Supersymmetric Dirac Leptogenesis and Lepton Flavor Violation [a]

by

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[a]PRD**73**, 063512 (2006) and ongoing work (Brooks Thomas, MT)

Outline

- Introduction
- Neutrinogenesis: Dirac Neutrinos & Leptogenesis
- Lepton Flavor Violation
- Conclusion

INTRODUCTION

- (Majorana) Leptogenesis. Economic way to address:
  - The observed Baryon Asymmetry in the Universe.
  - Neutrino phenomenology (large mixing angles and tiny non-zero masses)
- Dirac Leptogenesis (or Neutrinogenesis). Less economical but still successful with both these puzzles. In the absence of Majorana particles, Dirac Leptogenesis becomes a very interesting alternative.

Baryogenesis and Neutrino physics can significantly constrain the parameter space in the scenario. When Supersymmetry is invoqued, (Slepton mediated) Lepton Flavor Violating (LFV) processes will further constrain the scenario.

Dirac Leptogenesis*

We add new fields and a new $U(1)_N$ to the MSSM:

Field	L	$U(1)_N$	$SU(2)$	$U(1)_Y$
N_R	-1	+1	**1**	0
Φ	+1	-1	**2**	$-\frac{1}{2}$
$\overline{\Phi}$	-1	+1	**2**	$\frac{1}{2}$
χ	0	-1	**1**	0

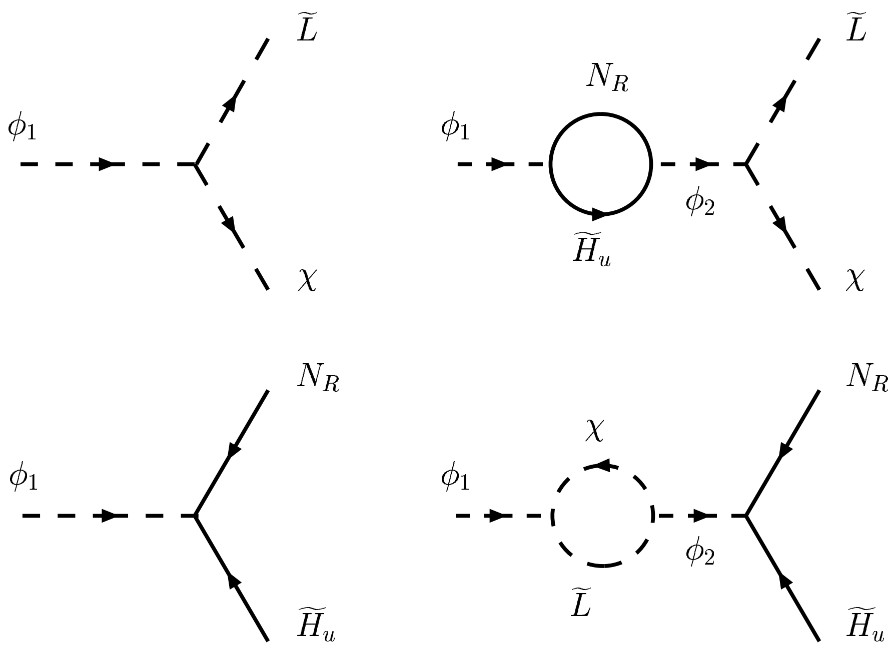
New terms in superpotential:

$$\mathcal{W} \ni \lambda\ N_R H_u \Phi + h\ L\overline{\Phi}\chi + M_\Phi \Phi\overline{\Phi}$$

*non-SUSY version→ Dick-Lindner-Ratz-Wright [hep-ph/9907562]
SUSY version→ Murayama-Pierce [hep-ph/0206177]

Baryogenesis

- Out-of-equilibrium decays of heavy Φ fields
- CP violation



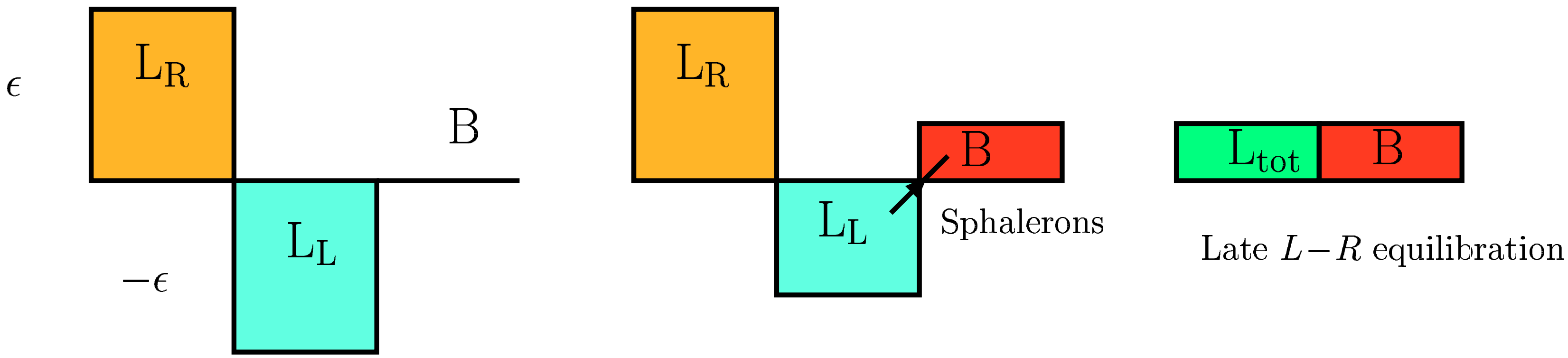
$$\frac{\Gamma(\phi_1 \to \widetilde{L}\chi) - \Gamma(\phi_1^c \to \widetilde{L}^c \chi^c)}{\Gamma_{\phi_1}} = \epsilon$$

$$\frac{\Gamma(\phi_1 \to \widetilde{H}_u^c N_R^c) - \Gamma(\phi_1^c \to \widetilde{H}_u N_R)}{\Gamma_{\phi_1}} = -\epsilon$$

With

$$\epsilon = \frac{1}{4\pi} \frac{\delta}{1-\delta} \frac{\mathrm{Im}(\lambda_{1\alpha}^* \lambda_{2\alpha} h_{1\beta}^* h_{2\beta})}{(|\lambda_{1\gamma}|^2 + |h_{1\gamma}|^2)} \quad \text{where} \quad \delta = M_{\Phi_1}/M_{\Phi_2}$$

- Leptogenesis



$L_L \ni \widetilde{L},\ \widetilde{e}_R,\ L,\ e_R,\ \widetilde{N}_R$ all in equilibrium due to:

- gauge interactions
- yukawa interactions
- large trilinear $\widetilde{N}_R \widetilde{L} H$

L_L and N_R are NOT in equilibrium (tiny neutrino yukawas)

AND sphalerons only act on L_L ($SU(2)$ doublets)

Boltzman Equations $\left(\text{with } (B - L_{tot})'=0\right)$

$$\frac{H(M_{\phi_1})}{z}\frac{d\phi}{dz} = -\langle\Gamma^{\phi}_{tot}\rangle\left(\phi-\phi^{eq}\right) - \left(\phi^2-\phi^2_{eq}\right)\gamma^{EW}_{2\to 2} + \frac{1}{2}\phi^{eq}\left(\frac{1}{14}L_L\langle\Gamma_L\rangle+L_R\ \langle\Gamma_R\rangle\right)$$

$$\frac{H(M_{\phi_1})}{z}\frac{dL_R}{dz} = 2\epsilon\ \langle\Gamma^{\phi}_{tot}\rangle\left(\phi-\phi^{eq}\right) - 2\phi^{eq}L_R\ \langle\Gamma^{Inv}_R\rangle - (L_R-L_L)\ \langle\Gamma_{2\to 2}\rangle + 2L_\phi\langle\Gamma_R\rangle$$

$$\frac{H(M_{\phi_1})}{z}\frac{dL_L}{dz} = -2\epsilon\ \langle\Gamma^{\phi}_{tot}\rangle\left(\phi-\phi^{eq}\right) - \frac{1}{7}\phi^{eq}L_L\ \langle\Gamma^{Inv}_L\rangle + (L_R-L_L)\ \langle\Gamma_{2\to 2}\rangle$$
$$- \langle\Gamma_{sph}\rangle\left(B+\frac{8}{15}L_L\right) + 2\langle\Gamma_L\rangle(L_\phi+L_{\overline{\phi}}) + 2\langle\Gamma_R\rangle L_{\overline{\phi}}$$

$$\frac{H(M_{\phi_1})}{z}\frac{dB}{dz} = -\langle\Gamma_{sph}\rangle\left(B+\frac{8}{15}L_L\right)$$

$$\frac{H(M_{\phi_1})}{z}\frac{dL_\phi}{dz} = -\langle\Gamma^{\phi}_{tot}\rangle L_\phi + \phi^{eq}\left[\frac{1}{7}L_L\langle\Gamma_L\rangle+2L_R\langle\Gamma_R\rangle\right]$$
$$\frac{H(M_{\phi_1})}{z}\frac{dL_{\overline{\phi}}}{dz} = -\langle\Gamma^{\phi}_{tot}\rangle L_{\overline{\phi}} + \frac{1}{7}\phi^{eq}L_L\langle\Gamma^{\phi}_{tot}\rangle$$

Dirac Neutrinos

Integrating-out Φ and $\overline{\Phi}$ we get

$$\mathcal{W}_{eff} \ni \frac{\lambda h}{M_{\Phi_1}} \chi L H_u N$$

After χ acquires a vev $\langle \chi \rangle$, the effective Dirac neutrino Yukawas are

$$y_\nu \sim \lambda h \frac{\langle \chi \rangle}{M_{\Phi_1}}$$

If $\langle \chi \rangle \sim$ TeV-ish $\rightarrow$ small Dirac neutrino yukawa

Hierarchical Dirac Neutrinos

We can reduce the number of parameters of

$$\mathcal{W} \ni \lambda\ N_R H_u \Phi + h\ L\overline{\Phi}\chi + M_\Phi \Phi\overline{\Phi} + y_e H_d L e_R$$

In the basis where y_e and M_Φ are diagonal, we ASSUME that λ and h are antisymmetric.

With a hierarchy $\delta = M_{\phi_1}/M_{\phi_2}$, one then generically obtains

$$(m_\nu^2) \propto \begin{pmatrix} \delta^2 & \delta & \delta \\ . & 1 & 1 \\ . & . & 1 \end{pmatrix}$$

which corresponds to a neutrino *Normal Hierarchy Scenario*

We fix $\delta = M_{\phi_1}/M_{\phi_2} = 0.1$

$\rightarrow$ correct neutrino phenomenology then requires:

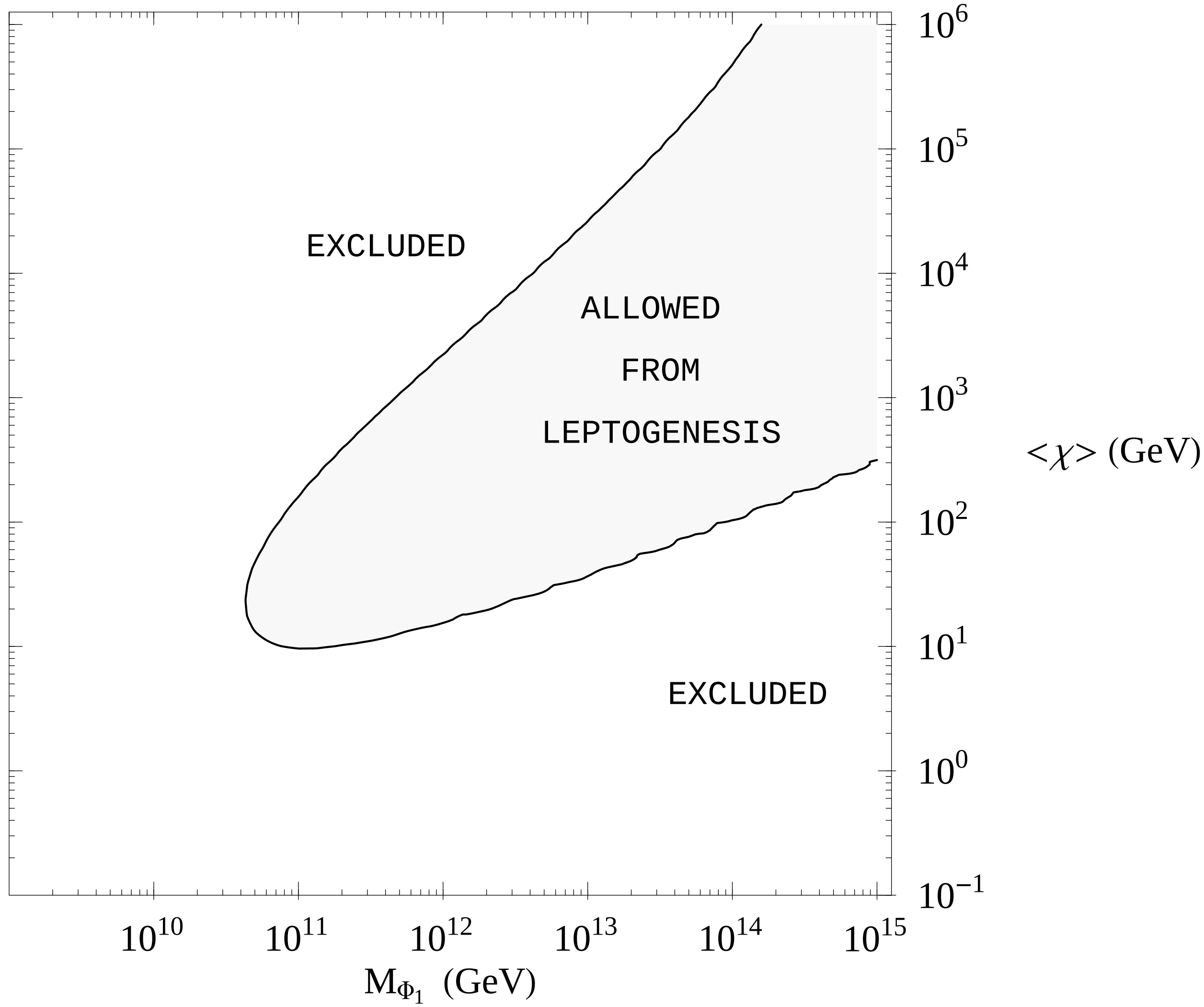
$$\lambda = f \begin{pmatrix} 0 & 1 & 0.8\text{-}1.2 \\ -1 & 0 & 1.5\text{-}4.5 \\ -(0.8\text{-}1.2) & -(1.5\text{-}4.5) & 0 \end{pmatrix}$$

$$h = f \begin{pmatrix} 0 & 0.8\text{-}1.2 & 0.8\text{-}1.2 \\ -(0.8\text{-}1.2) & 0 & 1.4\text{-}2.8 \\ -(0.8\text{-}1.2) & -(1.4\text{-}2.8) & 0 \end{pmatrix}$$

f : overall coupling strength linked to M_{ϕ_1} and $\langle\chi\rangle$ by requiring $\quad m_\nu = .05\ \text{eV} \propto \frac{f^2\langle\chi\rangle}{M_{\phi_1}} v$.

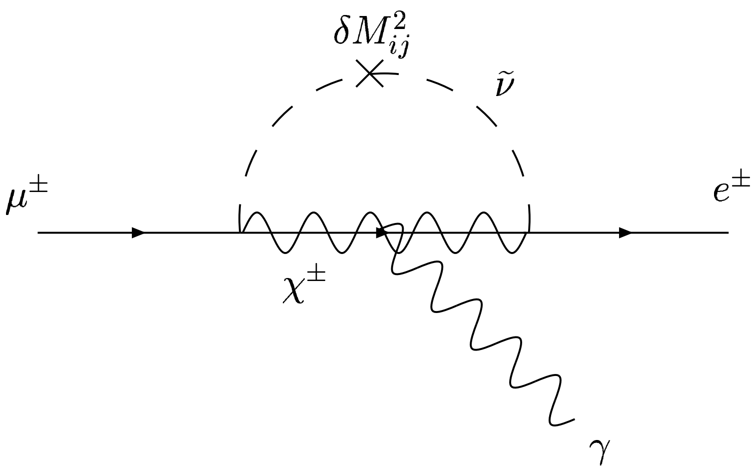
$\rightarrow$ we can trade f for M_{ϕ_1} and $\langle\chi\rangle \implies f^2 \propto \frac{M_{\phi_1}}{\langle\chi\rangle}$.

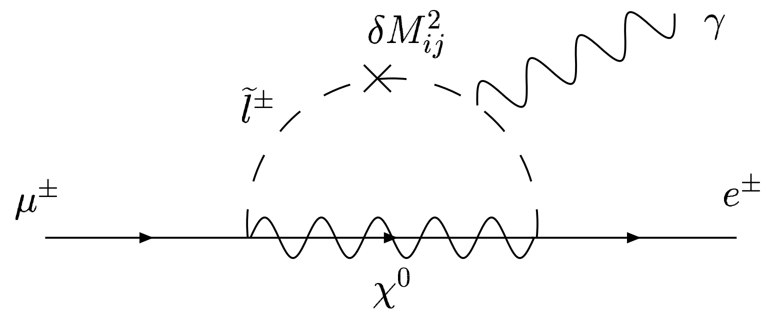
Hierarchical Neutrinogenesis Constraints



Lepton Flavor Violation

We are interested in the process $\mu \to e\gamma$, mediated by off-diagonal entries in the slepton masses.





With

$$Br(\mu \to e\gamma) \propto \frac{\alpha^3}{G_F^3} \left(\frac{(\delta M^2_{slep})_{21}}{M_S^4} \right)^2$$

The new terms in the superpotential (with flavor structure already **fixed** to fit neutrino data) will contribute to the slepton mass matrices, giving:

$$\begin{aligned} \left(M^2_{LL}\right)_{new} &= \left(M^2_{LL}\right)_0 + \langle\chi\rangle^2\ hh^+ \\ \left(M^2_{N_RN_R}\right)_{new} &= \left(M^2_{N_RN_R}\right)_0 + v^2 \sin\beta^2 \lambda^+\lambda \end{aligned}$$

If χ acquires a SUSY breaking F-term there will be another term from $\left(\frac{1}{M_\Phi}\chi H_u L N_R\right)$:

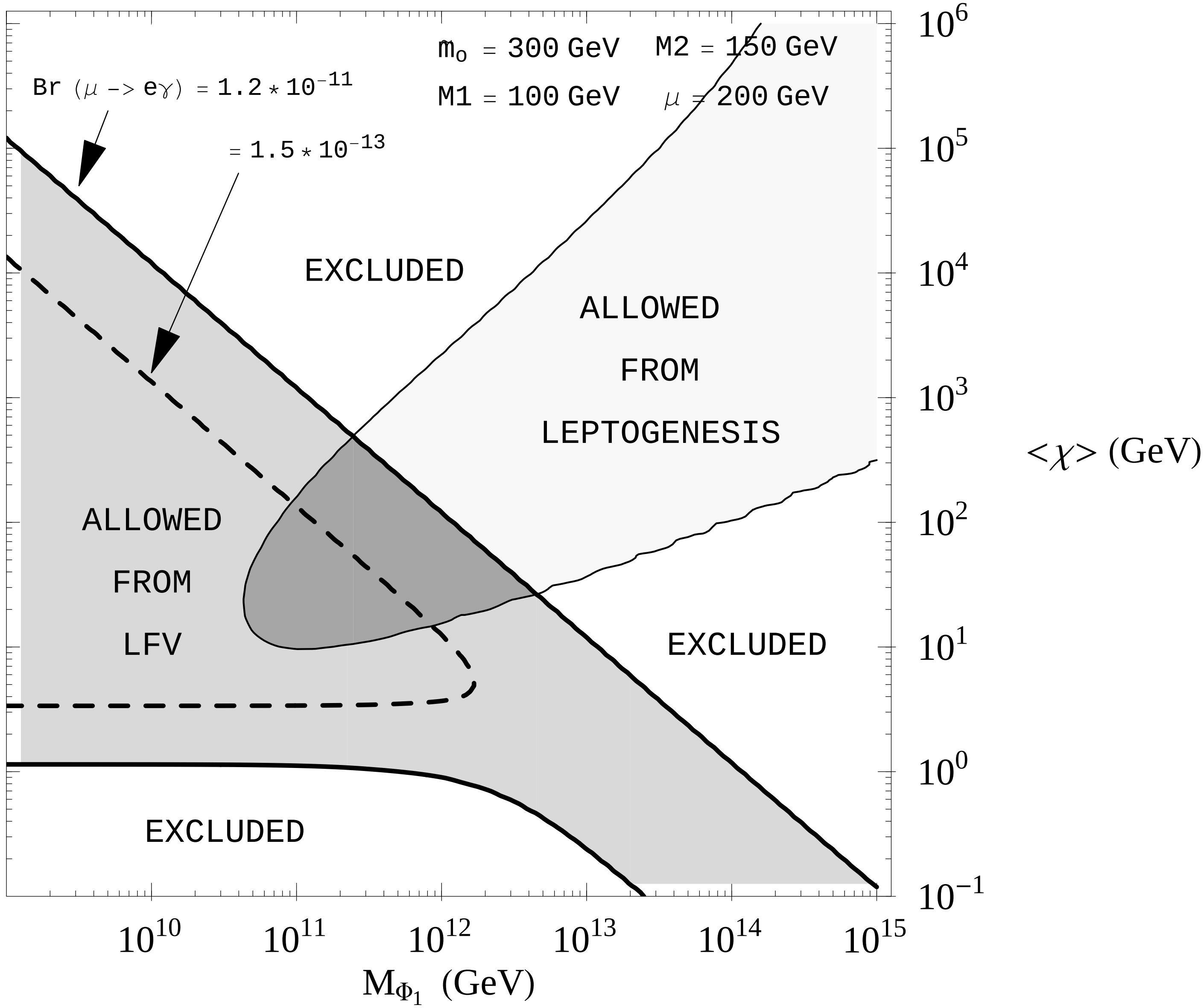
$$\left(M^2_{N_RL}\right)_{new} = \left(M^2_{N_RL}\right)_0 + v \sin\beta F_\chi \frac{h^+\lambda}{M_\Phi}$$

The $(M^2_{ij})_0$ are assumed to be flavor diagonal and universal.

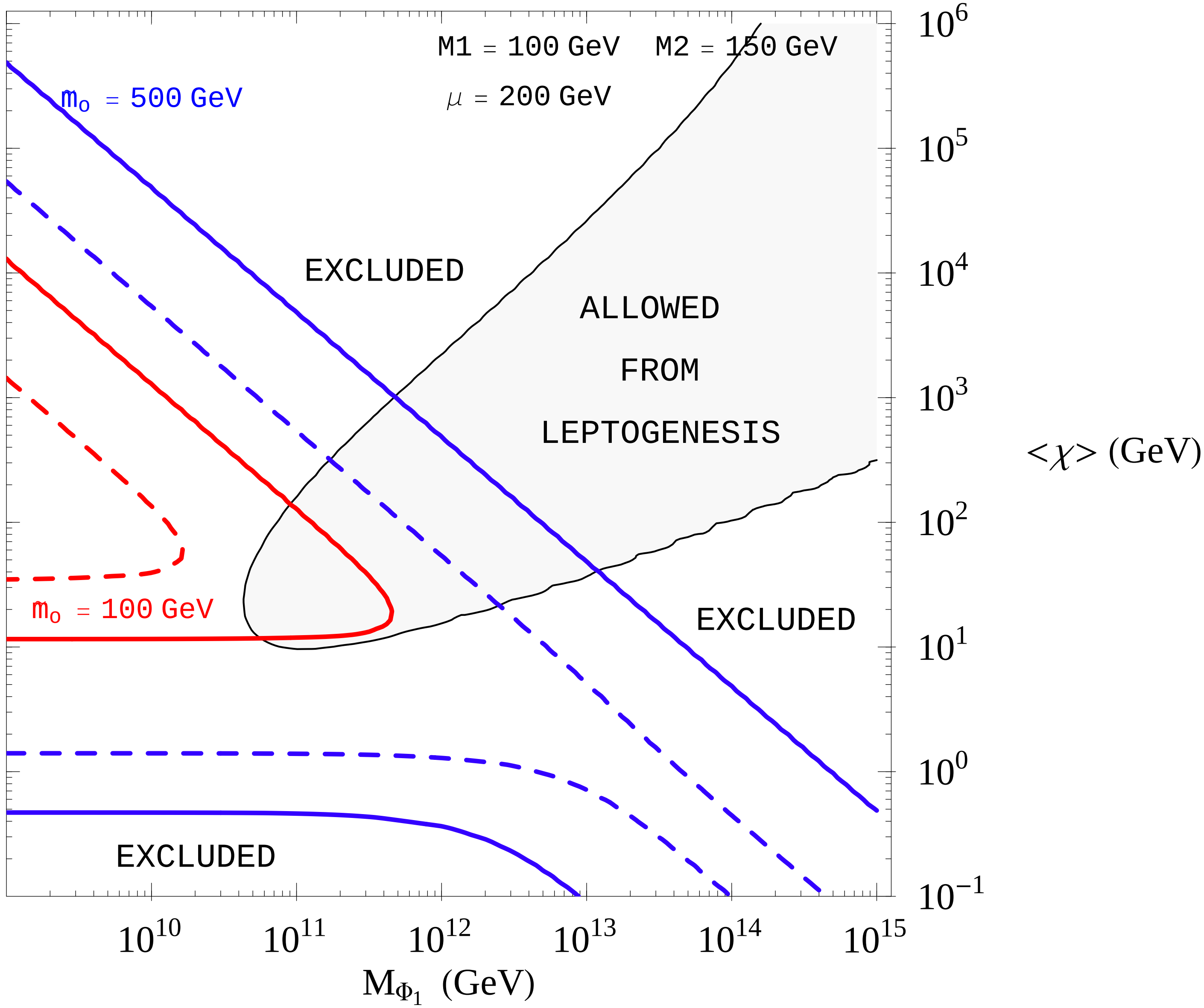
Parametric Dependance of Off-Diagonal Mass Terms

Contour of constant $Br(\mu \to e\gamma)$ in the $(M_{\phi_1}$-$\langle\chi\rangle)$ plane

- $\delta M^2_{LL} \propto f^2\langle\chi\rangle^2 \propto M_{\phi_1}\langle\chi\rangle \Longrightarrow \log\langle\chi\rangle = -\log M_{\phi_1} + C_1$
- $\delta M^2_{LN_R} \propto \dfrac{f^2}{M_{\phi_1}} \propto \dfrac{1}{\langle\chi\rangle} \Longrightarrow \log\langle\chi\rangle = C_2$
- $\dfrac{(\delta M^2_{LN_R})^2}{M^2_{N_R N_R}} \propto \dfrac{f^2}{M^2_{\phi_1}} \propto \dfrac{1}{M_{\phi_1}\langle\chi\rangle} \Longrightarrow \log\langle\chi\rangle = -\log M_{\phi_1} + C_3$



m̃o = 300 GeV
M2 = 150 GeV
M1 = 100 GeV
μ = 200 GeV
Br (μ -> eγ) = 1.2 * 10^-11
= 1.5 * 10^-13
EXCLUDED
ALLOWED
FROM
LEPTOGENESIS
ALLOWED
FROM
LFV
EXCLUDED
EXCLUDED
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
<χ> (GeV)
10^10
10^11
10^12
10^13
10^14
10^15
M_Φ1 (GeV)



M1 = 100 GeV   M2 = 150 GeV
μ = 200 GeV
m_o = 500 GeV
m_o = 100 GeV
EXCLUDED
ALLOWED
FROM
LEPTOGENESIS
EXCLUDED
EXCLUDED
10^10
10^11
10^12
10^13
10^14
10^15
M_Φ1 (GeV)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
<χ> (GeV)

Conclusions

- Dirac Leptogenesis is an interesting alternative to Majorana Leptogenesis-SeeSaw mechanism
- Neutrinos are DIRAC (no neutrinoless double beta decay)
- In a simple scenario, we linked successful Leptogenesis to neutrino data, and added bounds from LFV signals induced by the scenario's flavor structure.

Future directions:

It is known that mixing among Left and Right sneutrinos is also a key ingredient to obtain:

- a good sneutrino Dark Matter candidate..
- invisible Higgs decay into sneutrinos..