Lepton Flavor Violation and SUSY Dark Matter

Azar Mustafayev

in collaboration with V.Barger and D.Marfatia PLB'08 and PRD'09

Dark Matter and mSUGRA

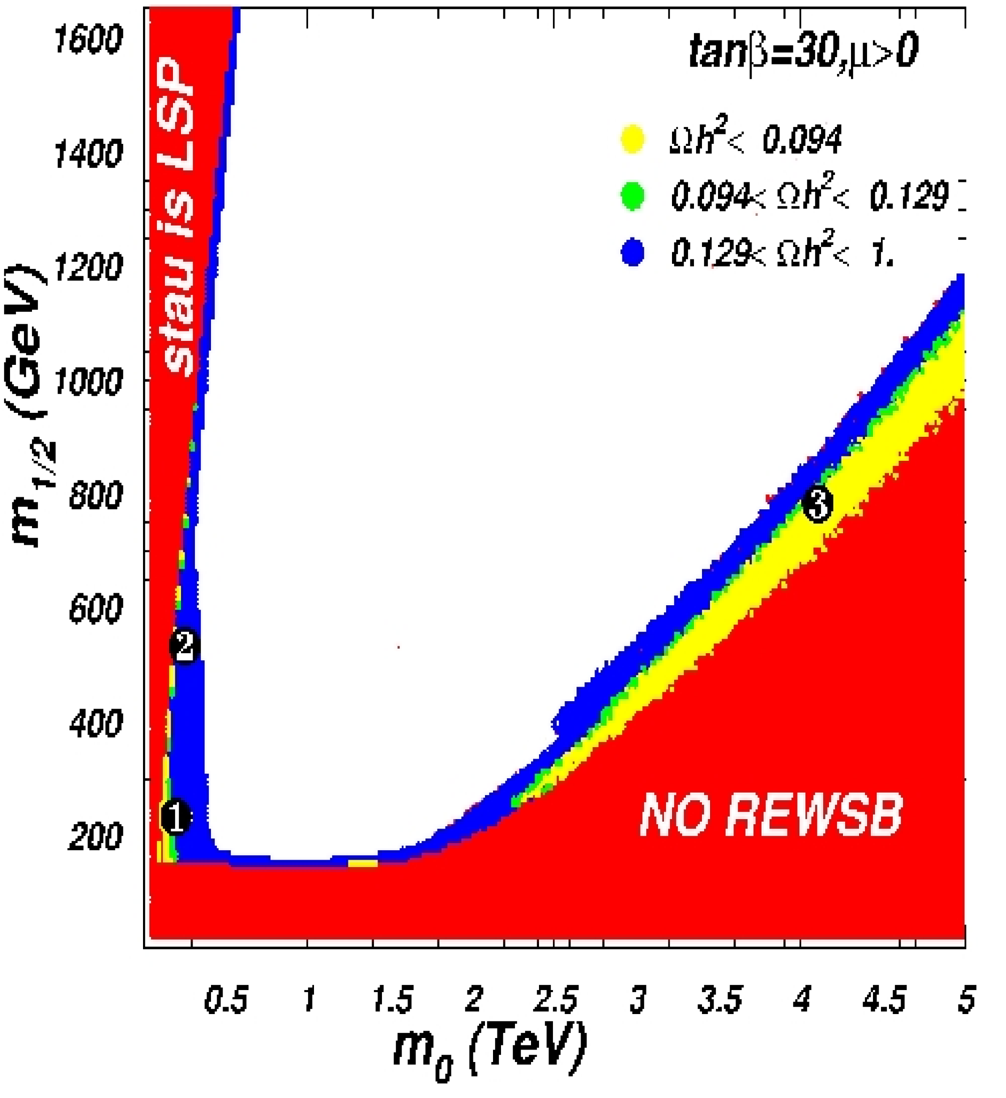
- WMAP measured relic density

$$\Omega_{CDM}h^2 = 0.1120^{+0.0074}_{-0.0076}$$

- Lightest neutralino $\widetilde{Z}_1$ is good DM candidate
- Most of para space ruled out due to too high RD $\Omega_{\widetilde{Z}_1}h^2 \gg 0.1$
- mSUGRA para space:

$$m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ sign(\mu)$$

- Several narrow RD-allowed regions in mSUGRA
  ⇨ SPS benchmark points



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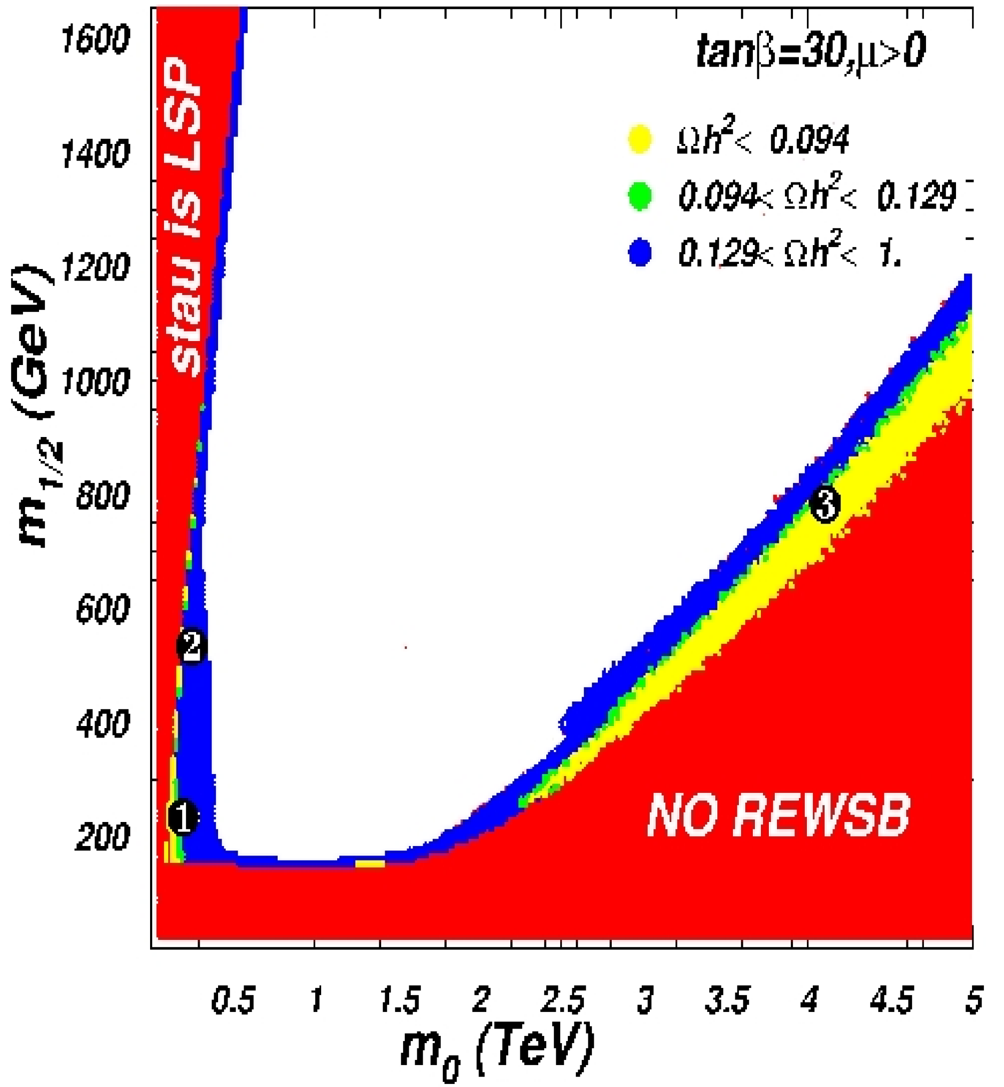
  → SPS benchmark points
- **Neutrinos are massless!**



SUSY seesaw

- Observed neutrino oscillations ⟶ massive neutrinos
- Mass scale $\sum m_\nu \lesssim 1\ eV$
- Seesaw mechanism (type-I):

$$\mathcal{M}_\nu = -\mathbf{f}_\nu M_N^{-1} \mathbf{f}_\nu{}^T v_u^2$$

- Right-handed neutrino masses $M_N \sim (10^{10} - 10^{16})\ GeV$

- Neutrino Yukawas from *SO(10)*
  - $\mathbf{f}_\nu = \mathbf{f}_u$ if higgses in **10**
  - $\mathbf{f}_\nu = 3\mathbf{f}_u$ if higgses in **126**

- **Common approach:**
  SPS points + RHNs ⟶ LFV predictions in RD-allowed regions

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RGE analysis

- Neutrino Yukawas appear in RGEs above seesaw scale

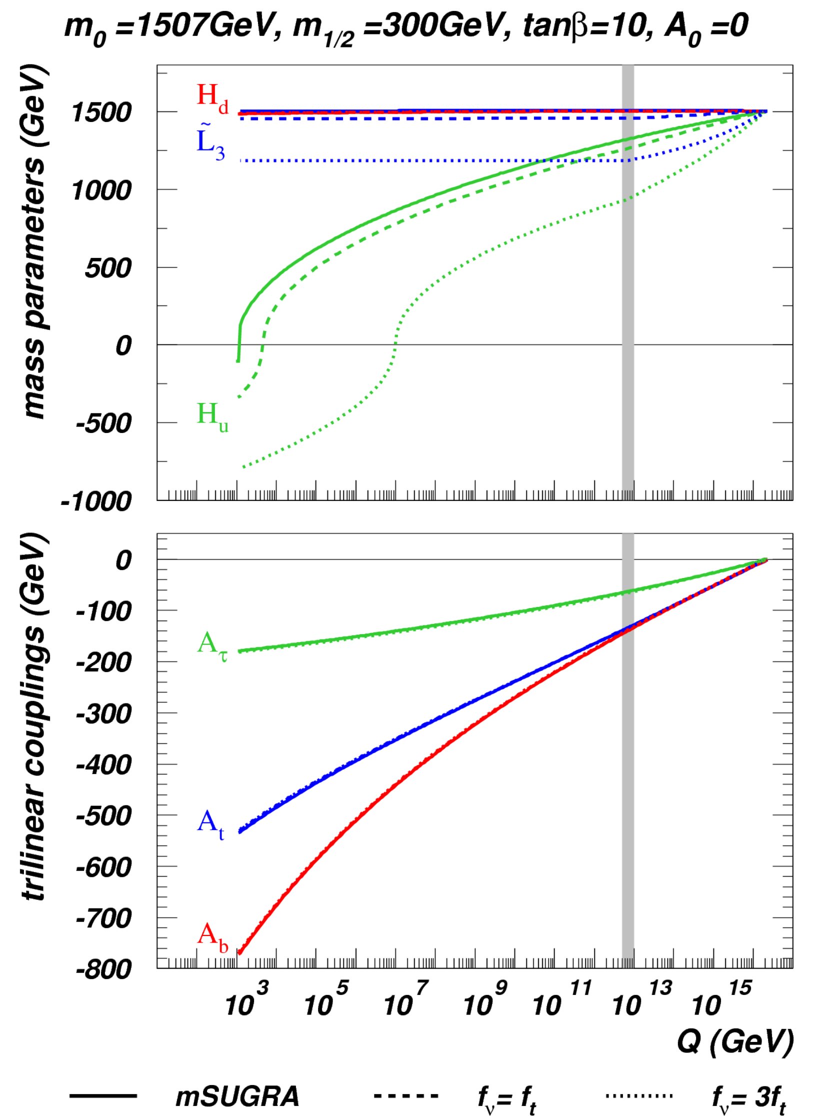
$$\frac{dm^2_{L_3}}{dt} \propto f_\tau^2 X_\tau + f_\nu^2 X_\nu$$

$$\frac{dm^2_{H_u}}{dt} \propto 3f_t^2 X_t + f_\nu^2 X_\nu$$

$$\frac{dA_\tau}{dt} \propto 3f_b^2 A_b + f_\nu^2 A_\nu$$

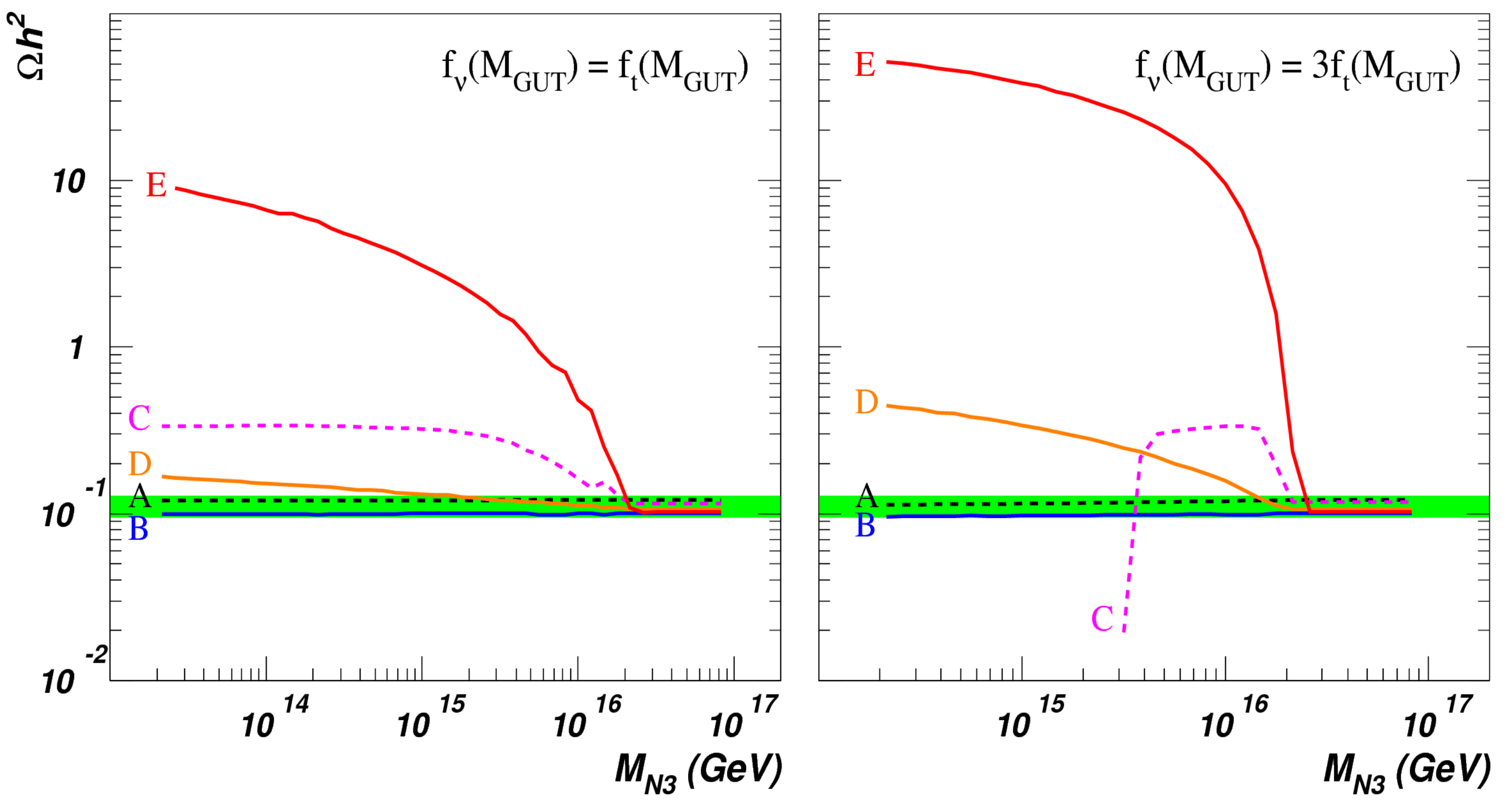
$$\frac{dA_t}{dt} \propto 3f_t^2 A_t + f_\nu^2 A_\nu$$

- EWSB: $\mu^2 \simeq -m^2_{H_u}$
- *CP*-odd Higgs mass $m^2_A \simeq m^2_{H_d} - m^2_{H_u}$
- $m^2_{L_3}$ ⟶ stau masses
- *A*-terms ⟶ L-R sfermion mixing



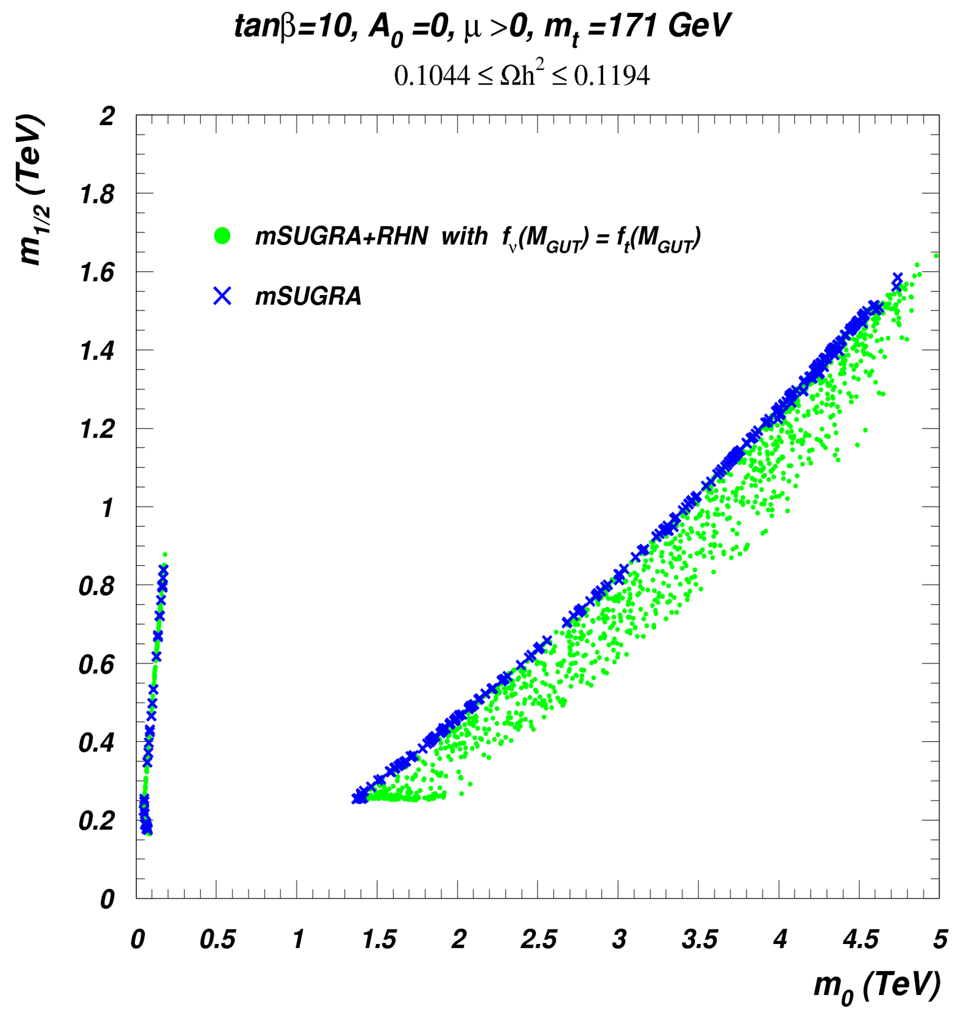
RHN effect on RD

- mSUGRA+RHN model parameters: $m_0,\ m_{1/2},\ A_0, \tan\beta,\ sign(\mu),\ M_{N3}$
- Benchmark points:
  A=bulk, B=stau co-annih., C=stop co-annih., D=Higgs funnel, E=HB/FP
- New co-annihilation with $\tilde{\nu}_\tau$ in case C



RD in mSUGRA+RHN

- Random scan in $(m_0, m_{1/2}, M_{N3})$
- Neutrino Yukawa effects can be compensated by SSB parameters ⇒ shifts of RD-allowed regions
- Expect effects on DM rates and/or collider signatures and LFV rates



LFV in mSUGRA-seesaw

- Radiative lepton decay (in mass-insertion approx.)

$$BR(l_i \to l_j \gamma) \propto \frac{\alpha^3}{G_F^2 m_s^8} \left|(m_L^2)_{i\neq j}\right|^2 \tan^2\beta$$

- Induced by neutrino Yukawa

$$(m_L^2)_{i\neq j} \simeq -\frac{1}{8\pi^2}(3m_0^2 + A_0^2) \sum_k (\mathbf{f}_\nu^T)_{ik} (\mathbf{f}_\nu^*)_{kj} \log \frac{M_{GUT}}{M_{N_k}}$$

- Sensitive to SSB values

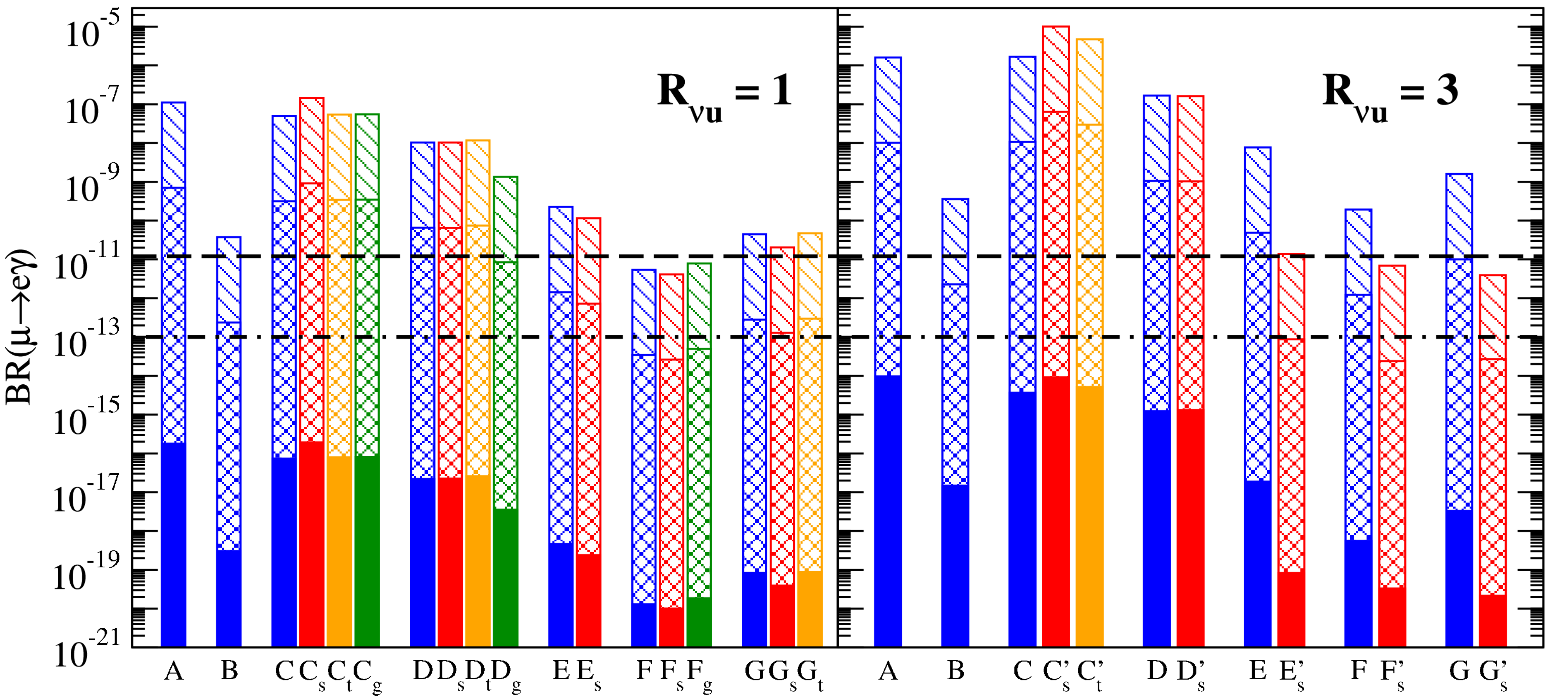
$$m_s^8 \simeq 0.5 m_0^2 m_{1/2}^2 \left(m_0^2 + 0.6 m_{1/2}^2\right)^2$$

- Similar expressions for $l_i \to 3l_j$ decays and $\mu \to e$ conversion in Nuclei
- Consider two extremal cases for each unification $(R_{\nu u} = 1,\ 3)$
  - Small mixing $\mathbf{f}_\nu = R_{\nu u} \mathbf{f}_u$
  - Large mixing $\mathbf{f}_\nu = R_{\nu u} \mathbf{V}_{TBM} \mathbf{f}_u^{diag}$

Large mixing case

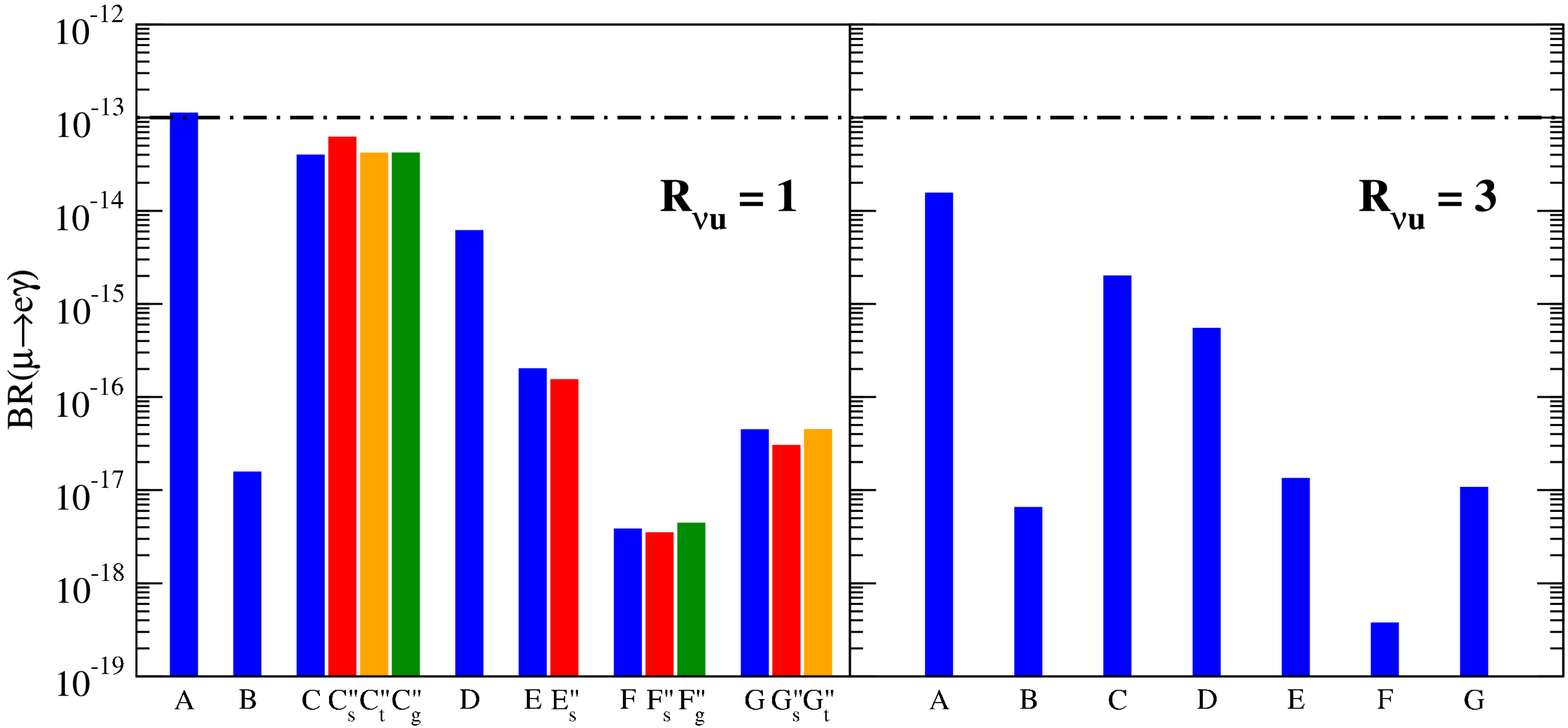
Correct RD by adjusting one parameter:

● $= m_0$ ● $= A_0$ ● $= m_{1/2}$



- Rates change from factor a few up to about order of magnitude

Small mixing case



- Completely untouched by current experimental bounds
- Larger yukawa produces order of magnitude *smaller* rates!

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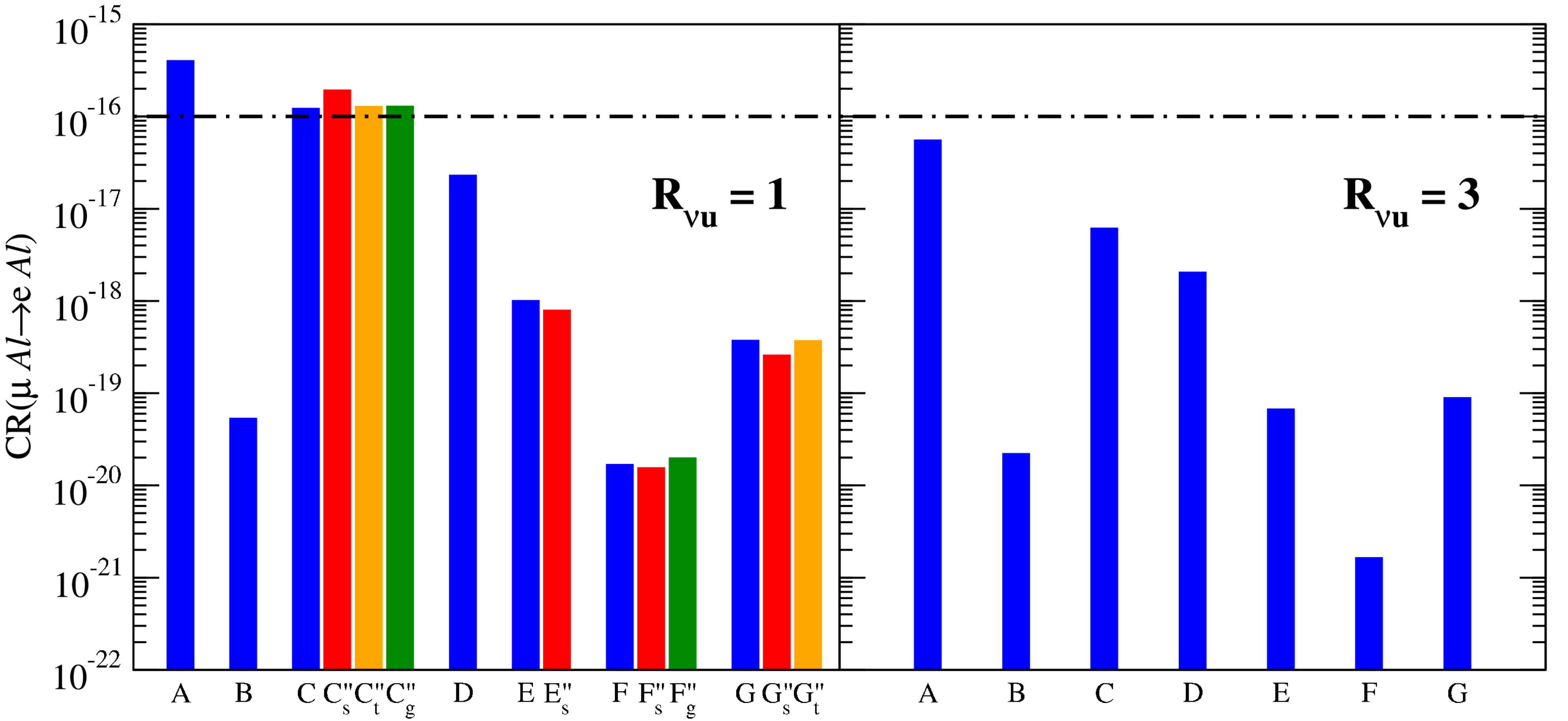

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- Only Mu2e (or PRIME) will be able to test

Summary

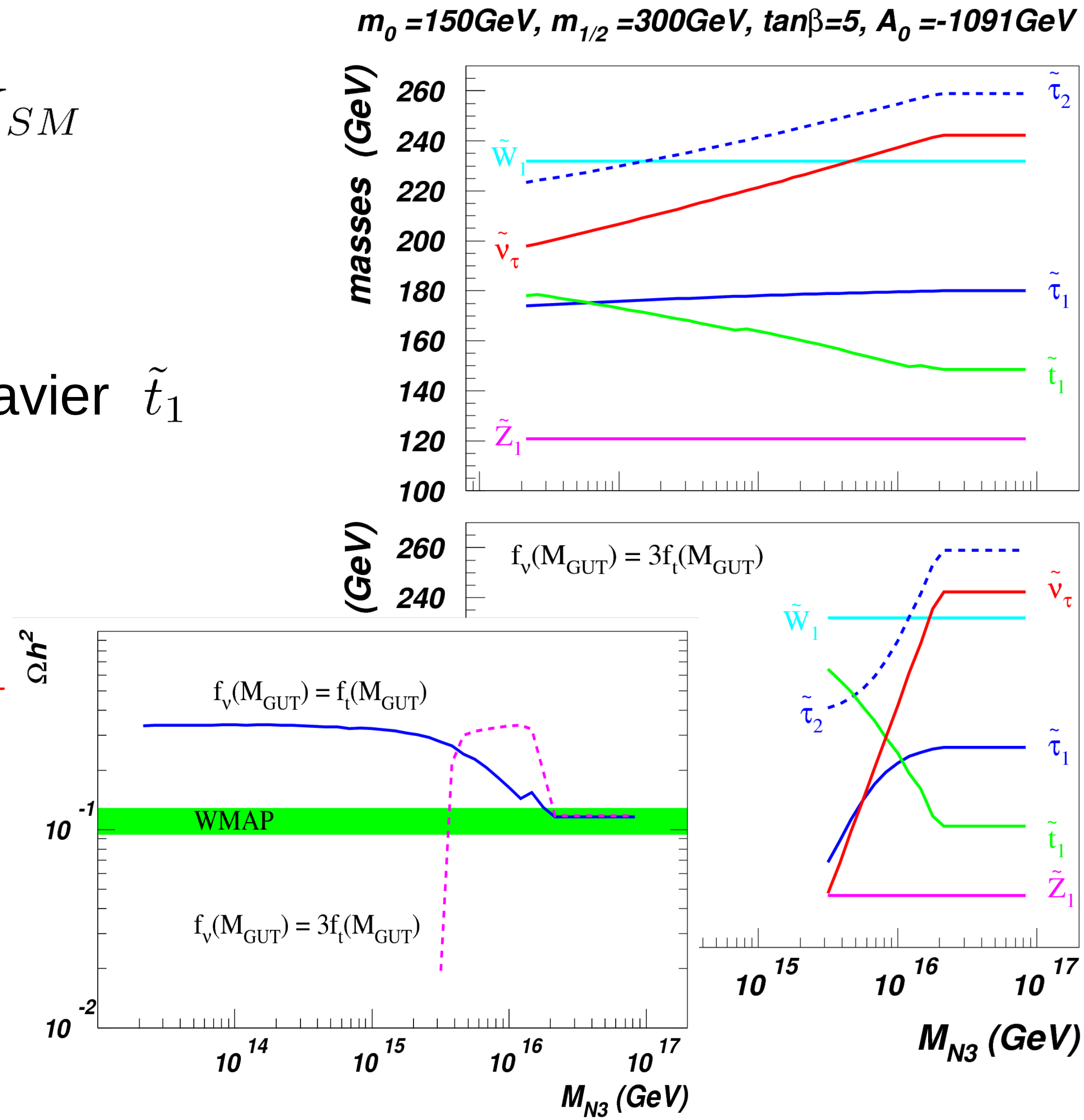
- Neutrino Yukawa coupling can significantly affect neutralino DM
- Most prominent when SSB slepton mass and/or trilinears large
  - Stop coannihilation, *A*-funnel and HB/FP regions of mSUGRA
- Effects in stau coannihilation and the bulk are small *only* because in mSUGRA $\tilde{\tau}_1 \simeq \tilde{\tau}_R$
- Neutrino-neutralino interplay can change LFV predictions

  for $R_{\nu u} = 1$ by factor ~5
- Large unification parameter $R_{\nu u} = 3$ is not excluded by LFVs and for small mixing produce order of magnitude *smaller* rates
  → need Mu2e to probe

Backup slides

Stop coannihilation

- Small $m_0, m_{1/2}$ and large A_0
- Light $\tilde{t}_1 \implies$ rapid $\widetilde{Z}_1 \tilde{t}_1 \to X_{SM}$
- RHN effects:
  - lighter $\tilde{\nu}_\tau,\ \tilde{\tau}_2 \simeq \tilde{\tau}_L$
  - smaller L-R mixing ⟶ heavier $\tilde{t}_1$
  - $\tilde{\tau}_1$ becomes $\tilde{\tau}_L$
- Coannih. with $\tilde{t}_1$ closes
- New coannih. channel with $\tilde{\nu}_\tau$



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- Positron, muon and gamma rates are up by 100-150% (300-700%)