Gravitino Dark Matter with Sneutrino NLSP in NUHM

Yudi Santoso

yudi.santoso@durham.ac.uk

Institute for Particle Physics Phenomenology
Department of Physics, University of Durham, U.K.

This talk is based on work in collaboration with John Ellis and Keith Olive.

Intro: Gravitino Dark Matter

- Gravitino is one candidate for dark matter in supergravity models.
- Gravitino is a very weakly interacting particle, with coupling $\sim 1/M_{\rm Pl}$.
  - Practically undetectable. (Except for its gravitational effect.)
  - The next lightest supersymmetric particle (NLSP) could be long lived.
- We have many possibilities for the NLSP: neutralino, stau, stop, sneutrino, ... Each with its own distinct phenomena.
- This talk: left-sneutrino NLSP, assuming conserved R-parity.

Phenomenological Constraints
for Gravitino Dark Matter

- Primordial light element abundances - BBN.
- Direct detection of the other sparticles at colliders.
- Astrophysical constraints: CMB spectrum, cosmic rays flux.

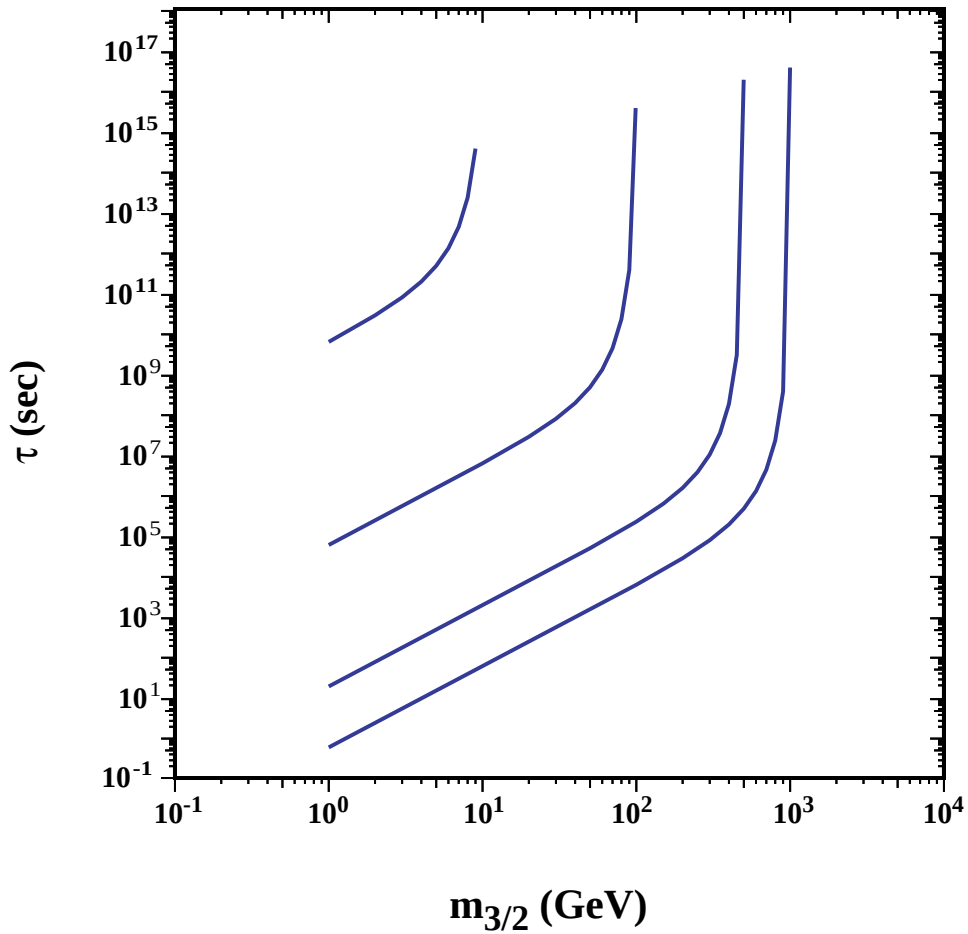
BBN Constraints

- BBN: light elements produced by nucleosynthesis in the early universe as the universe expands and cools down.
- Decay of a metastable particle during or after the BBN time can alter the light element abundances through the participation of the energetic products in the nucleosynthesis processes.
  - Electromagnetic.
  - Hadronic.
- For sneutrino NLSP these effects are small because sneutrino is neutral.

Sneutrino Decay and Lifetime

$$\widetilde{\nu} \rightarrow \widetilde{G} + \nu$$

$$\Gamma_{2b} = \frac{1}{48\pi} \frac{m_{\tilde{\nu}}^5}{M_{\rm Pl}^2 m_{3/2}^2} \left(1 - \frac{m_{3/2}^2}{m_{\tilde{\nu}}^2}\right)^4$$



- 3-body decays: $\widetilde{\nu} \to \widetilde{G} + \nu + (\gamma, Z)$, $\widetilde{\nu} \to \widetilde{G} + \ell + W$
- 4-body decays: $\widetilde{\nu} \to \widetilde{G} + \nu + f + \bar{f}$, $\widetilde{\nu} \to \widetilde{G} + \ell + f + \bar{f}'$

These give hadronic shower. We can use the 3-b $\widetilde{\nu} \to \widetilde{G} + \nu + \gamma$ to gauge the maximum strength of hadronic BR.

Sneutrino and BBN

- Effect of sneutrino decays on BBN:
  - Energy transfer (elastic/inelastic) from energetic neutrino to background particles.
  - EM and hadronic effect from 3- and 4-body decays.
- Kanzaki etal (PRD **76** (2007) 105017): The hadronic effect is important, the constraint depends on hadronic BR B_h. It is safe if the sneutrino density before decay is

$$Y_{\tilde{\nu}} M_{\tilde{\nu}} \lesssim \mathcal{O}(10^{-11}) \text{ GeV for } B_h = 10^{-3}$$

$$Y_{\tilde{\nu}} M_{\tilde{\nu}} \lesssim \mathcal{O}(10^{-8}) \text{ GeV for } B_h = 10^{-6}$$

($M_{\tilde{\nu}} \sim O(100 \text{ GeV})$)

Relic Density

- Gravitino Dark Matter relic density:

$$\Omega_{\tilde{G}} h^2 = \frac{m_{3/2}}{m_{\tilde{\nu}}} \Omega_{\tilde{\nu}} h^2 + \Omega_{\tilde{G}}^{\mathrm{T}} h^2$$

- Sneutrino density before decay - freeze out density calculated by the usual method of solving the Boltzmann equation in expanding universe.
- The yield, $Y_{\tilde{\nu}} = n_{\tilde{\nu}}/s$,

$$Y_{\tilde{\nu}} M_{\tilde{\nu}} = \Omega_{\tilde{\nu}} h^2 \times (3.65 \times 10^{-9}\ \mathrm{GeV})$$

The NUHM Model

Non-universal Higgs Masses Model

- As in CMSSM we have universal gaugino mass $m_{1/2}$, sfermion mass m_0, and trilinear coupling A_0, at the GUT scale.
- However, the Higgs masses $m_{1,2}$ are not equal to m_0,
- We can trade $m_{1,2}$ with μ and m_A as our free parameters through the electroweak symmetry breaking condition.
- Thus the NUHM parameters are: $m_{1/2}, m_0, A_0, \tan\beta, \mu$ and m_A.
- Note: gravitino mass, $m_{3/2}$, is another free parameter.

Sneutrino NLSP Realization

The MSSM RGE:

$$\frac{dm^2_{\widetilde{L}_L}}{dt} = \frac{1}{8\pi^2}(-3g_2^2M_2^2 - g_1^2M_1^2 - 2S)$$

$$\frac{dm^2_{\widetilde{e}_R}}{dt} = \frac{1}{8\pi^2}(-4g_1^2M_1^2 + 4S)$$

$$\frac{dm^2_{\widetilde{L}_{3L}}}{dt} = \frac{1}{8\pi^2}(-3g_2^2M_2^2 - g_1^2M_1^2 + h_\tau^2(m^2_{\widetilde{L}_{3L}} + m^2_{\widetilde{\tau}_R} + m_1^2 + A_\tau^2) - 2S)$$

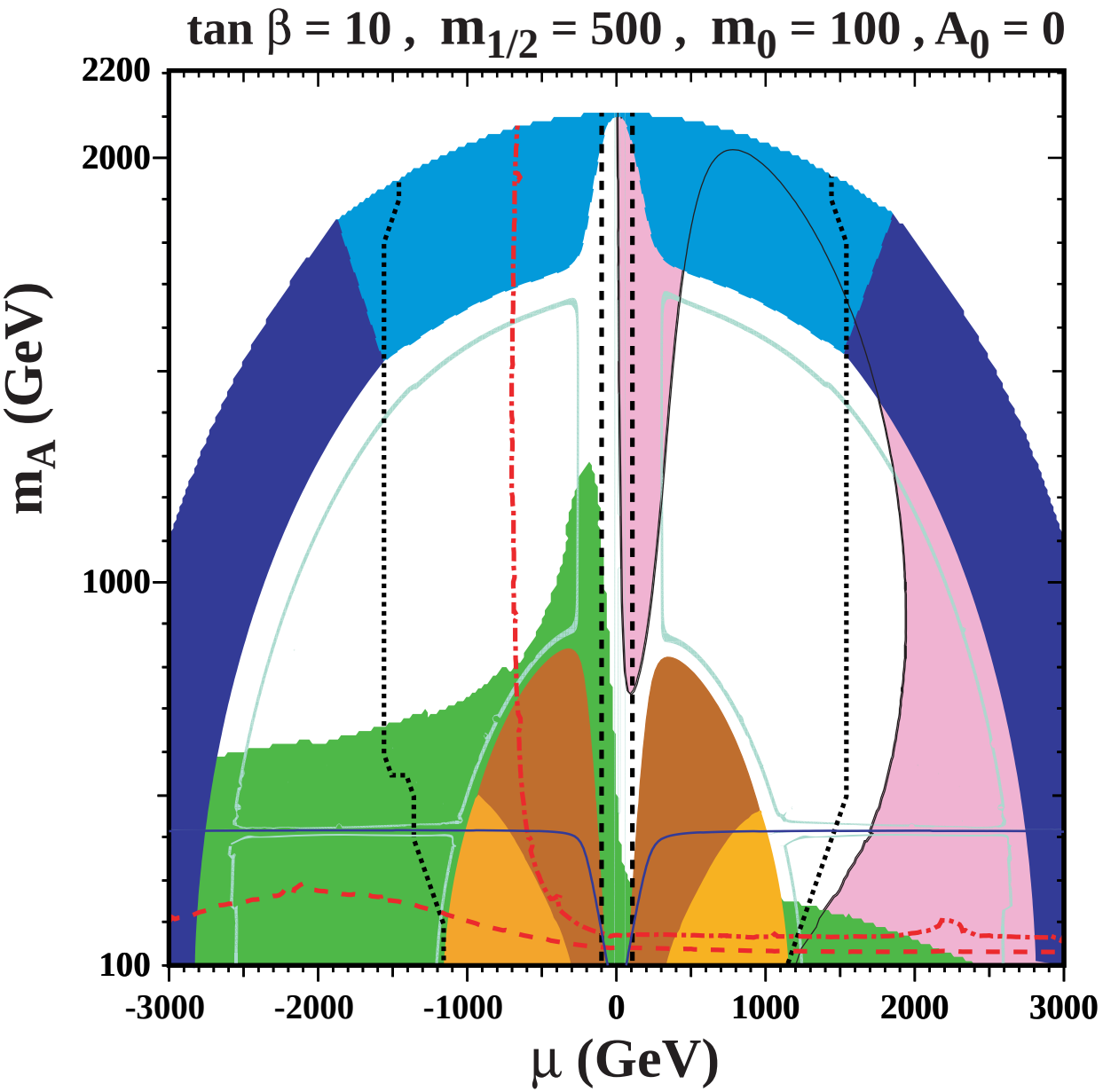
$$\frac{dm^2_{\widetilde{\tau}_R}}{dt} = \frac{1}{8\pi^2}(-4g_1^2M_1^2 + 2h_\tau^2(m^2_{\widetilde{L}_{3L}} + m^2_{\widetilde{\tau}_R} + m_1^2 + A_\tau^2) + 4S)$$

The S term:

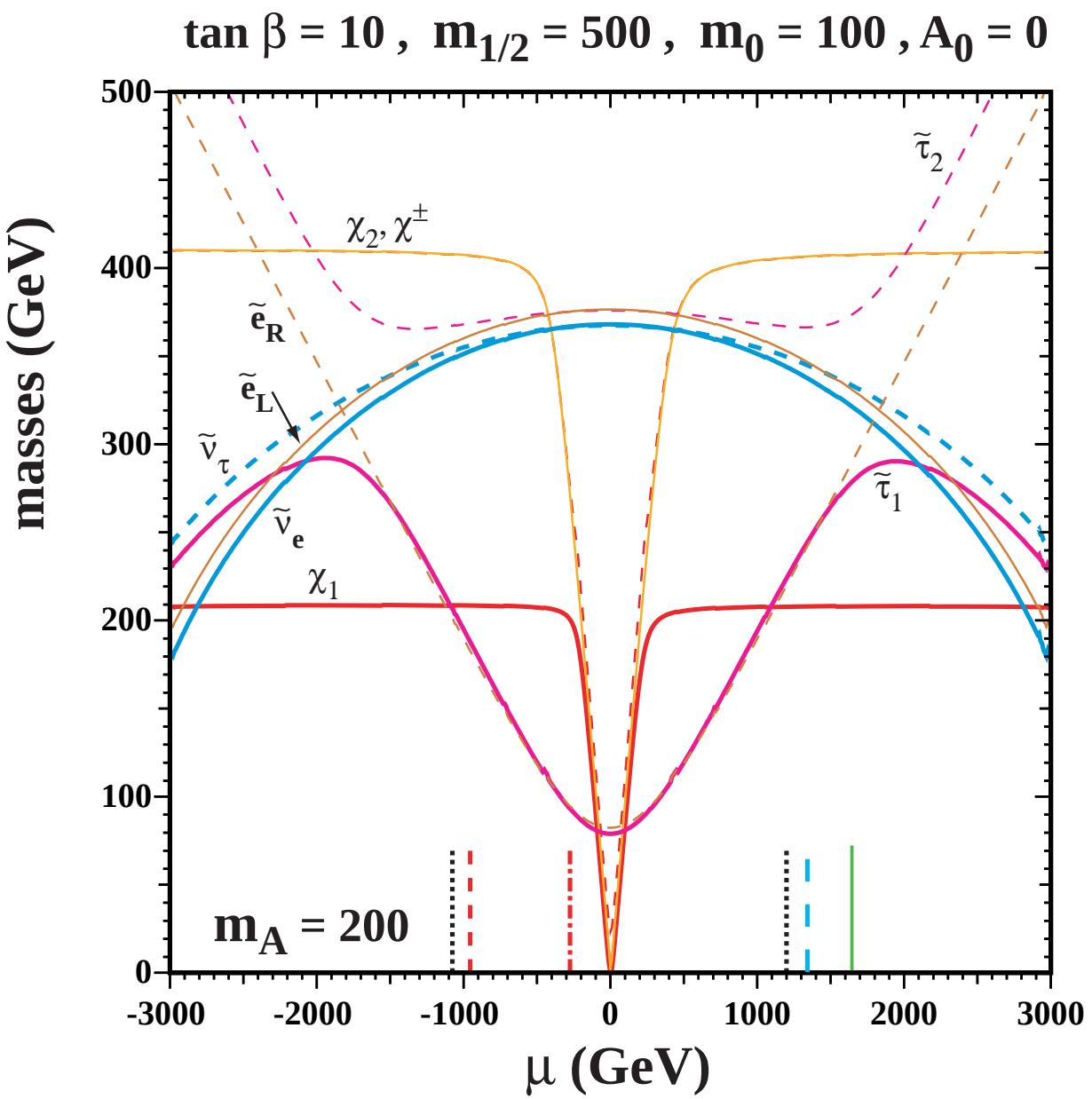
$$S \equiv \frac{g_1^2}{4}(m_2^2 - m_1^2 + 2(m_{\widetilde{Q}_L}^2 - m_{\widetilde{L}_L}^2 - 2m_{\widetilde{u}_R}^2 + m_{\widetilde{d}_R}^2 + m_{\widetilde{e}_R}^2) + (m_{\widetilde{Q}_{3L}}^2 - m_{\widetilde{L}_{3L}}^2 - 2m_{\widetilde{t}_R}^2 + m_{\widetilde{b}_R}^2 + m_{\widetilde{\tau}_R}^2))$$

- If S is negative and large sneutrino can be the NLSP.
- In NUHM $m_{1,2} \neq m_0$.

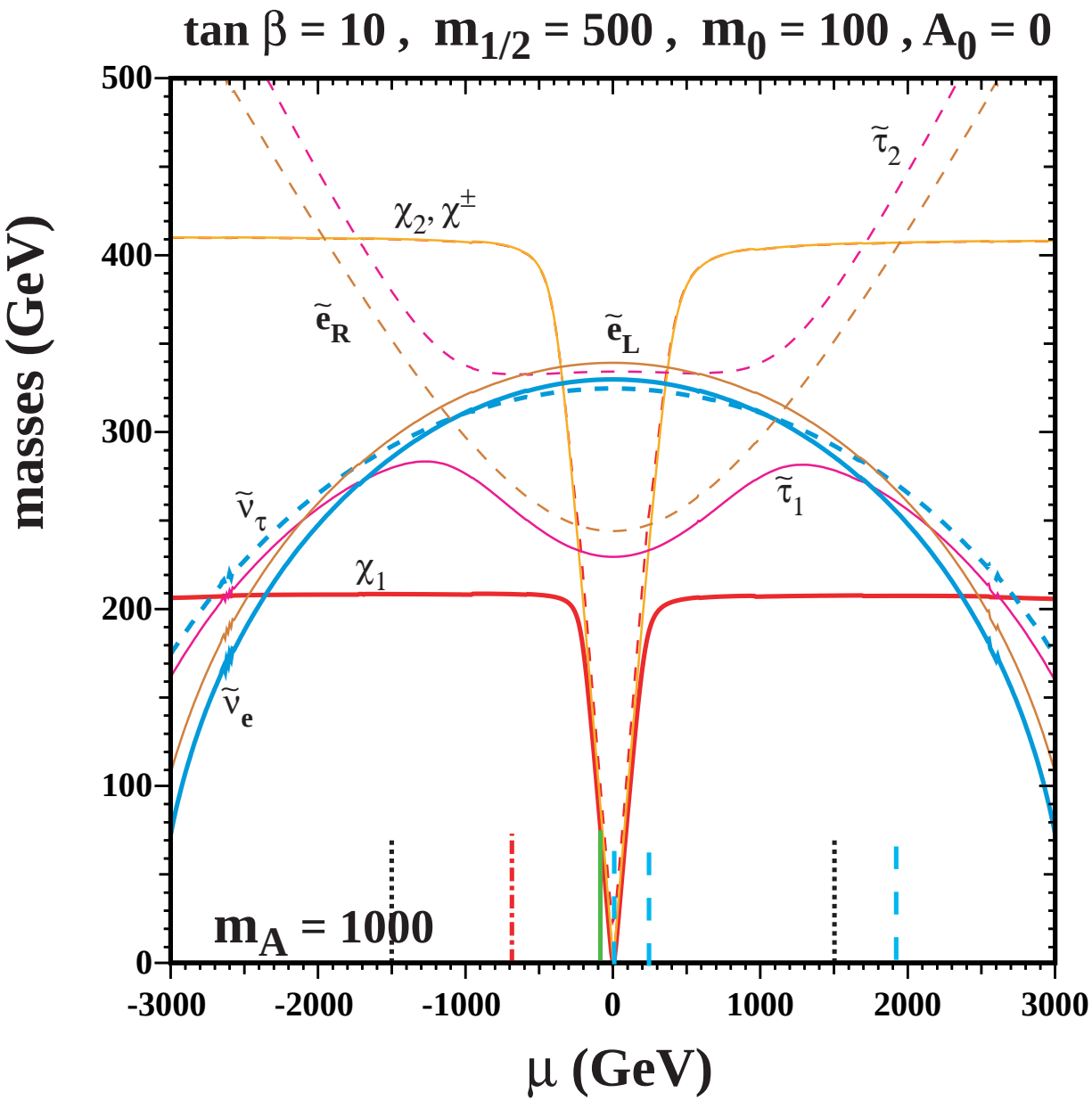
Sneutrino in NUHM



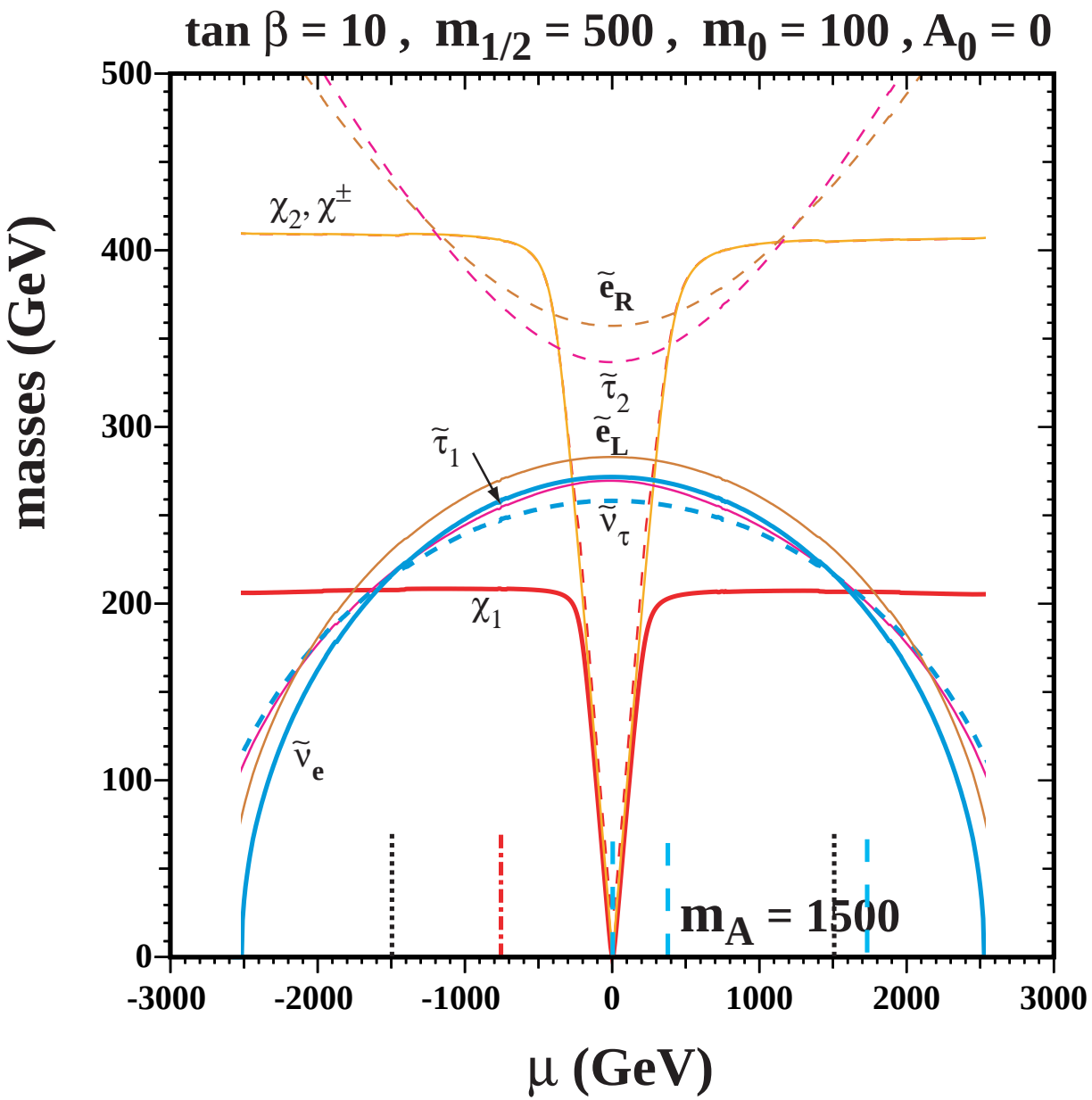
NUHM Spectrum



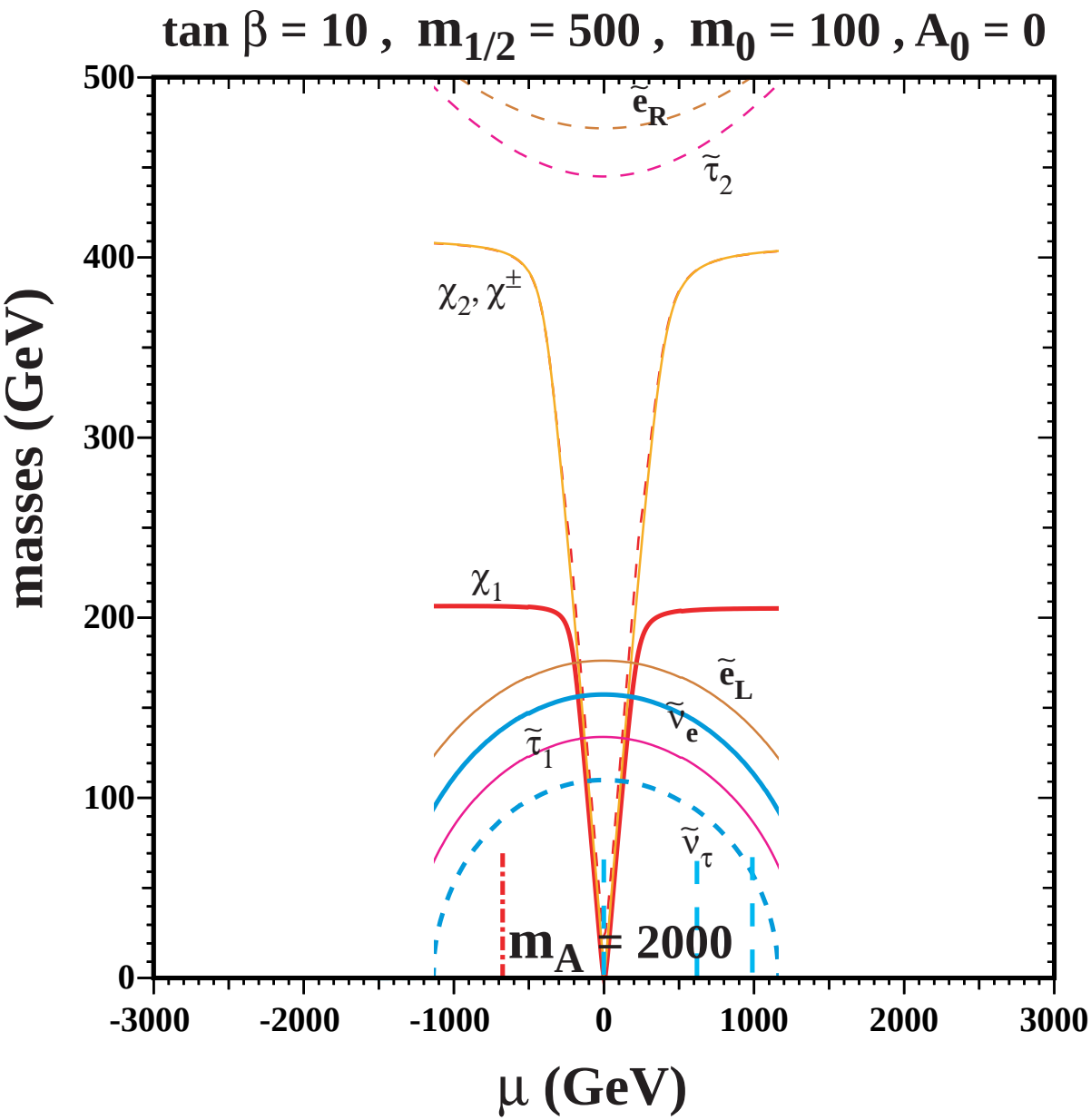
NUHM Spectrum



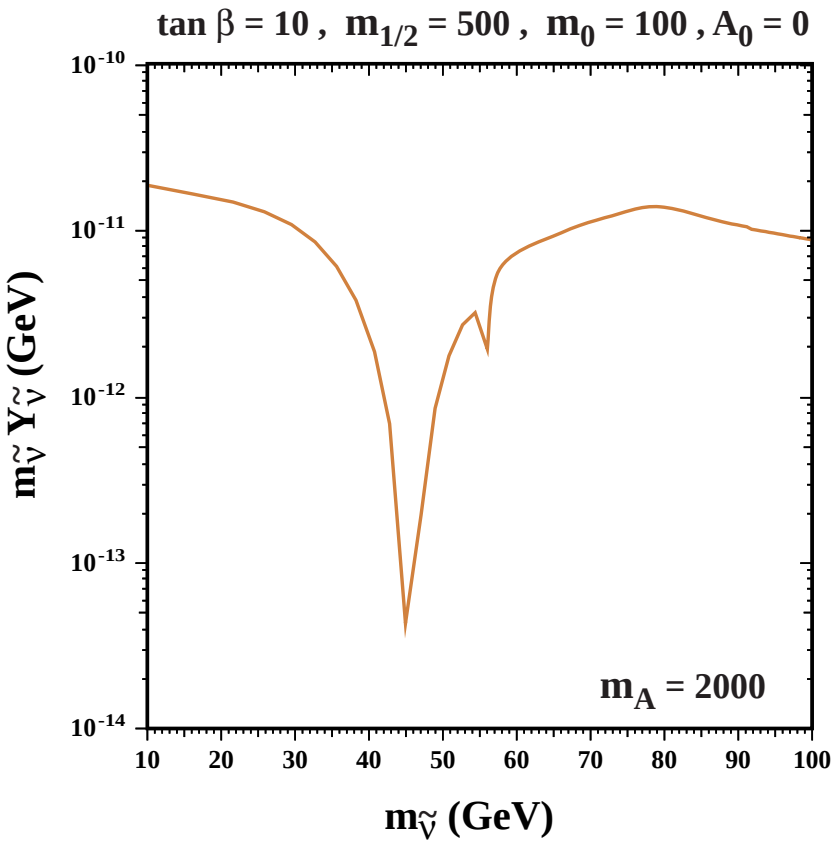
NUHM Spectrum

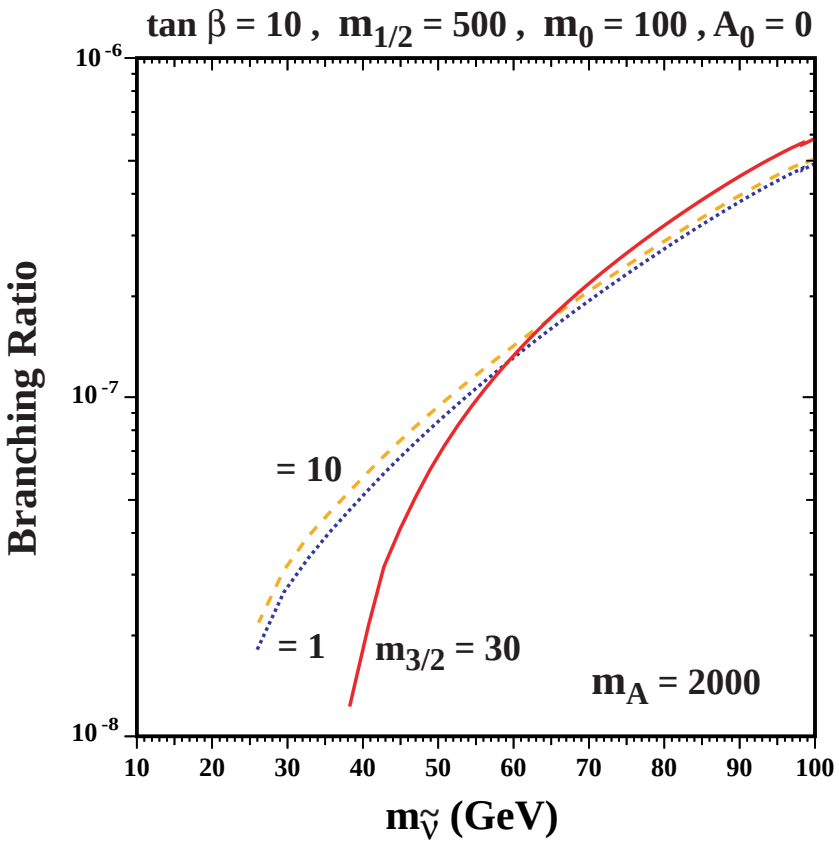


NUHM Spectrum



Sneutrino 'Relic' Density





Concluding Remarks

- Gravitino is a feasible and interesting candidate for dark matter.
- There are many possible phenomenology with gravitino dark matter depending on the NLSP.
- Sneutrino is one possible NLSP that can be realized within the NUHM model.