$U'^{M}_{\rm PMNS} = U^{\dagger}_{\nu} U^{l^M}_{L}$$

Relevant Interactions

- The matrices relate the gauge eigenstates (superscripts 0) and mass eigenstates

$$l^0_{L,R} = U^l_{L,R} l_{L,R} \ , \qquad l^{M,0}_{R,L} = U^{l^M}_{R,L} l^M_{R,L} \ ,$$

$$U_\nu = U^\nu_L = U^\nu_R = \frac{1}{\sqrt{3}} \begin{pmatrix} 1 & 1 & 1 \\ 1 & \omega^2 & \omega \\ 1 & \omega & \omega^2 \end{pmatrix} \ ,$$

$$\omega \equiv \exp(i2\pi/3)$$

TABLE I: Matrix elements for $M^k (k = 0, 1, 2, 3)$ where $\omega \equiv \exp(i2\pi/3)$ and g_{0S} and g_{1S} are Yukawa couplings.

M^k_{jn}	Value
$M^0_{12}, M^0_{13}, M^0_{21}, M^0_{23}, M^0_{31}, M^0_{32}$	0
$M^0_{11}, M^0_{22}, M^0_{33}$	g_{0S}
$M^1_{11}, M^2_{11}, M^3_{11}$	$\frac{2}{3}\mathrm{Re}\,(g_{1S})$
$M^1_{22}, M^2_{22}, M^3_{22}$	$\frac{2}{3}\mathrm{Re}\,(\omega^* g_{1S})$
$M^1_{33}, M^2_{33}, M^3_{33}$	$\frac{2}{3}\mathrm{Re}\,(\omega g_{1S})$
M^1_{12}, M^1_{21}	$\frac{2}{3}\mathrm{Re}\,(\omega g_{1S})$
M^2_{12}, M^3_{21}	$\frac{1}{3}\,(g_{1S} + \omega g^*_{1S})$
M^3_{12}, M^2_{21}	$\frac{1}{3}\,(g^*_{1S} + \omega^* g_{1S})$
M^1_{13}, M^1_{31}	$\frac{2}{3}\mathrm{Re}\,(\omega^* g_{1S})$
M^2_{13}, M^3_{31}	$\frac{1}{3}\,(g_{1S} + \omega^* g^*_{1S})$
M^3_{13}, M^2_{31}	$\frac{1}{3}\,(g^*_{1S} + \omega g_{1S})$
M^1_{23}, M^1_{32}	$\frac{2}{3}\mathrm{Re}\,(g_{1S})$
M^2_{23}, M^3_{32}	$\frac{2\omega^*}{3}\mathrm{Re}\,(g_{1S})$
M^3_{23}, M^2_{32}	$\frac{2\omega}{3}\mathrm{Re}\,(g_{1S})$

Relevant Interactions

- The second relevant term is the higgs coupling to the SM fermion and mirror fermion.

$$\mathcal{L}_{\widetilde{H}} = -\frac{g}{2m_W}\sum_{a,f}\widetilde{H}_a\left\{m_f\frac{O_{a1}}{s_2}\overline{f}f + m_{f^M}\frac{O_{a2}}{s_{2M}}\overline{f^M}f^M\right\}$$

- In this model the physical Higgses and unphysical ones are related via

$$\begin{pmatrix}\widetilde{H}_1\\ \widetilde{H}_2\\ \widetilde{H}_3\end{pmatrix} = \begin{pmatrix}a_{1,1} & a_{1,1M} & a_{1,1'}\\ a_{1M,1} & a_{1M,1M} & a_{1M,1'}\\ a_{1',1} & a_{1',1M} & a_{1',1'}\end{pmatrix}\cdot\begin{pmatrix}H_1^0\\ H_{1M}^0\\ H_1^{0\prime}\end{pmatrix} \equiv O\cdot\begin{pmatrix}H_1^0\\ H_{1M}^0\\ H_1^{0\prime}\end{pmatrix}$$

Relevant Interactions

- The parameters are define as

$$s_2 = \frac{v_2}{v}\ , \qquad s_{2M} = \frac{v_{2M}}{v}\ , \qquad s_M = \frac{2\sqrt{2}v_M}{v}$$

- With the Vev relation

$$v = \sqrt{v_2^2 + v_{2M}^2 + 8v_M^2} = 246\ \text{GeV},$$

LFV Neutral Higgs Decay

- The diagram for the process $\widetilde{H}_a(q) \to l_i(p) + \bar{l}_j(p')$

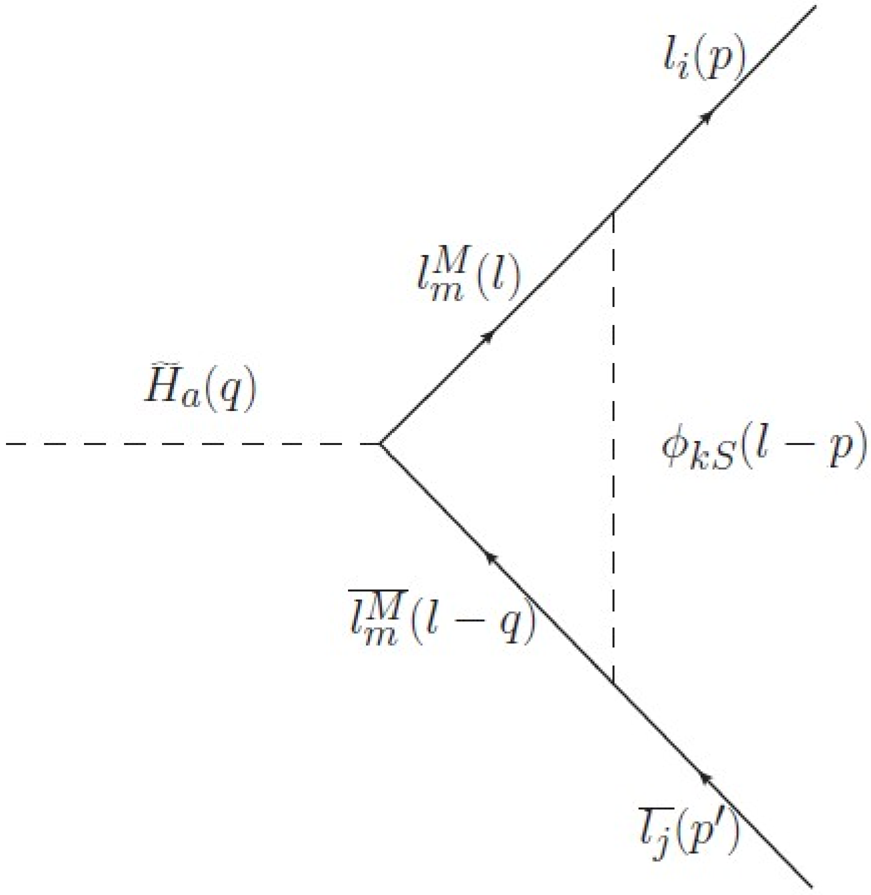


FIG. 1

LFV Neutral Higgs Decay

- The matrix element can be written as

$$i\mathcal{M} = i\frac{1}{16\pi^2}\overline{u_i}(p)\left(C_L^{aij}P_L + C_R^{aij}P_R\right)v_j(p')$$

- In terms of scalar and pseudoscalar coupling, it can be written as

$$i\mathcal{M} = i\frac{1}{16\pi^2}\overline{u_i}(p)\left(A^{aij} + iB^{aij}\gamma_5\right)v_j(p')$$

- where

$$A^{aij} = \frac{1}{2}\left(C_L^{aij} + C_R^{aij}\right) \quad , \quad B^{aij} = \frac{1}{2i}\left(C_R^{aij} - C_L^{aij}\right)$$

LFV Neutral Higgs Decay

$$
\begin{aligned}
C_L^{aij} = {} & \frac{g O_{a1}}{2 s_2 m_W (m_i^2 - m_j^2)} \sum_{k,m} \int_0^1 dx \Bigg\{ \bigg[(1-x) \left(m_i m_j^2 \mathcal{U}_{im}^{L\,k} \left(\mathcal{U}_{mj}^{L\,k}\right)^* + m_j m_i^2 \mathcal{U}_{im}^{R\,k} \left(\mathcal{U}_{mj}^{R\,k}\right)^* \right) \\
& + \; m_i m_j M_m \mathcal{U}_{im}^{L\,k} \left(\mathcal{U}_{mj}^{R\,k}\right)^* \bigg] \log \left(\frac{\Delta_1}{\Delta_2} \right) + M_m \mathcal{U}_{im}^{R\,k} \left(\mathcal{U}_{mj}^{L\,k}\right)^* \left(m_i^2 \log \Delta_1 - m_j^2 \log \Delta_2 \right) \Bigg\} \\
& + \frac{g O_{a2}}{2 s_{2M} m_W} \sum_{k,m} M_m \mathcal{U}_{im}^{R\,k} \left(\mathcal{U}_{mj}^{L\,k}\right)^* \left(-\frac{1}{2} - 2 \int_0^1 dx \int_0^{1-x} dy \log \Delta_3 \right) \\
& - \frac{g O_{a2}}{2 s_{2M} m_W} \sum_{k,m} M_m \int_0^1 dx \int_0^{1-x} dy \frac{1}{\Delta_3} \Bigg\{ (1-2y) \frac{m_i M_m}{m_{\widetilde{H}_a}^2} \mathcal{U}_{im}^{L\,k} \left(\mathcal{U}_{mj}^{L\,k}\right)^* \\
& + (1-2x) \frac{m_j M_m}{m_{\widetilde{H}_a}^2} \mathcal{U}_{im}^{R\,k} \left(\mathcal{U}_{mj}^{R\,k}\right)^* + (1-x-y) \frac{m_i m_j}{m_{\widetilde{H}_a}^2} \mathcal{U}_{im}^{L\,k} \left(\mathcal{U}_{mj}^{R\,k}\right)^* \\
& - \left[xy + (1-x-y)(y r_i + x r_j) - r_m \right] \mathcal{U}_{im}^{R\,k} \left(\mathcal{U}_{mj}^{L\,k}\right)^* \Bigg\}
\end{aligned}
$$

LFV Neutral Higgs Decay

$$
\begin{aligned}
C_R^{aij} = {} & \frac{gO_{a1}}{2s_2 m_W (m_i^2 - m_j^2)} \sum_{k,m} \int_0^1 dx \Bigg\{ \Bigg[(1-x) \Big(m_i m_j^2 \mathcal{U}^{R\,k}_{im} \left(\mathcal{U}^{R\,k}_{mj}\right)^* + m_j m_i^2 \mathcal{U}^{L\,k}_{im} \left(\mathcal{U}^{L\,k}_{mj}\right)^* \Big) \\
& + m_i m_j M_m \mathcal{U}^{R\,k}_{im} \left(\mathcal{U}^{L\,k}_{mj}\right)^* \Bigg] \log\left(\frac{\Delta_1}{\Delta_2}\right) + M_m \mathcal{U}^{L\,k}_{im} \left(\mathcal{U}^{R\,k}_{mj}\right)^* \left(m_i^2 \log \Delta_1 - m_j^2 \log \Delta_2\right) \Bigg\} \\
& + \frac{gO_{a2}}{2s_{2M} m_W} \sum_{k,m} M_m \mathcal{U}^{L\,k}_{im} \left(\mathcal{U}^{R\,k}_{mj}\right)^* \left(-\frac{1}{2} - 2 \int_0^1 dx \int_0^{1-x} dy \log \Delta_3 \right) \\
& - \frac{gO_{a2}}{2s_{2M} m_W} \sum_{k,m} M_m \int_0^1 dx \int_0^{1-x} dy \frac{1}{\Delta_3} \Bigg\{ (1-2y) \frac{m_i M_m}{m^2_{\widetilde{H}_a}} \mathcal{U}^{R\,k}_{im} \left(\mathcal{U}^{R\,k}_{mj}\right)^* \\
& + (1-2x) \frac{m_j M_m}{m^2_{\widetilde{H}_a}} \mathcal{U}^{L\,k}_{im} \left(\mathcal{U}^{L\,k}_{mj}\right)^* + (1-x-y) \frac{m_i m_j}{m^2_{\widetilde{H}_a}} \mathcal{U}^{R\,k}_{im} \left(\mathcal{U}^{L\,k}_{mj}\right)^* \\
& - \left[xy + (1-x-y)(y r_i + x r_j) - r_m\right] \mathcal{U}^{L\,k}_{im} \left(\mathcal{U}^{R\,k}_{mj}\right)^* \Bigg\}
\end{aligned}
$$

LFV Neutral Higgs Decay

- The deltas are given by

$$\Delta_1 = xr_m + (1-x)r_k - x(1-x)r_j - i0^+ \,,$$

$$\Delta_2 = xr_m + (1-x)r_k - x(1-x)r_i - i0^+ \,,$$

$$\Delta_3 = (x+y)r_m + (1-x-y)(r_k - yr_i - xr_j) - xy - i0^+$$

where

$$r_m = M_m^2/m_{\widetilde{H}_a}^2 \quad r_{i,j} = m_{i,j}^2/m_{\widetilde{H}_a}^2 \quad r_k = m_k^2/m_{\widetilde{H}_a}^2$$

LFV Neutral Higgs Decay

- The partial decay width is given by

$$\Gamma^{aij} = \frac{1}{2^{11}\pi^5} m_{\widetilde{H}_a} \lambda^{\frac{1}{2}} \left(1, \frac{m_i^2}{m_{\widetilde{H}_a}^2}, \frac{m_j^2}{m_{\widetilde{H}_a}^2}\right) \times \left[|A^{aij}|^2 \left(1 - \frac{(m_i + m_j)^2}{m_{\widetilde{H}_a}^2}\right) + |B^{aij}|^2 \left(1 - \frac{(m_i - m_j)^2}{m_{\widetilde{H}_a}^2}\right) \right]$$

with the lambda function is defined as

$$\lambda(x, y, z) = x^2 + y^2 + z^2 - 2(xy + yz + zx)$$

Numerical Analysis

- We adopt the following strategy in our numerical analysis

$$\text{Scenario 1: } U'_{\text{PMNS}} = U^{M}_{\text{PMNS}} = U'^{M}_{\text{PMNS}} = U_\nu = \frac{1}{\sqrt{3}}\begin{pmatrix} 1 & 1 & 1 \\ 1 & \omega^2 & \omega \\ 1 & \omega & \omega^2 \end{pmatrix}$$

$$\text{Scenario 2: } U'_{\text{PMNS}} = U^{M}_{\text{PMNS}} = U'^{M}_{\text{PMNS}} = U_{\text{PMNS}}, \text{ where}$$

$$U^{\text{NH}}_{\text{PMNS}} = \begin{pmatrix} 0.8221 & 0.5484 & -0.0518 + 0.1439i \\ -0.3879 + 0.07915i & 0.6432 + 0.0528i & 0.6533 \\ 0.3992 + 0.08984i & -0.5283 + 0.05993i & 0.7415 \end{pmatrix}$$

Numerical Analysis

$$U^{\rm IH}_{\rm PMNS} = \begin{pmatrix} 0.8218 & 0.5483 & -0.08708 + 0.1281i \\ -0.3608 + 0.0719i & 0.6467 + 0.04796i & 0.6664 \\ 0.4278 + 0.07869i & -0.5254 + 0.0525i & 0.7293 \end{pmatrix}$$

- All Yukawa couplings g_{0S}, g_{1S}, g'_{0S} and g'_{1S} are assumed to be real. For simplicity, we will assume $g_{0S} = g'_{0S}$, $g_{1S} = g'_{1S}$ and study the following 6 cases:

  (a) $g_{0S} \neq 0$, $g_{1S} = 0$. The A_4 triplet terms are switched off.

  (b) $g_{1S} = 10^{-2} \times g_{0S}$. The A_4 triplet couplings are merely one percent of the singlet ones.

Numerical Analysis

(c) $g_{1S} = 10^{-1} \times g_{0S}$. The A_4 triplet couplings are 10 percent of the singlet ones.

(d) $g_{1S} = 0.5 \times g_{0S}$. The A_4 triplet couplings are one half of the singlet ones.

(e) $g_{1S} = g_{0S}$. Both A_4 singlet and triplet terms have the same weight.

(f) $g_{0S} = 0$, $g_{1S} \neq 0$. The A_4 singlet terms are switched off.

- For the masses of the singlet scalars ϕ_{kS}, we take

$$m_{\phi_{0S}} : m_{\phi_{1S}} : m_{\phi_{2S}} : m_{\phi_{3S}} = M_S : 2M_S : 3M_S : 4M_S$$

with a fixed common mass $M_S = 10$ MeV. As long as $m_{\phi_{kS}} \ll m_{l_m^M}$, our results will not be affected much by this assumption.

Numerical Analysis

- 125 GeV Higgs can be identified as :
- Dr.Jeykell : when the higgs doublet is dominant

$$O = \begin{pmatrix} 0.998 & -0.0518 & -0.0329 \\ 0.0514 & 0.999 & -0.0140 \\ 0.0336 & 0.0123 & 0.999 \end{pmatrix}$$

with $\mathrm{Det}(O) = +1$, $m_{\widetilde{H}_1} = 125.7$ GeV, $m_{\widetilde{H}_2} = 420$ GeV, $m_{\widetilde{H}_3} = 601$ GeV, $s_2 = 0.92$, $s_{2M} = 0.16$ and $s_M = 0.36$. In this case,

$$h \equiv \widetilde{H}_1 \sim H_1^0\,, \quad \widetilde{H}_2 \sim H_{1M}^0\,, \quad \widetilde{H}_3 \sim H_1^{0\prime}$$

Numerical Analysis

- Mr.Hyde : the higgs double is sub-dominant

$$O = \begin{pmatrix} 0.187 & 0.115 & 0.976 \\ 0.922 & 0.321 & -0.215 \\ 0.338 & -0.940 & 0.046 \end{pmatrix}$$

with $\mathrm{Det}(O) = -1$, $m_{\widetilde{H}_1} = 125.6$ GeV, $m_{\widetilde{H}_2} = 454$ GeV, $m_{\widetilde{H}_3} = 959$ GeV, $s_2 = 0.401$, $s_{2M} = 0.900$ and $s_M = 0.151$. In this case,

$$h \equiv \widetilde{H}_1 \sim H_1^{0\prime}\,, \quad \widetilde{H}_2 \sim H_1^0\,, \quad \widetilde{H}_3 \sim H_{1M}^0$$

Numerical Analysis

- We plot the contour of the Branching Ratio for 4 processes on (Log(Mm),Log(g0S or g1S))

$$\mathcal{B}(h \to \tau\mu) = 0.84\% \qquad \text{(red)}$$

$$\mathcal{B}(\mu \to e\gamma) = 5.7 \times 10^{-13} \qquad \text{(black)}$$

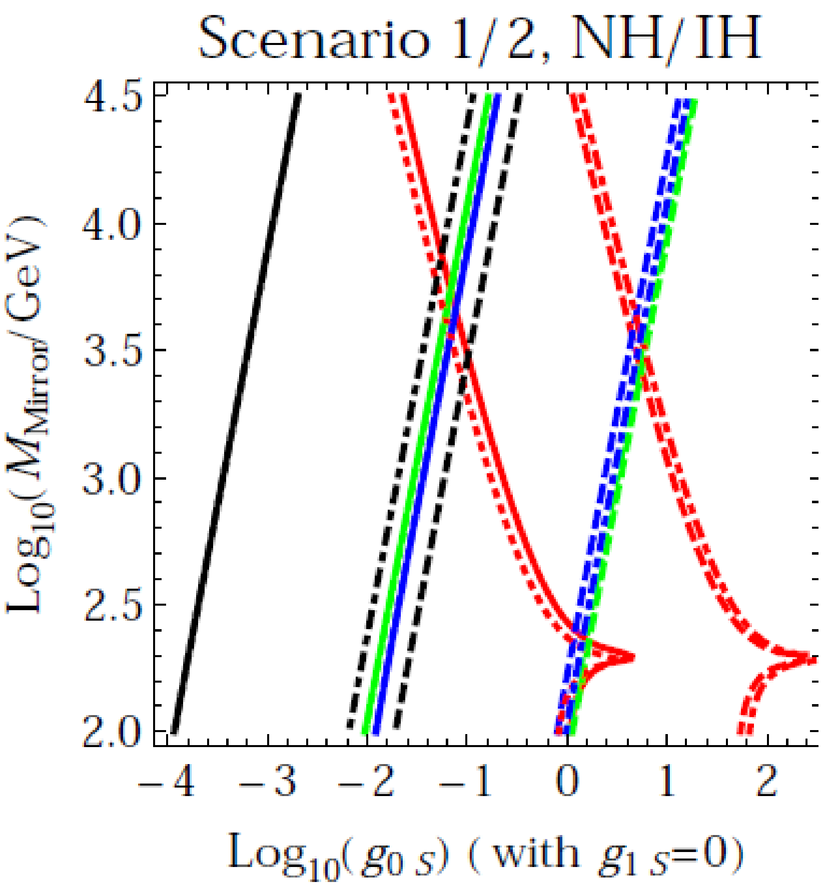
$$\mathcal{B}(\tau \to \mu\gamma) = 4.4 \times 10^{-8} \qquad \text{(blue)}$$

$$\mathcal{B}(\tau \to e\gamma) = 3.3 \times 10^{-8} \qquad \text{(green)}$$

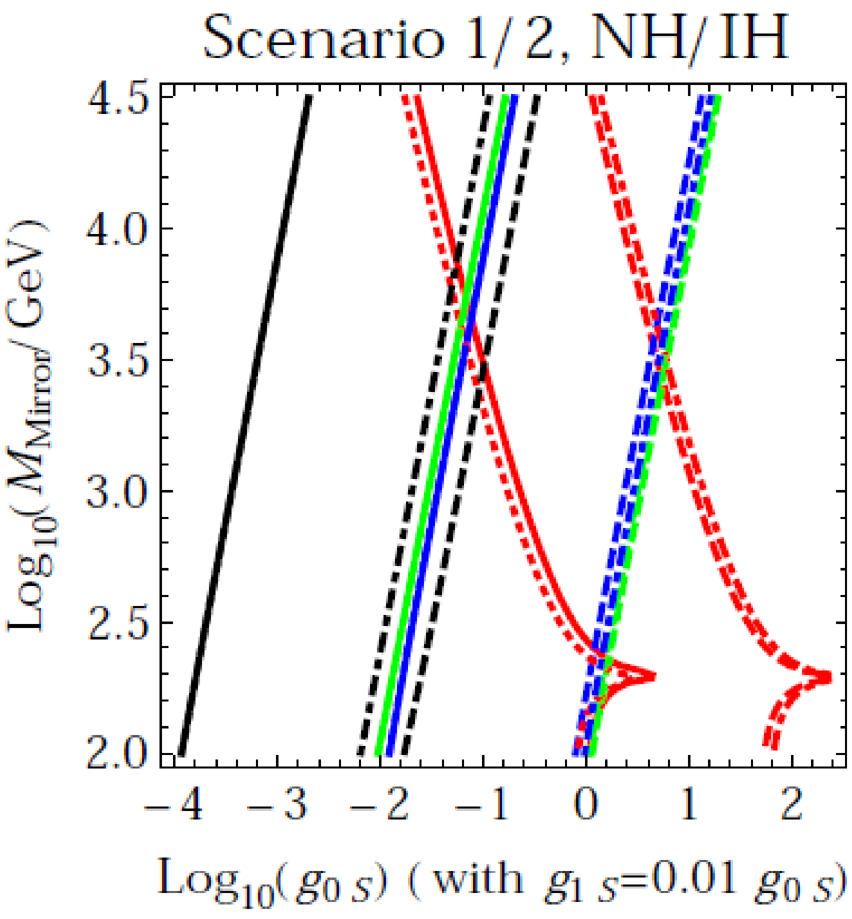
Numerical Analysis

- We study scenario 1 and 2 as well as normal hierarchy and inverted hierarchy for 6 different couplings.
- The line with the same color denotes the same process.
- For Normal Hierarchy (NH), solid line indicates scenario 1, while dashed line for scenario 2.
- For Inverted Hierarchy (IH), dotted line denotes scenario 1, and dot-dashed one is scenario 2.

Figure 2 (Dr.Jeykell Scenario)

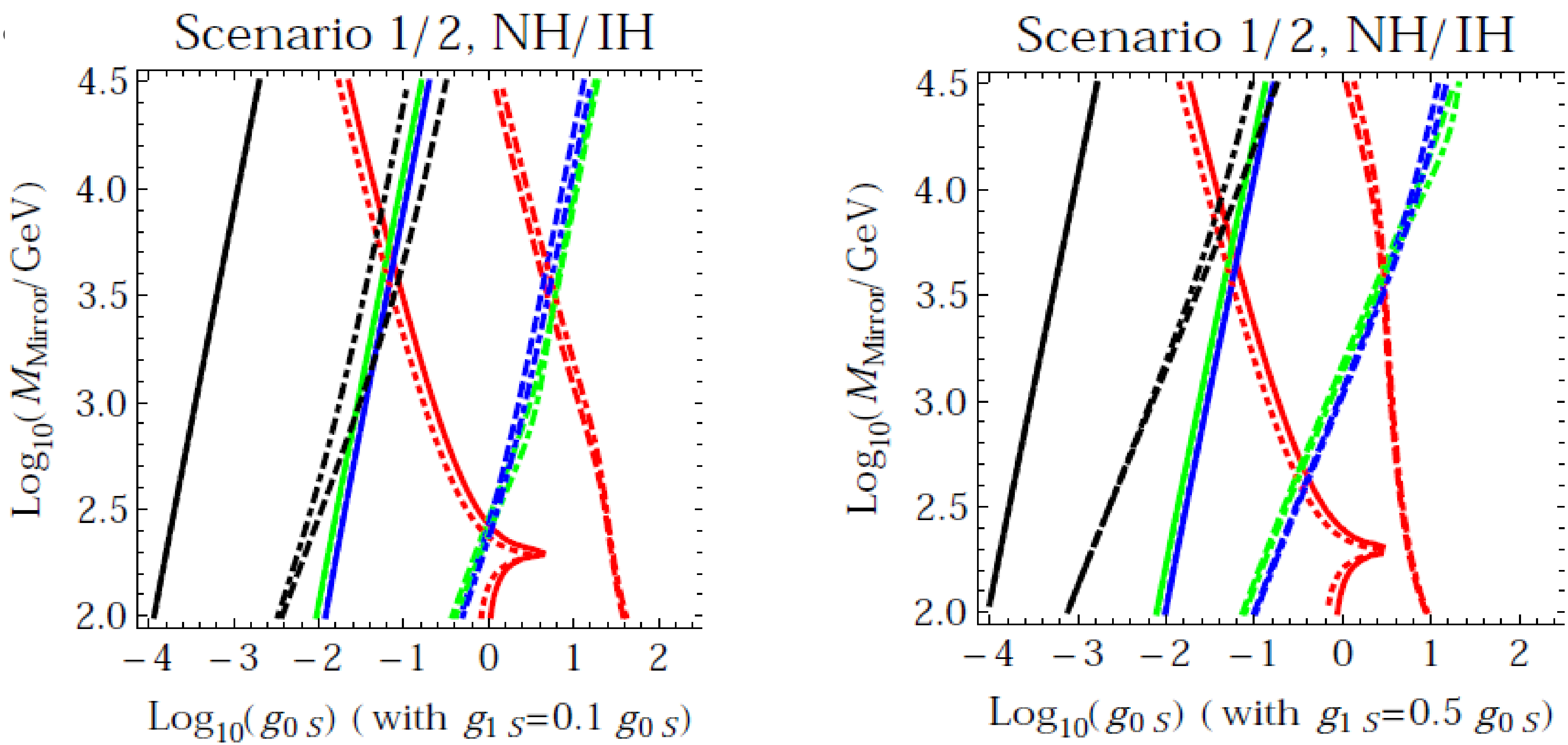


(a)



(b)

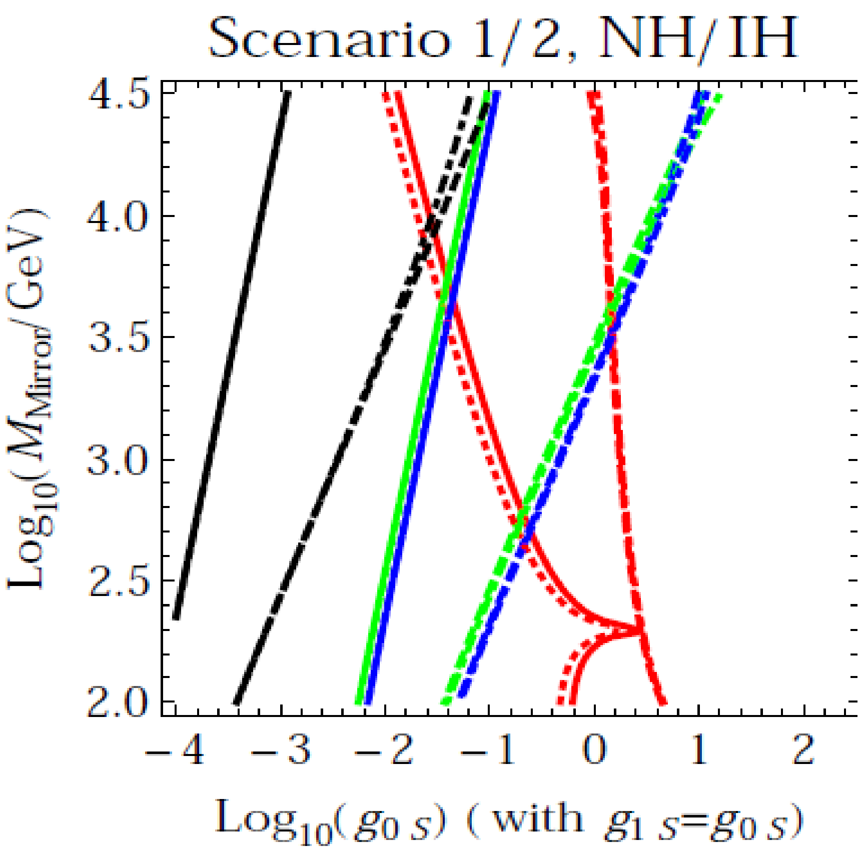
Figure 2 (Dr.Jeykell)



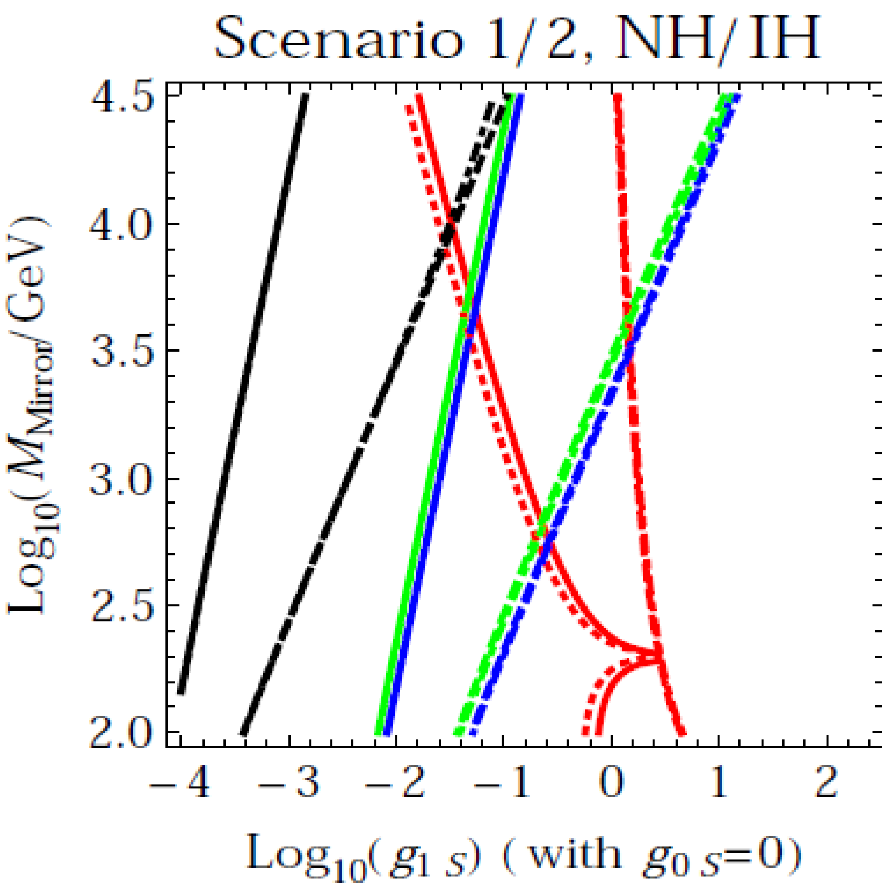
(c)

(d)

Figure 2 (Dr.Jeykell)

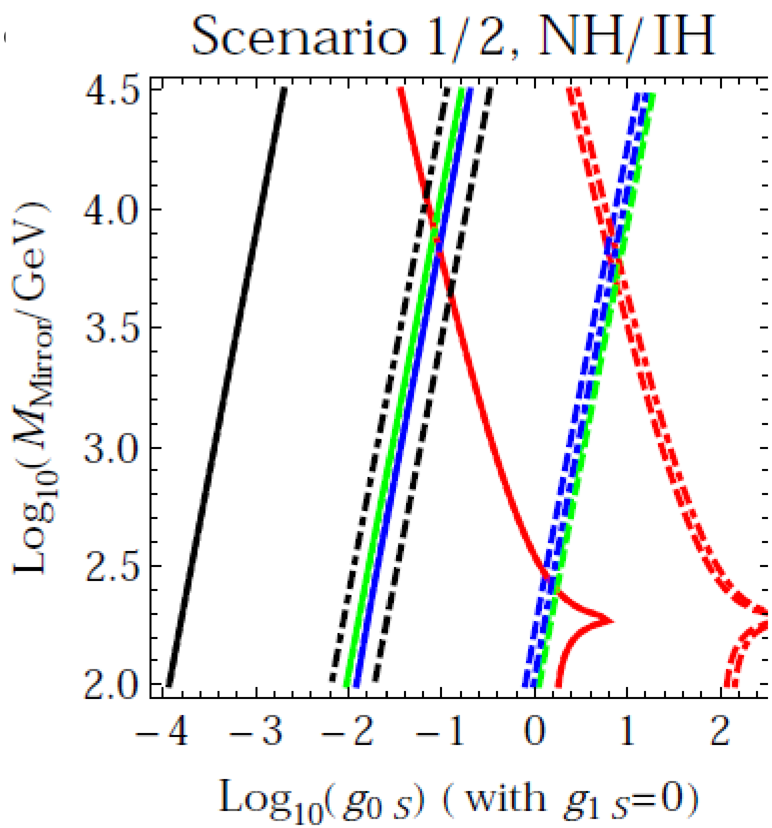


(e)

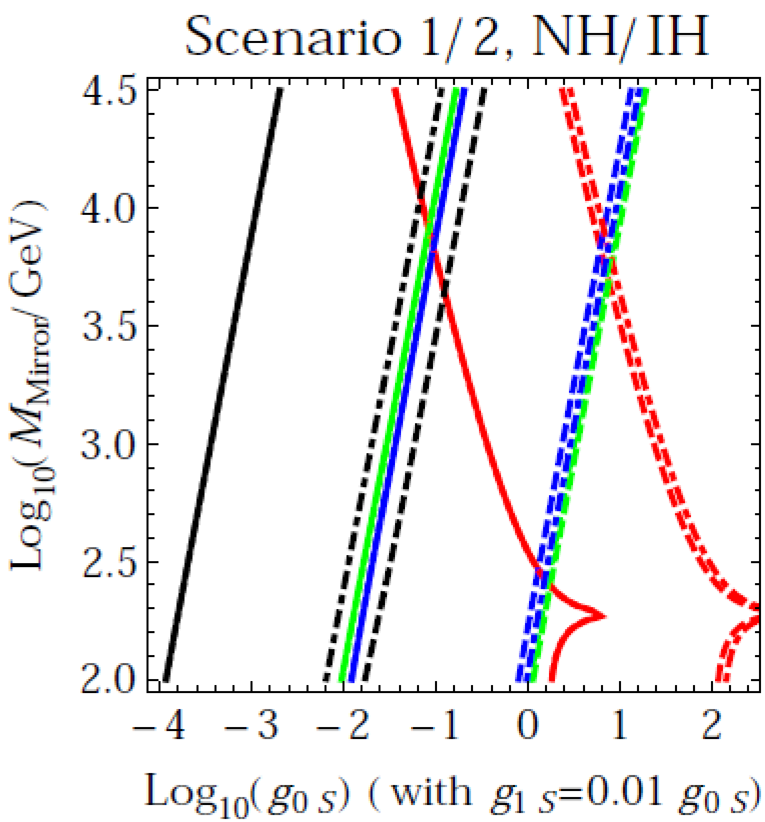


(f)

Figure 3 (Mr.Hyde)

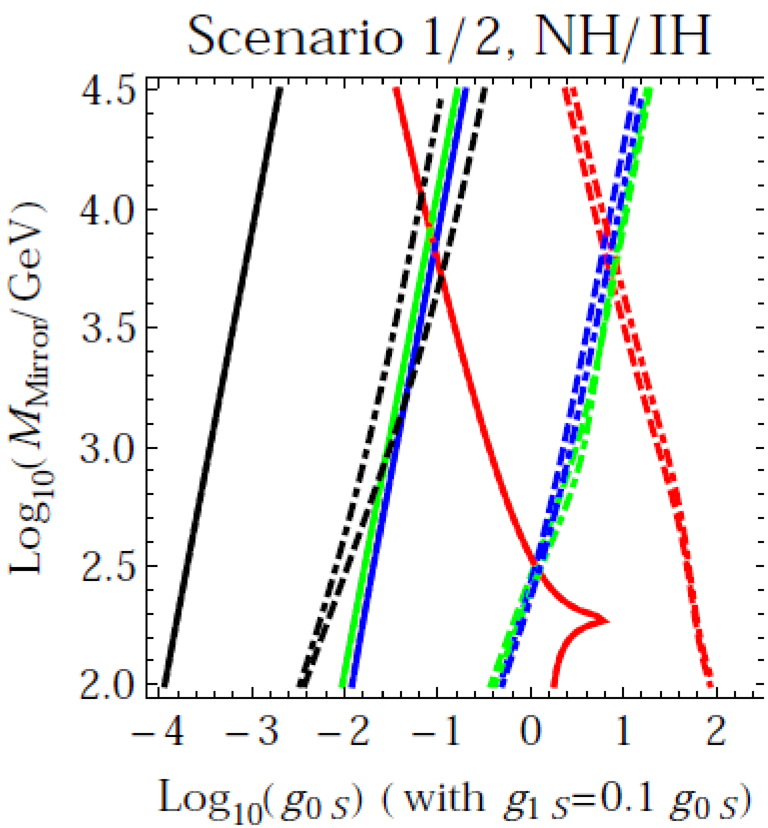


(a)

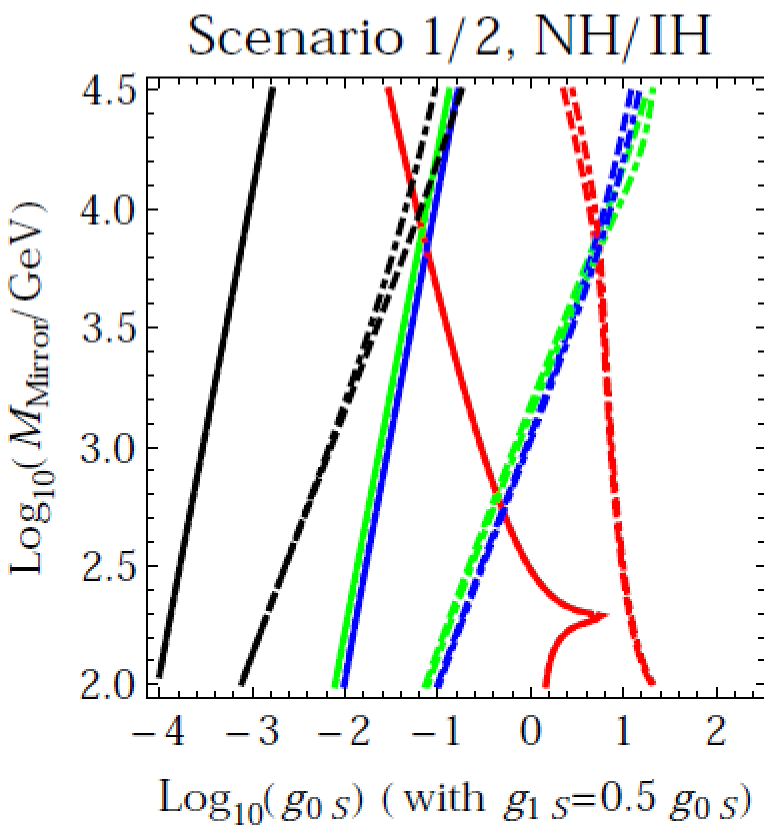


(b)

Figure 3 (Mr.Hyde)

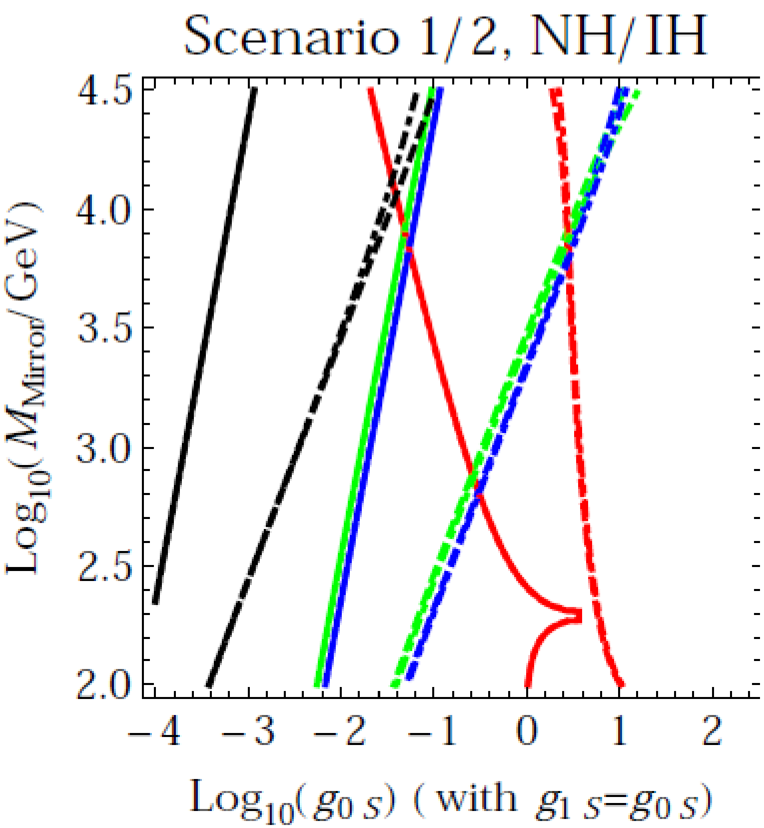


(c)

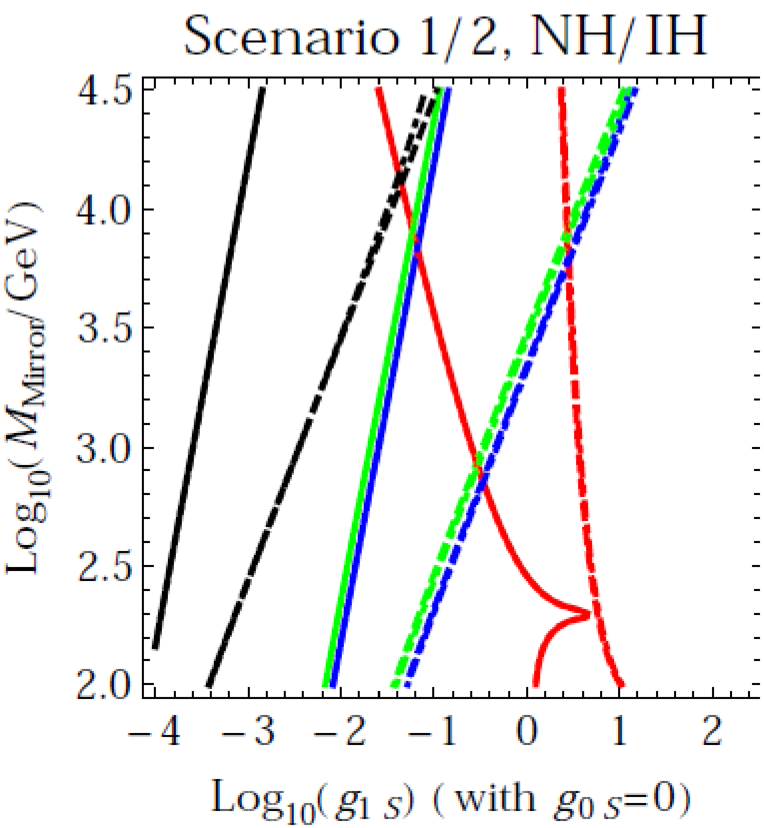


(d)

Figure 3 (Mr.Hyde)



(e)



(f)

Numerical Analysis

- The bumps at $M_{\text{mirror}} \sim 200$ GeV at all the plots in these two figures are due to large cancellation in the amplitudes between the two one-particle reducible (wave function renormalization) diagrams and the irreducible one-loop diagram

- For the two processes $\tau \to \mu\gamma$ (blue lines) and $\tau \to e\gamma$ (green lines) in all these plots, the solid and dotted lines are coincide to each other while the dashed and dot-dashed lines are very close together.

- However, for the process $\mu \to e\gamma$ (black lines):
only the solid and dotted lines are coincide to each other. Thus there are some differences between normal and inverted mass hierarchies in Scenario 2 but not in Scenario 1 for this process, in particular for cases (a)-(d) in which $g_{1S} \leq 0.5 g_{0S}$.

Numerical Analysis

- For the black lines from the most stringent limit of $\mu \to e\gamma$, their intersections with the red lines are well beyond 10 TeV for the mirror lepton masses. Similar statements can be obtained from the other plots in these two figures. Such a large mirror lepton mass $M_{\rm mirror}$ or coupling g_{0S} indicates a break down of the perturbative calculation and/or violation of unitarity.

- In the event that the CMS result is just a statistical fluctuation, the limits will be improved further in LHC Run 2. The contour lines of these future limits would be located to the left side of the current red lines in the two Figs. (2) and (3). Their intersections with the black, blue and green lines would then be at lower mirror lepton masses and smaller Yukawa couplings

- Certainly this would alleviate the tension mentioned above.

Conclusion

To summarize, CMS has reported excess in the charged lepton flavor violating Higgs decay $h \to \tau\mu$ at 2.4σ level. More data is needed to collect at Run 2 so as to confirm whether these are indeed true signals or simply statistical fluctuations.

If the branching ratio of $h \to \tau\mu$ is indeed at the percent level, new physics associated with lepton flavor violation may be at a scale not too far from the electroweak scale. Crucial question is whether this large branching ratio of $h \to \tau\mu$ is compatible with the current low energy limits of $\tau \to \mu\gamma$ and $\tau \to e\gamma$ from Belle experiments and the most stringent limit of $\mu \to \gamma$ from MEG experiment.

We demonstrate that in general there is tension between the LHC result and the low energy limits since these results are compatible only if the mirror lepton masses are quite heavy and/or the Yukawa couplings involving the scalar singlets are large.


THANK
YOU