Neutrino-Flavoured Sneutrino Dark Matter

Christopher McCabe

UNIVERSITY OF OXFORD

In collaboration with John March-Russell and Matthew McCullough

JHEP 1003:108,2010 (arXiv:0911.4489)

Science & Technology Facilities Council

4th UniverseNet School. 13th September 2010

Motivation

- SUSY with R-parity has many nice features
  - Solves the hierarchy problem
  - Precision gauge coupling unification
  - Natural dark matter candidate
- Is the MSSM enough?
  - No explanation for neutrino masses
  - Can there be interesting structure in the dark sector (c.f. our sector)?
  - Is the neutralino the only good dark matter candidate?
- Can simple extensions to the MSSM answer some of these questions and still give a natural dark matter candidate?

Extending the MSSM...

hep-ph/0403067 March-Russell & West

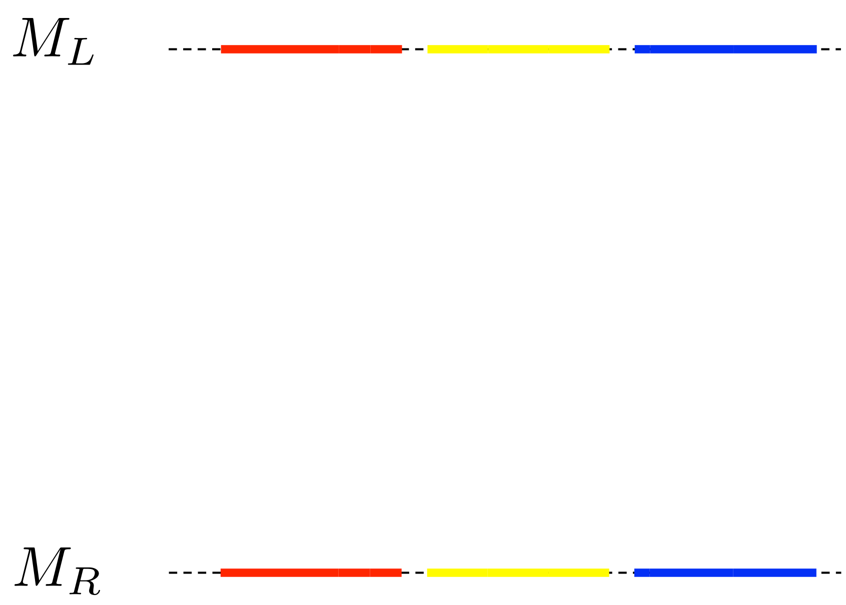
- Add 3 right-handed neutrinos N and their super-partners $\tilde{n}$

$$\Delta\mathcal{L} = \int d^2\theta \left(\lambda_{ij} L_i N_j H_u + \frac{1}{2} M_N N_i N_i \right)$$
$$+ m_{\tilde{n}}^2 \, |\tilde{n}_i|^2 + A \, \tilde{L}_i \tilde{n}_i h_u + \frac{1}{2} \lambda_{ij} \, M_B^2 \, \tilde{n}_i \tilde{n}_j + h.c.$$

- Important features:
  - Right-handed neutrinos have weak scale masses: $M_N \sim \mathrm{TeV}$
  - Yukawa coupling suppressed: $\lambda_{ij} \sim 10^{-7} - 10^{-8}$
  - A-term weak scale and flavour diagonal: $A \sim \mathrm{TeV}$
  - Small right-handed sneutrino lepton-number violating B-term with flavour structure: $\lambda_{ij} \, M_B^2 \sim (100\mathrm{MeV})^2$
- These terms all arise from higher dimensional operators and are justified with an R-symmetry

The Sneutrino Spectrum

- Initially turn off A and B-terms
- 3 complex right and 3 complex left handed sneutrinos



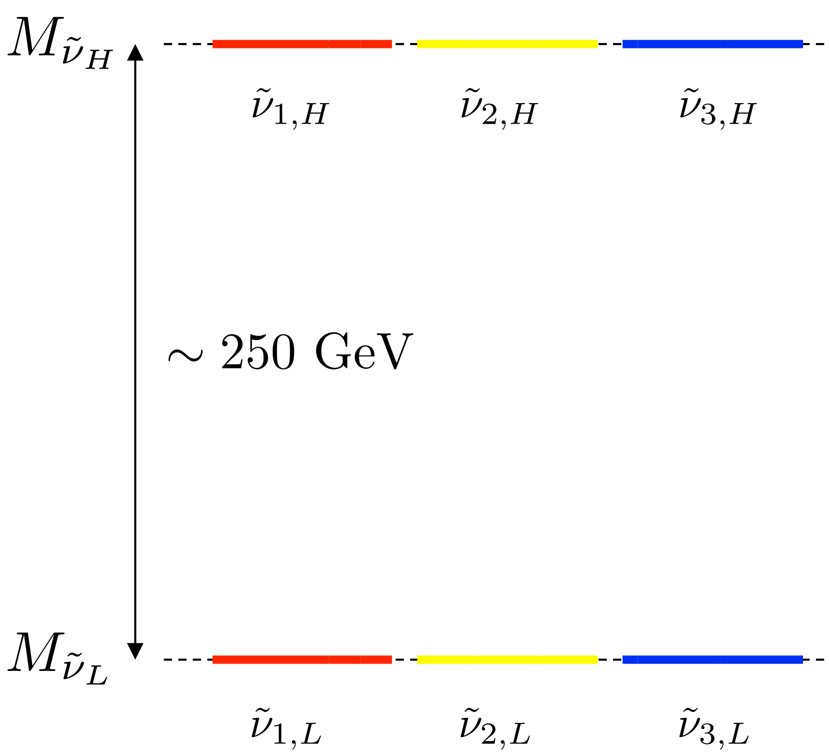
The Sneutrino Spectrum

- Initially turn off A and B-terms
- 3 complex right and 3 complex left handed sneutrinos

- Turn on A
- Mixes left and right sneutrinos

$$\tilde{\nu}_{i,H} = \cos\theta\tilde{\nu} + \sin\theta\tilde{n}$$
$$\tilde{\nu}_{i,L} = -\sin\theta\tilde{\nu} + \cos\theta\tilde{n}$$

$$M^2_{\tilde{\nu}_H} = \frac{M_L^2\cos^2\theta - M_R^2\sin^2\theta}{\cos 2\theta}$$
$$M^2_{\tilde{\nu}_L} = \frac{M_R^2\cos^2\theta - M_L^2\sin^2\theta}{\cos 2\theta}$$
$$\tan 2\theta = \frac{2Av\sin\beta}{M_R^2 - M_L^2}$$



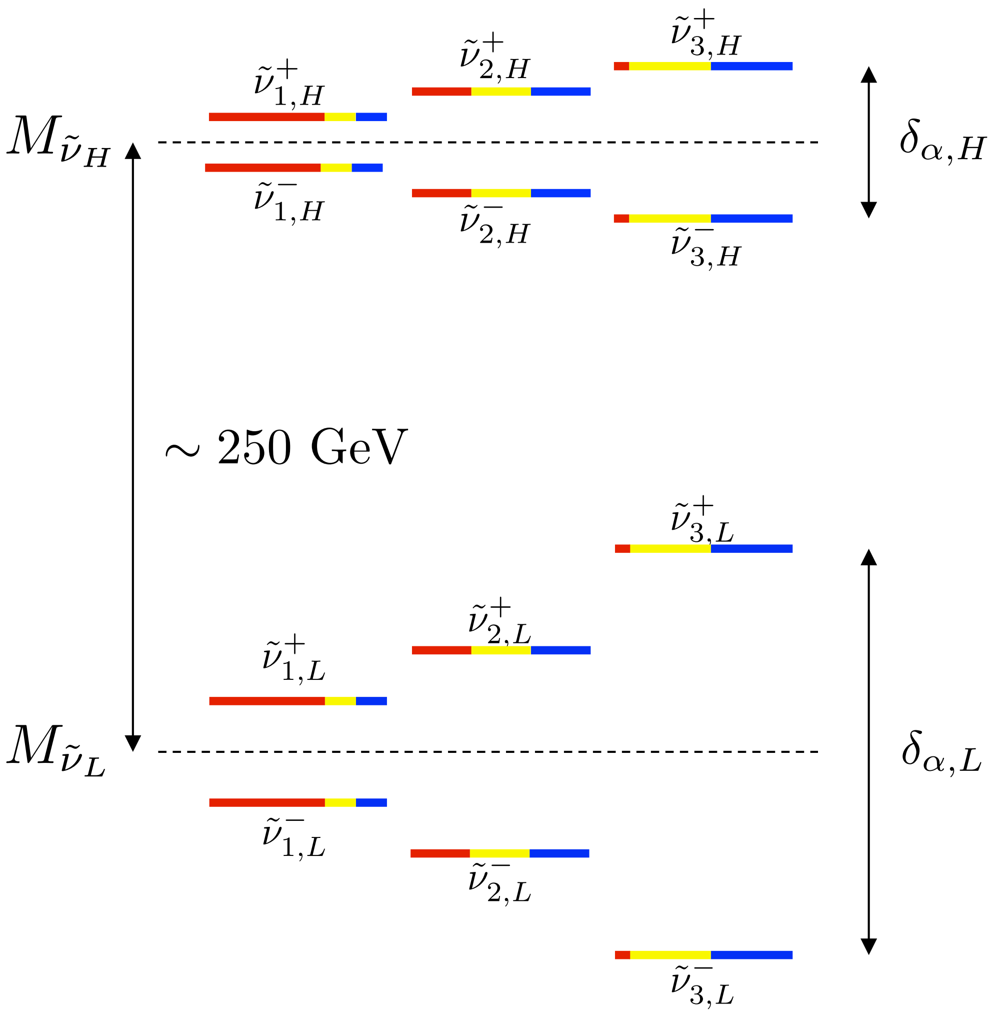
The Sneutrino Spectrum

- Initially turn off A and B-terms
- 3 complex right and 3 complex left handed sneutrinos

- Turn on A
- Mixes left and right sneutrinos

- Turn on B
- Splits spectrum into CP even and CP odd states
- Mixes flavours. Structure determined by: λ_{ij}

$$\delta_{\alpha,H} \sim 10 \text{ keV}$$
$$\delta_{\alpha,L} \sim 100 \text{ keV}$$



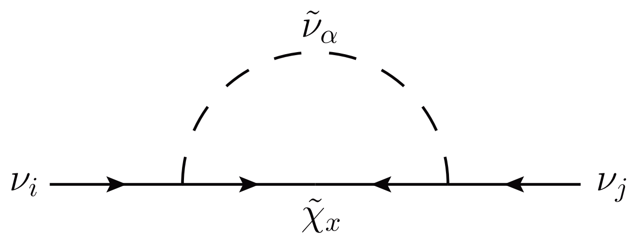
Generating Neutrino Properties...

- Neutrino masses will be generated in two ways
  - See-saw mechanism gives a small contribution:

$$M_{\nu_{ij}} = \frac{v^2 \sin^2\beta}{M_N} \lambda_{ik}\lambda_{kj} \sim 10^{-5}\ \mathrm{eV}$$

    - Recall $\lambda_{ij} \sim 10^{-7} - 10^{-8}$

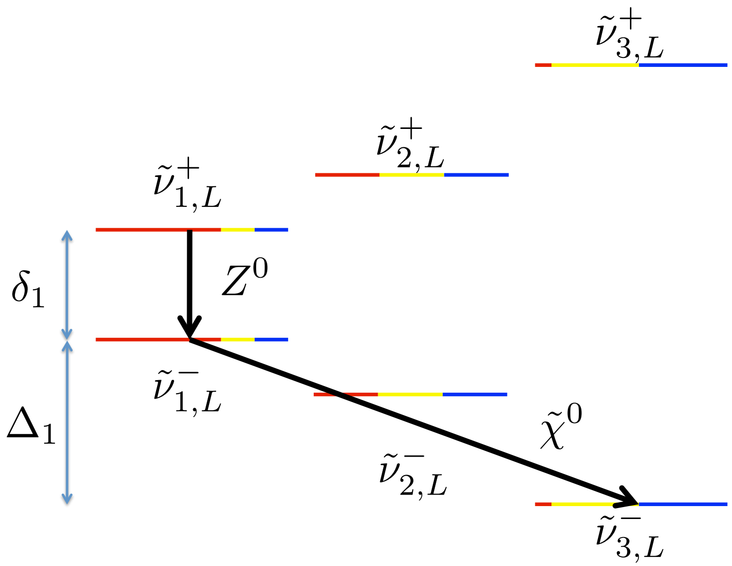
- Dominate contribution from sneutrino-neutralino loop:



$$M_{\nu_{ij}} \sim \lambda_{ij} \times f(M_{\tilde{\chi}^0_x}, M_{\tilde{\nu}_L}, M_{\tilde{\nu}_L}, \theta)$$

  - Notice that flavour structure determined by λ_{ij} . BUT recall that the sneutrino flavour structure is also determined by λ_{ij}
    - ✧ We have neutrino-flavoured sneutrinos!

Lifetimes of the lightest states



- Scalars can decay to pseudoscalars via a Z boson with lifetime:

$$\Gamma_Z^{\tilde{\nu}^+_{1,L}} \sim (9\times 10^4\ \mathrm{yrs})^{-1}\left(\frac{\sin\theta}{0.1}\right)^4\left(\frac{\delta_1}{100\ \mathrm{keV}}\right)^5$$

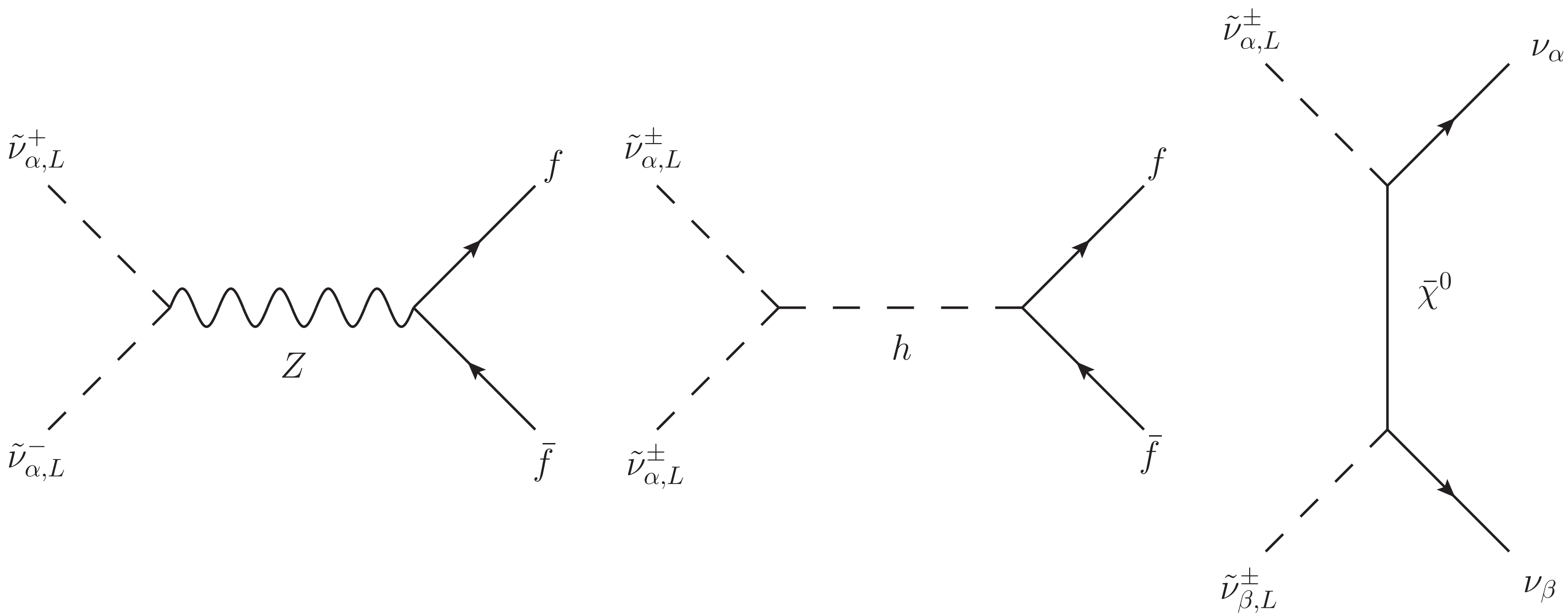
- Pseudoscalars can decay by neutralino exchange with lifetime:

$$\Gamma_\chi^{\tilde{\nu}^-_{1,L}} \sim (10^{10}\ \mathrm{yrs})^{-1}\left(\frac{\chi}{0.22}\right)\left(\frac{\sin\theta}{0.1}\right)^4\left(\frac{\Delta_1}{25\ \mathrm{keV}}\right)^5\left(\frac{100\ \mathrm{GeV}}{m_{\tilde{\nu}}}\right)^2\left(\frac{200\ \mathrm{GeV}}{m_{\chi_1}}\right)^2$$

- Depending on parameters, we can have a dark matter cocktail containing the three lightest pseudoscalars or just the lightest
- For this talk, we'll assume all have decayed to the lightest state

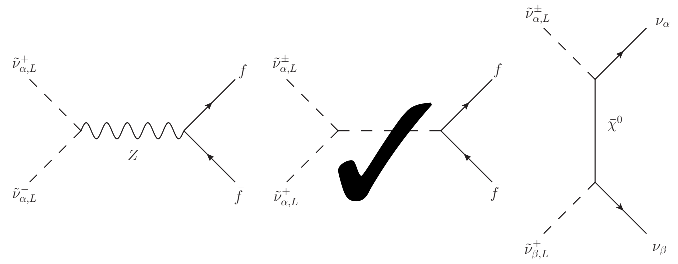
Can Sneutrinos Be The Dark Matter?

- Thermal Relic Density?
  - Main diagrams:

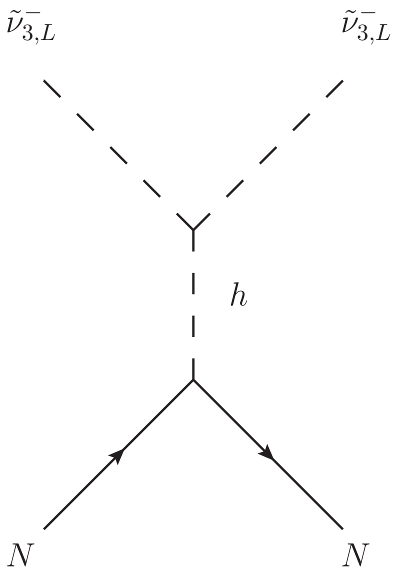


Can Sneutrinos Be The Dark Matter?

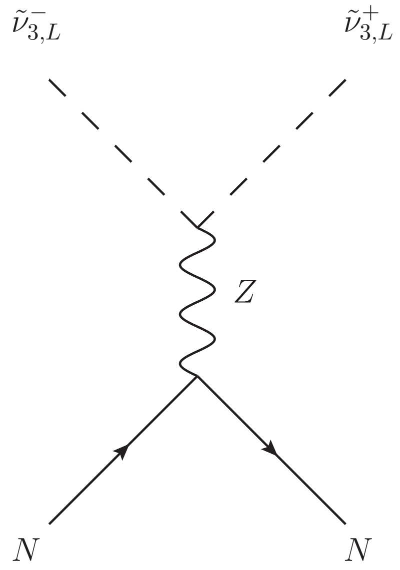
- Thermal Relic Density?
  - Main diagrams:



- Direct detection limits?
  - Elastic scattering

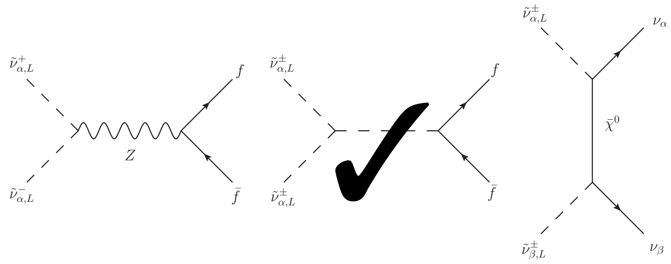


  - Inelastic scattering

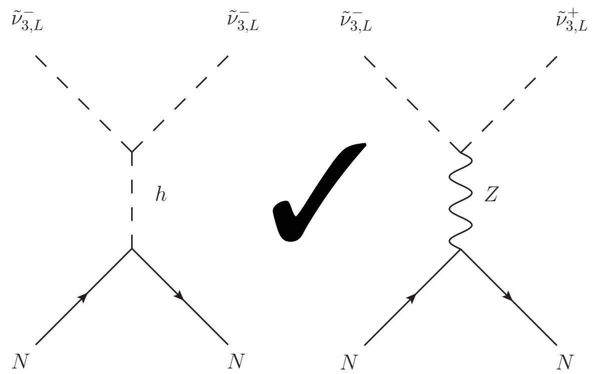


Can Sneutrinos Be The Dark Matter?

- Thermal Relic Density?
  - Main diagrams:



- Direct detection limits?
  - Elastic scattering
  - Inelastic scattering

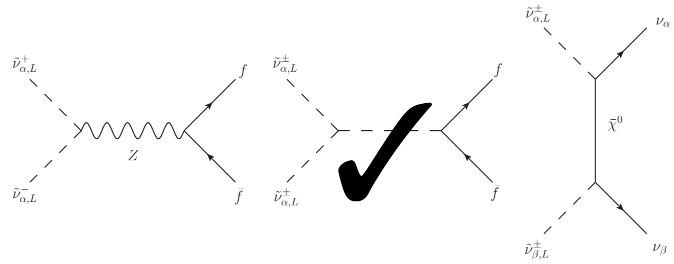


- Indirect detection limits?
  - Dark matter capture in the Sun
  - Limits from the measured neutrino flux at Super-Kamiokande

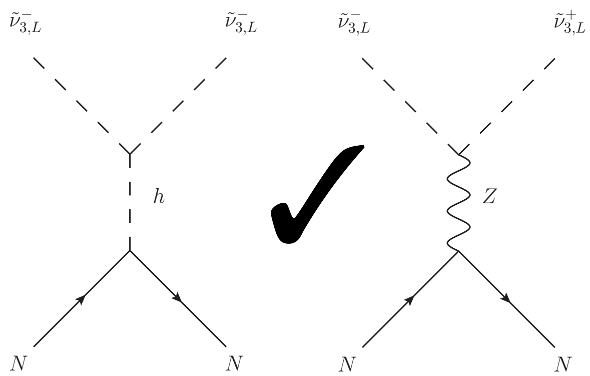
arXiv/0905.1333 Nussinov etal
arXiv/0905.1847 Menon etal

Can Sneutrinos Be The Dark Matter?

- Thermal Relic Density?
  - Main diagrams:



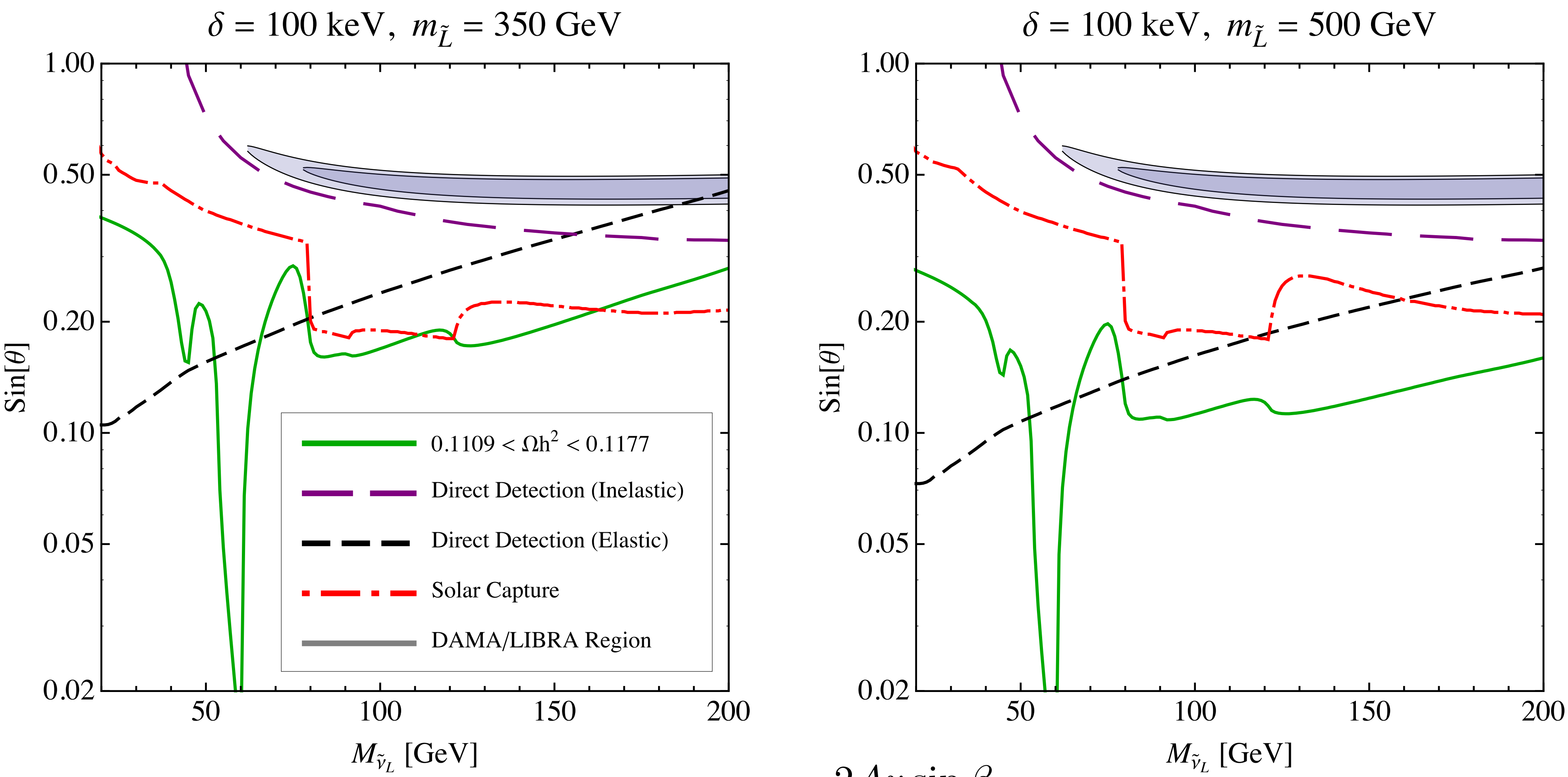
- Direct detection limits?
  - Elastic scattering
  - Inelastic scattering



- Indirect detection limits?
  - Dark matter capture in the Sun
  - Limits from the measured neutrino flux at Super-Kamiokande

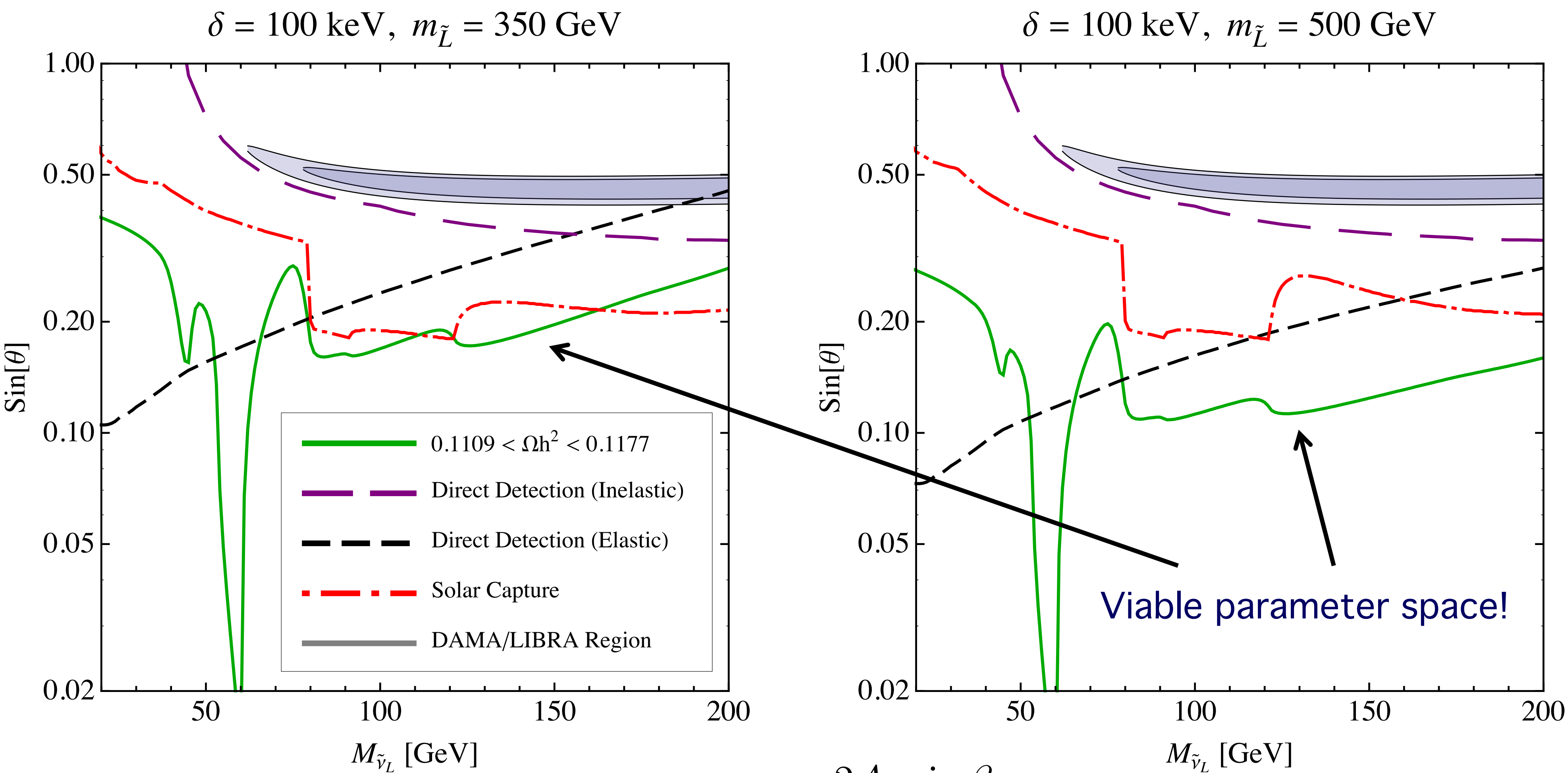
arXiv/0905.1333 Nussinov etal
arXiv/0905.1847 Menon etal

Examples of parameter space I



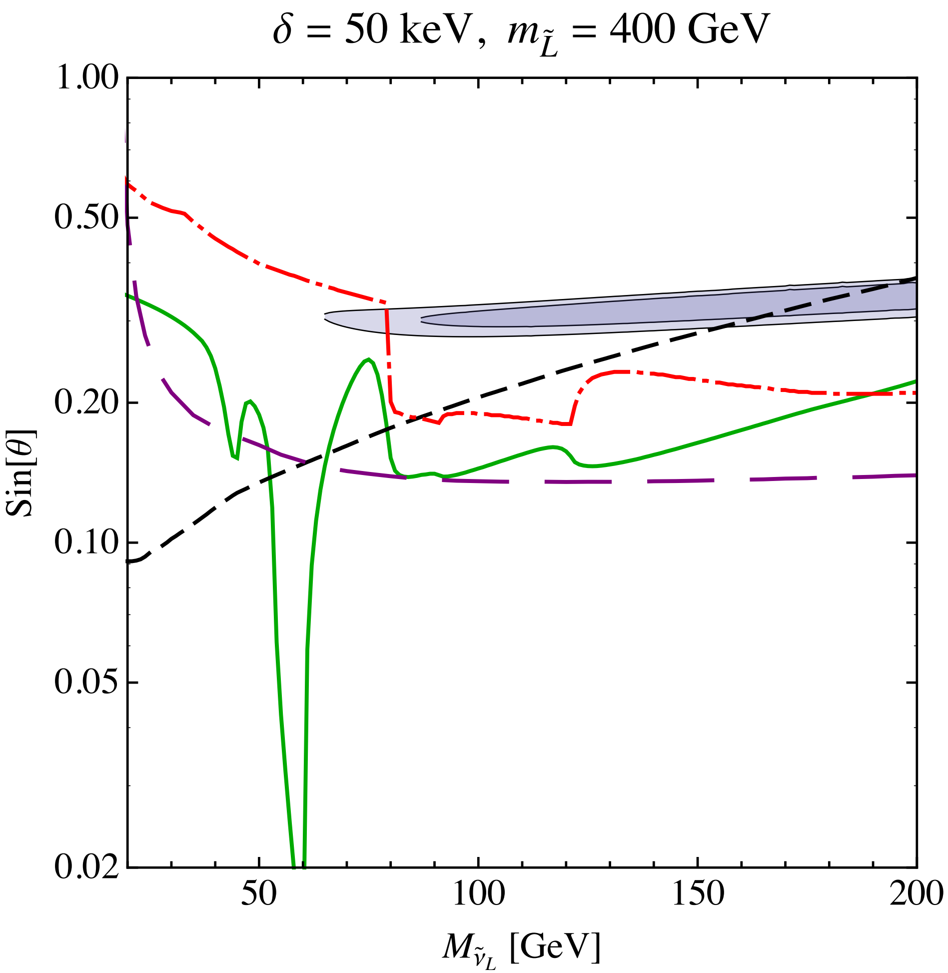
Recall: $$\tan 2\theta = \frac{2Av\sin\beta}{M_R^2 - M_L^2}$$

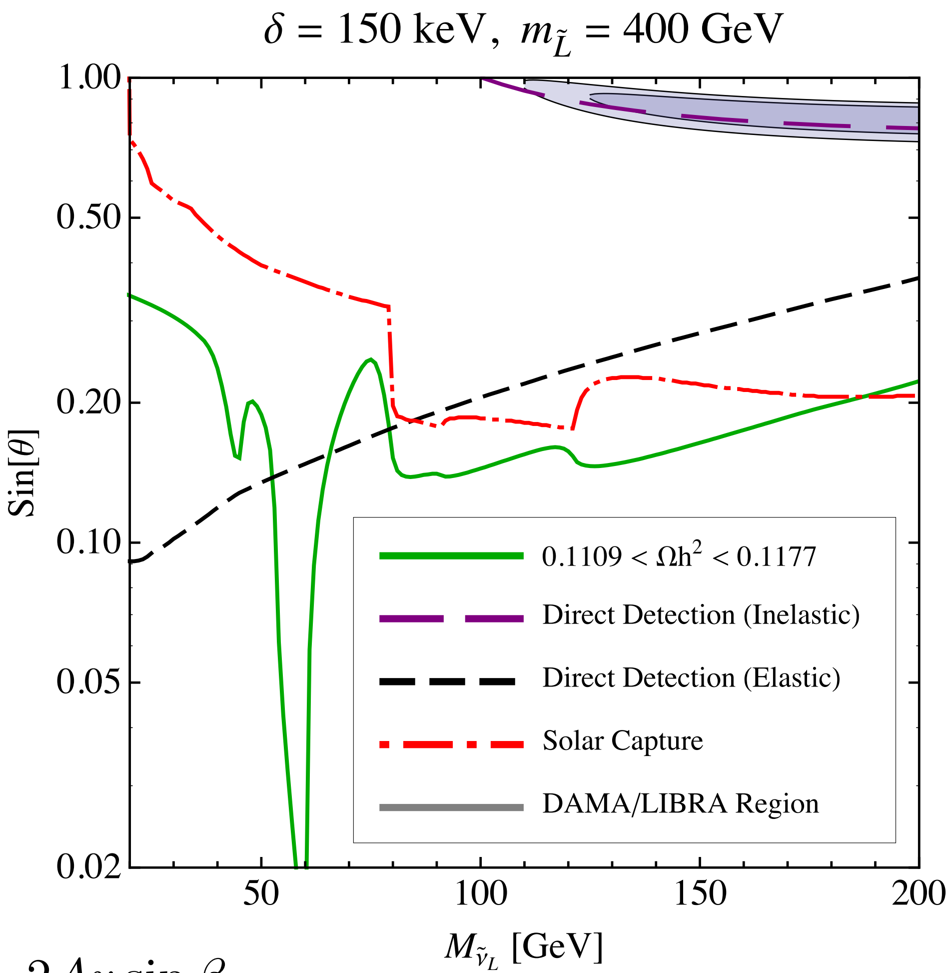
Examples of parameter space I



Recall: $\tan 2\theta = \dfrac{2Av\sin\beta}{M_R^2 - M_L^2}$

Examples of parameter space II

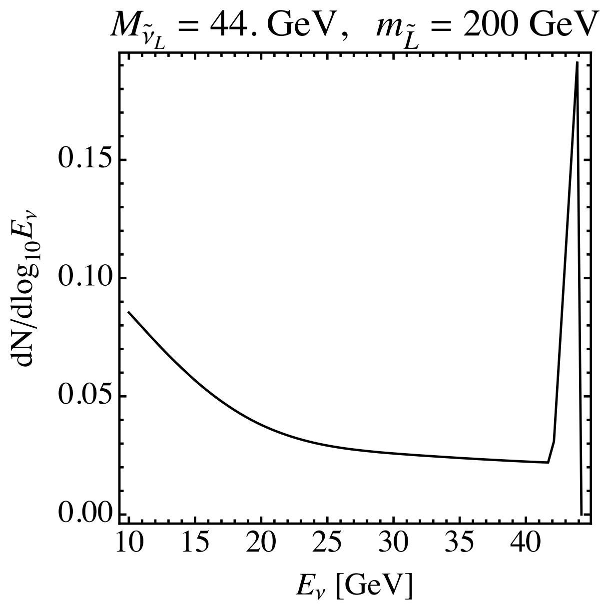


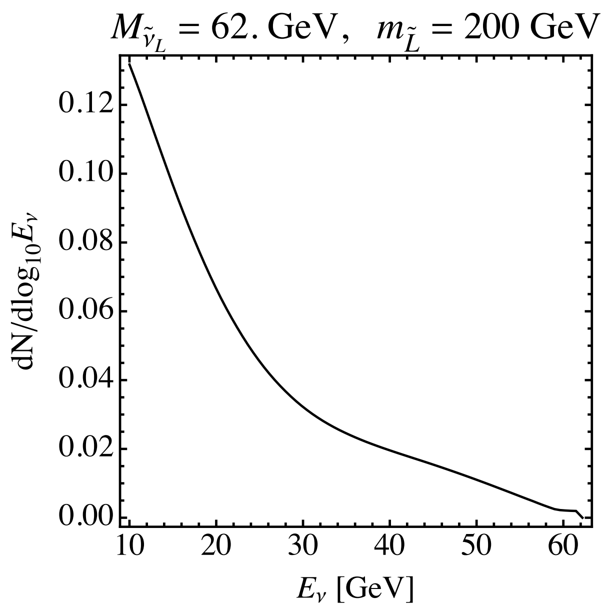


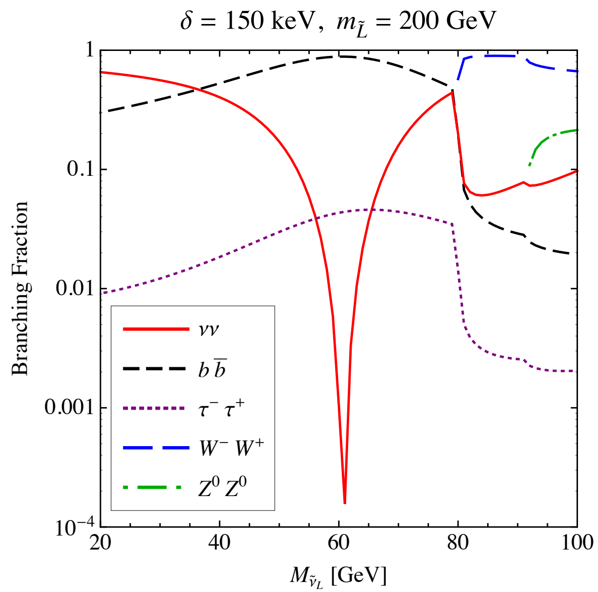
Recall: $\tan 2\theta = \dfrac{2Av\sin\beta}{M_R^2 - M_L^2}$

Tests of the model/Future signals?

- Possible spectrum at neutrino telescopes







- Possible peak from direct annihilation into neutrinos?

Conclusions

- A simple extension to the MSSM can lead to a much richer structure in the dark matter sector
  - A link between dark matter and neutrino physics
  - Interesting direct detection signals?
    - Elastic scattering
    - Inelastic scatterting
  - Interesting indirect signals at neutrino telescopes?