Phenomenological Constraints on GeV-mass Mixed Sneutrino Dark Matter

Akiteru Santa (Univ. of Toyama)

arxiv: 1503.06783

Collaborators:
Mitsuru Kakizaki (Univ. of Toyama), Eun-Kyung Park(Hokkaido Univ.),
Jae-hyeon Park(Univ. of Valencia)

9-11Jun. 2015, CosKASI DM workshop 2015

Presentation Outline

1. Motivation

2. Mixed Sneutrino Dark Matter Scenarios (Review)

3. Analysis of light mixed sneutrino DM scenarios

   - **New! Relaxation of gaugino mass universality**

   - **New! Vacuum meta-stability bound**

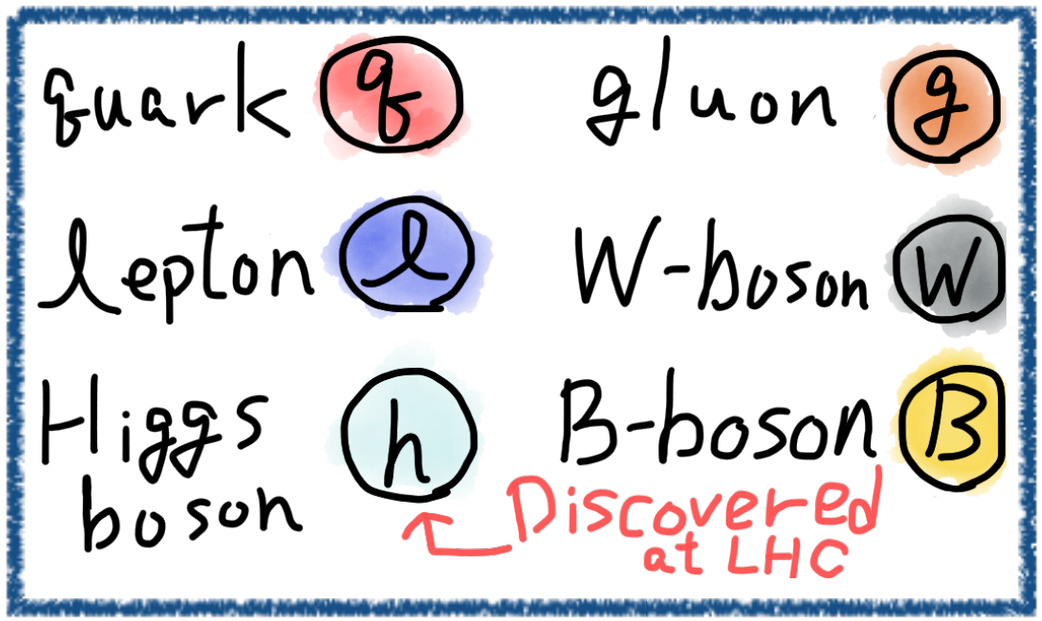
     =>New! Allowed region with GeV-mass neutralino

4. Summary

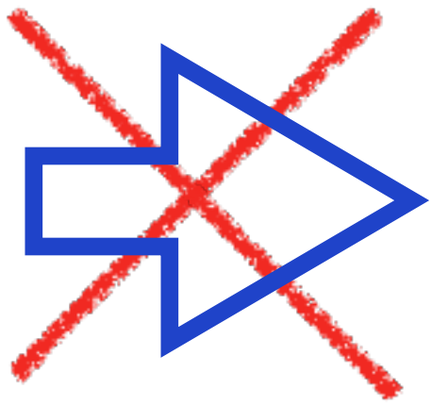
5. Future Works

Motivation

The Standard Model



cannot solve



Problems

- Dark Matter
- Neutrino Mass
- Baryon Asymmetry
- Inflation
- Hierarchy Problem

etc.

We should extend the standard model and solve such problems !

Mixed Sneutrino DM Scenarios 1/2

Earlier Works Arkani-Hamed,Hall,Murayama,Smith and Weiner (2001)
G. Belanger, M. Kakizaki, E. K. Park, S. Kraml and A. Pukhov (2010)
B. Dumont, G. Belanger, S. Fichet, S. Kraml and T. Schwetz (2012) etc.

Mixed Sneutrino DM Scenarios

- SM particles t l h g W B
- Right-handed neutrino ν_R
- SUSY particles
  ex. sneutrinos $\tilde{\nu}_L$ $\tilde{\nu}_R$
  bino $\tilde{B}$
  wino $\tilde{W}$
  higgsino $\tilde{h}$ } neutralino $\tilde{\chi}^0$
  chargino $\tilde{\chi}^\pm$
  ⋮

can solve

Problems

- ✳ Dark Matter
- ✳ Neutrino Mass
- ✳ Hierarchy Problem

These problems are related through one supermultiplet

$$\overline{N}_R = \tilde{\nu}^c_R + \sqrt{2}\nu^c_R\theta + F_{\nu^c_R}\theta^2$$

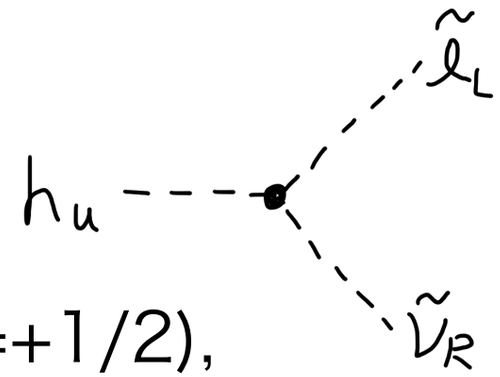
Mixed Sneutrino DM Scenarios 2/2

Lagrangian:

$$\mathcal{L} \sim (\mathcal{L}_{\rm SM} + \mathcal{L}_{\nu_R}) \times {\rm SUSY} + \mathcal{L}_{\rm SUSY\ breaking}$$

Sneutrino Trilinear Coupling :

$$\mathcal{L}_{\rm SUSY\ breaking} \supset -A_{\tilde{\nu}} h_u \cdot \tilde{l}_L \tilde{\nu}_R^c + {\rm h.c.}$$



$A_{\tilde{\nu}}$:Coupling constant, h_u:Higgs doublet (Y=+1/2),
$\tilde{l}_L$:Left-handed slepton doublet, $\tilde{\nu}_R$:Right-handed sneutrino

=> Off-diagonal components of sneutrino mass matrix

$$-\mathcal{L}_{mass} = (\tilde{\nu}_L^*, \tilde{\nu}_R^*) \begin{pmatrix} m_{\tilde{L}}^2 + \frac{1}{2} m_Z^2 \cos 2\beta & \frac{v}{\sqrt{2}} A_{\tilde{\nu}} \sin\beta \\ \frac{v}{\sqrt{2}} A_{\tilde{\nu}} \sin\beta & m_{\tilde{N}}^2 \end{pmatrix} \begin{pmatrix} \tilde{\nu}_L \\ \tilde{\nu}_R \end{pmatrix}$$

=> Left- and right-handed sneutrios mix:

$$\begin{pmatrix} \cos\theta_{\tilde{\nu}} & -\sin\theta_{\tilde{\nu}} \\ \sin\theta_{\tilde{\nu}} & \cos\theta_{\tilde{\nu}} \end{pmatrix} \begin{pmatrix} \tilde{\nu}_R \\ \tilde{\nu}_L \end{pmatrix} = \begin{pmatrix} \tilde{\nu}_1 \\ \tilde{\nu}_2 \end{pmatrix}$$

WIMP candidate

=>The sneutrino DM scenarios can be tested by various experiments !

Earlier works of Mixed Sneutrino DM

Assumption

B. Dumont et al. (2012) etc.

The gaugino mass universality: $6M_{\widetilde{B}} = 3M_{\widetilde{W}} = M_{\widetilde{g}}$

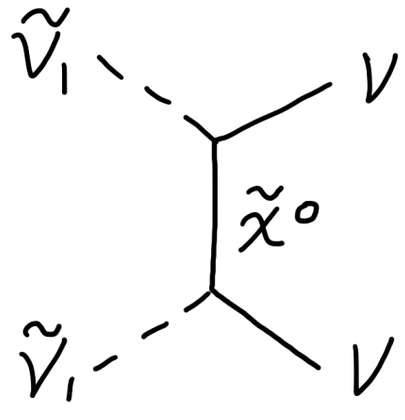
Experimental constraints ATLAS(2014, 2015), CMS(2014)

- gluino mass limit: $M_{\tilde{g}} > 1.4\ \mathrm{TeV}$ => $m_{\tilde{\chi}_1^0} \sim M_{\widetilde{B}} \sim \mathcal{O}(100\ \mathrm{GeV})$
- Higgs boson invisible decay:
  $\mathrm{BR}(h \to \mathrm{inv.}) < 0.29\ (95\%\mathrm{CL})$ => $\sin\theta_{\tilde{\nu}} < 0.16$ for $m_{\tilde{\nu}_1} \leq m_h/2$

Results of earlier works

- Heavy sneutrino DM case $(m_{\tilde{\nu}_1} > m_h/2)$
  There is an allowed region
- Light sneutrino DM case $(m_{\tilde{\nu}_1} \leq m_h/2)$
  Relic density:

$$\Omega h^2 \sim 0.1 \times \left(\frac{m_{\tilde{\chi}_1^0}}{100\ \mathrm{GeV}}\right)^2 (\sin\theta_{\tilde{\nu}})^{-4}$$



=>Light sneutrino DM case with the gaugino mass universality is excluded !

Keys of our work 1/2

We focus on GeV-mass mixed sneutrino DM scenarios

KEY1: To relax the gaugino mass universality

$$6M_{\widetilde{B}} = 3M_{\widetilde{W}} = M_{\widetilde{g}} \Rightarrow 6M_{\widetilde{B}} \neq 3M_{\widetilde{W}} \neq M_{\widetilde{g}}$$

Relic density of GeV-mass sneutrino with GeV-mass neutralino:

$$\Omega h^2 \sim 0.1 \times \left(\frac{m_{\tilde{\chi}_1^0}}{1\ \mathrm{GeV}}\right)^2 \left(\frac{\sin\theta_{\tilde{\nu}}}{0.1}\right)^{-4}$$

Consistent !

Limit from Higgs invisible decay searches:

$$\sin\theta_{\tilde{\nu}} < 0.16 \text{ for } m_{\tilde{\nu}_1} \leq m_h/2$$

Keys of our work 2/2

We focus on GeV-mass mixed sneutrino DM scenarios

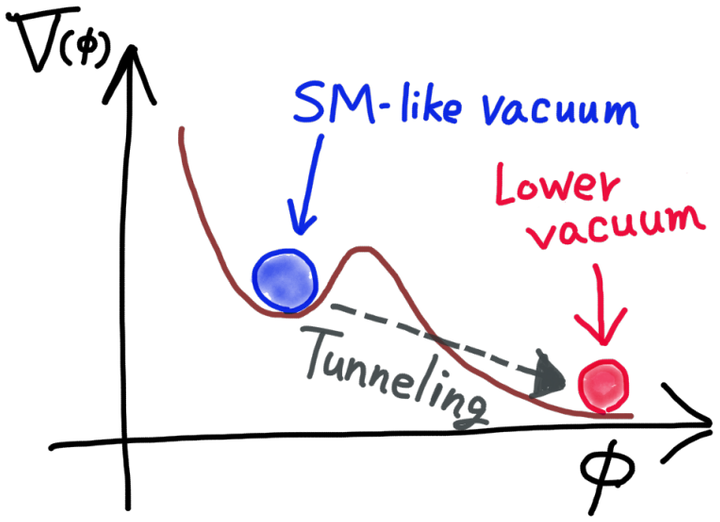
KEY1: To relax the gaugino mass universality

KEY2: To impose vacuum meta-stability bound

Sneutrino trilinear coupling :

$$\mathcal{L}_{\text{SUSY breaking}} \supset -A_{\tilde{\nu}} h_u \cdot \tilde{l}_L \tilde{\nu}_R^c + \text{h.c.}$$

=> **Deeper vacuum than the SM-like one**



Meta-stability bound:

$$\Gamma^{-1} > t_0$$

Γ : the decay rate of the SM − like vacuum

t_0 : the lifetime of the universe

Sneutrino mixing angle:

$$\sin 2\theta_{\tilde{\nu}} = \frac{\sqrt{2} A_{\tilde{\nu}} v \sin\beta}{m^2_{\tilde{\nu}_2} - m^2_{\tilde{\nu}_1}}$$

$m_{\tilde{\nu}_1}$	$\theta_{\tilde{\nu}}$ upper limit
0.1 GeV	0.52
1 GeV	0.83

for $m_{\tilde{\nu}_2} = 125$ GeV, $\tan\beta = 10$, $m_A = 400$ GeV

Collider experiments

LEP2(2006), ATLAS(2014, 2015), CMS(2014)

Invisible decay searches

$\Delta\Gamma(\mathrm{Z} \to \mathrm{inv}) < 2.0\ \mathrm{MeV}\ (95\%\ \mathrm{CL}) \Rightarrow \sin\theta_{\widetilde{\nu}} < 0.4$

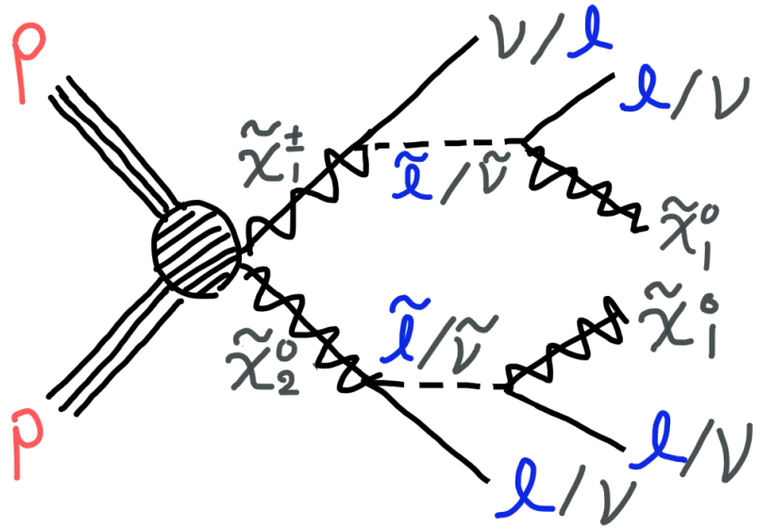
$\mathrm{BR}(h \to \mathrm{inv}) < 0.29 \quad (95\%\ \mathrm{CL}) \Rightarrow \sin\theta_{\widetilde{\nu}} < 0.16$
for $m_{\widetilde{\nu}_2} > m_h - m_{\widetilde{\nu}_1},\ \mu \geq 500\mathrm{GeV}$

Superparticle searches

example:

$\widetilde{\chi}_1^{\pm}\widetilde{\chi}_1^{\mp},\ \widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^{0} \to 2\tau,\ 3\tau$ searches

$\Rightarrow\ m_{\widetilde{\chi}_1^{\pm}} > 420\ \mathrm{GeV}$

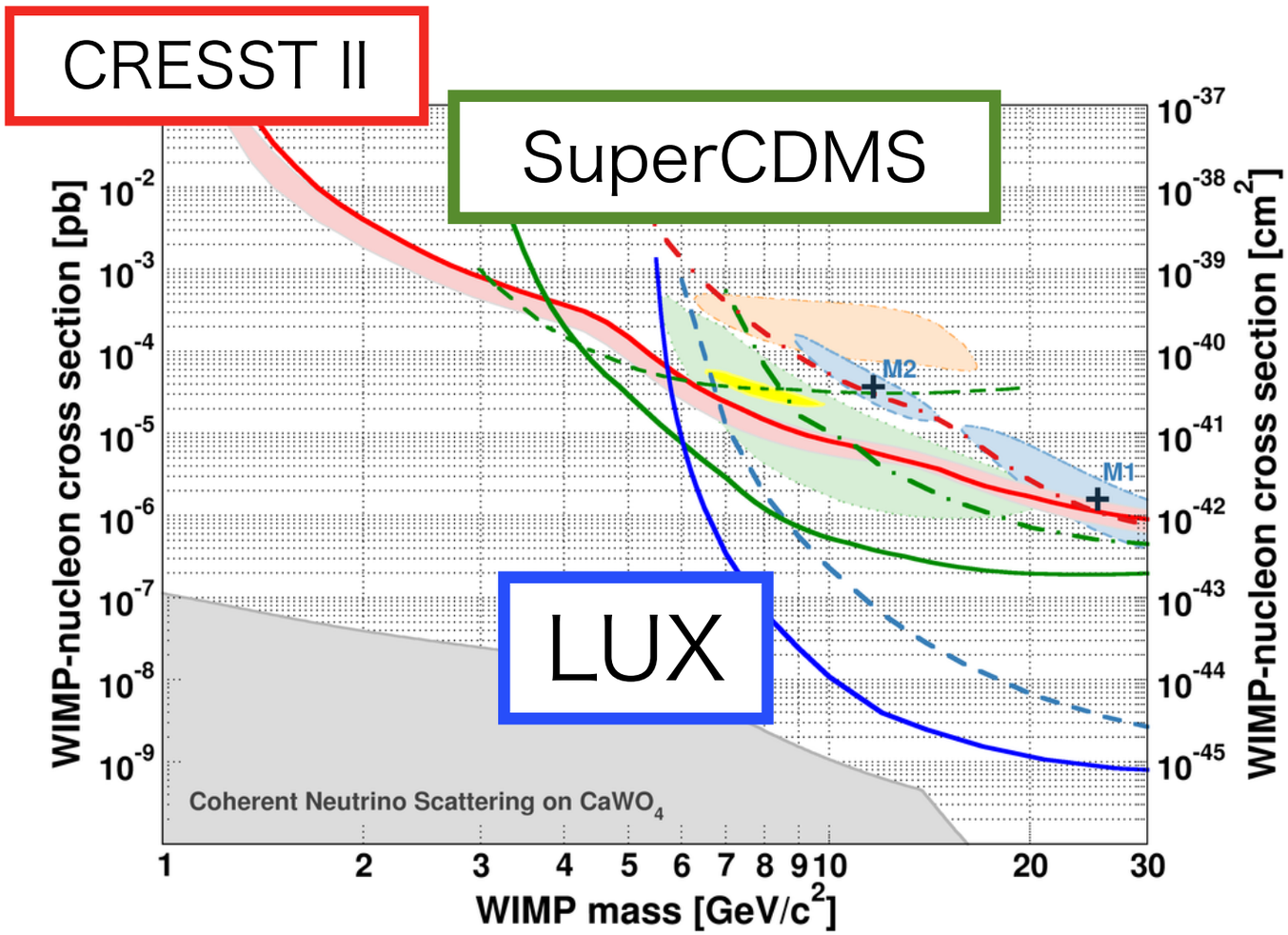


Mono-photon searches

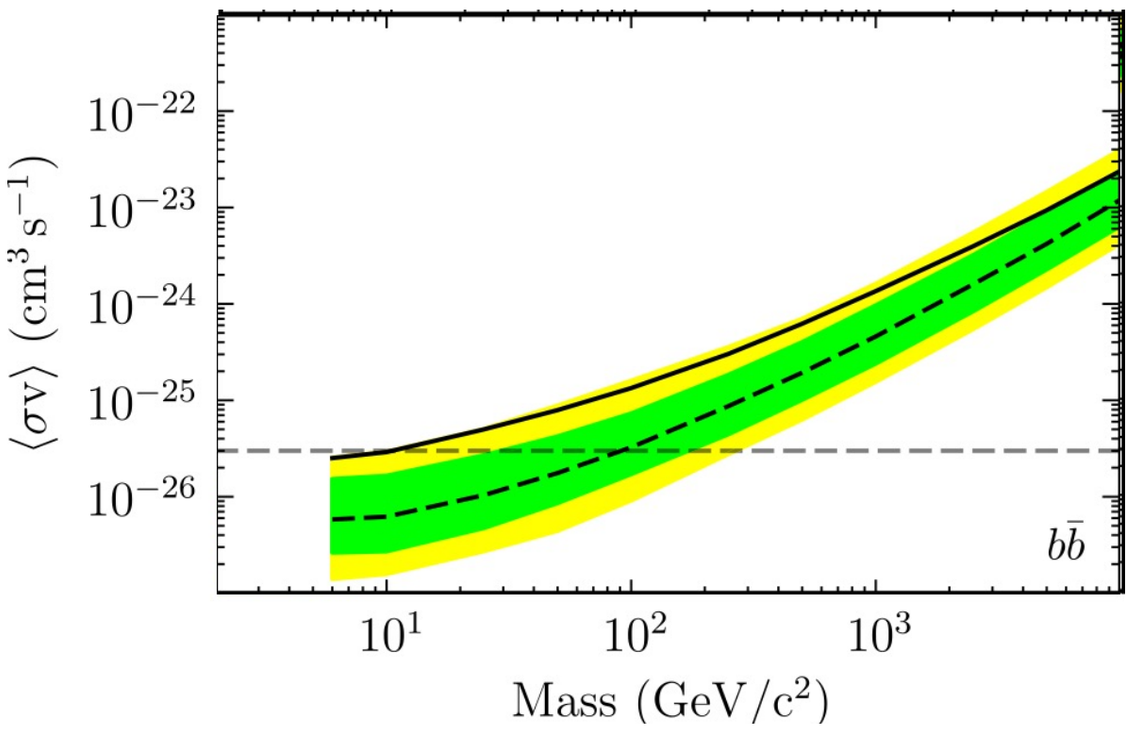
$\sigma_n \lesssim \mathcal{O}(10^{-37})\ \mathrm{cm}^2$
for mediator mass : $m_V \sim 100\ \mathrm{GeV}$,
DM mass : $m_\chi \lesssim 50\ \mathrm{GeV}$

9

Direct, indirect detections



CRESST II (2014)



FermiLAT (2014)

$m_{\tilde{\nu}_1}$	1 GeV	10 GeV
Direct Detection	Energy threshold =>Insensitive	LUX(2014) SuperCDMS(2014)
Indirect Detection	$\tilde{\nu}\tilde{\nu} \to \nu\nu$ is dominant =>Insensitive	$\tilde{\nu}\tilde{\nu}^* \to b\bar{b}$ is dominant =>FermiLAT(2014)

New! Allowed Region

Assumption

$$m_{\tilde{\nu}_{\tau 1}} < m_h/2 < m_{\tilde{\nu}_{e,\mu 1}}$$

Scan bounds

Parameter	Reference value/ Scan bound
μ	500 GeV
$\tan\beta$	10
$m_{\tilde{\nu}_1}$	[0.1 GeV, 10 GeV]
$m_{\tilde{\nu}_2}$	126 GeV
$\sin\theta_{\tilde{\nu}}$	[0.01, 0.3]
$M_{\widetilde{B}}$	[0.1 GeV, 20 GeV]

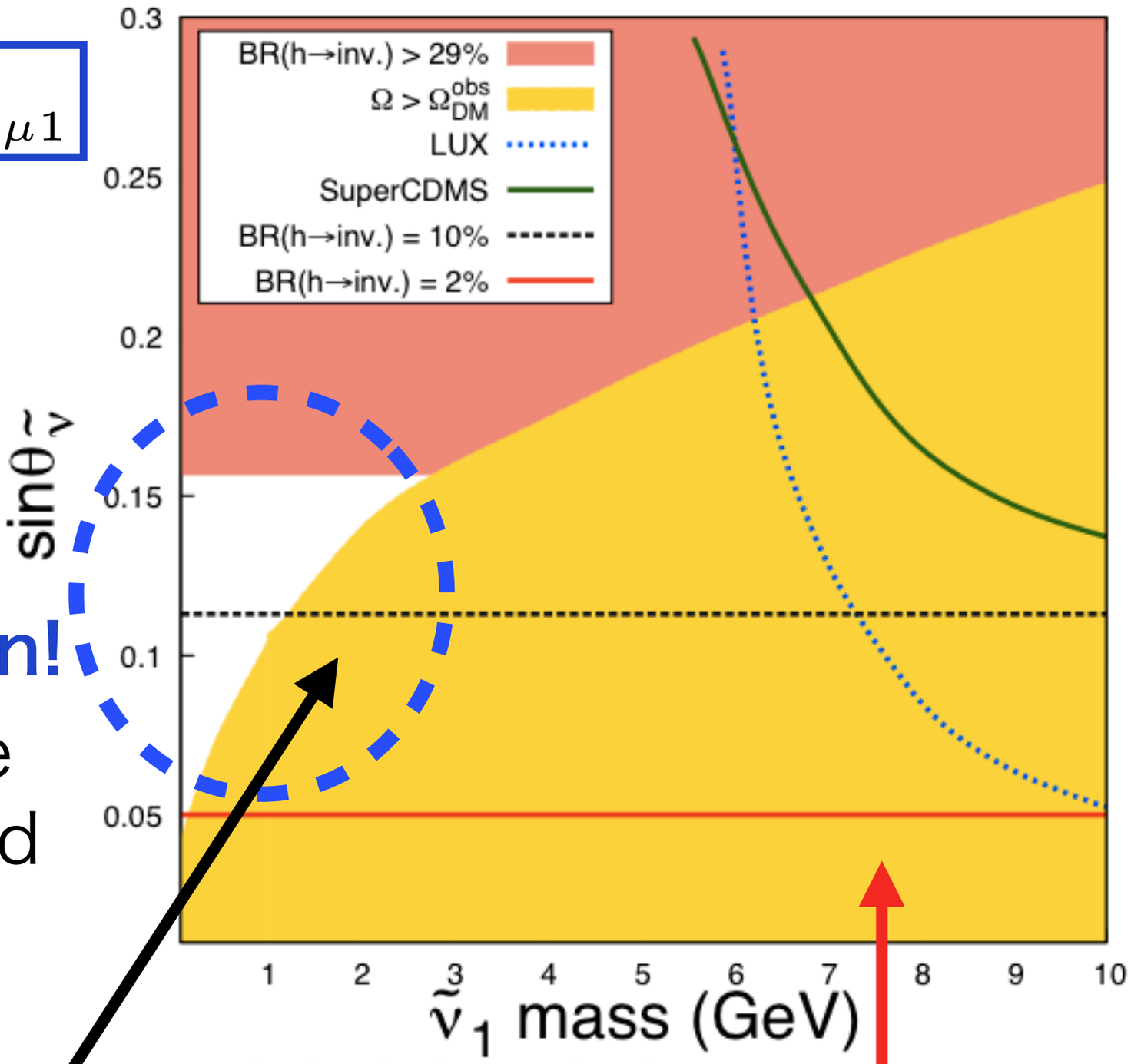
Consistent region!

The mass region above 0.1 GeV can be covered at future colliders !!

- **Future experiments**
  - LHC(14 TeV, 3000 fb^-1)

$$\mathrm{BR}(h \to \mathrm{inv}) < 8.0\%\ (95\%\ \mathrm{CL})$$

ATL-PHYS-PUB-2013-014



- ILC(250 GeV, 250fb^-1)

$$\mathrm{BR}(h \to \mathrm{inv.}) < 0.69\%\ (95\%\mathrm{CL})$$

Ishikawa(LCWS14)

Summary

Mixed sneutrino DM scenarios

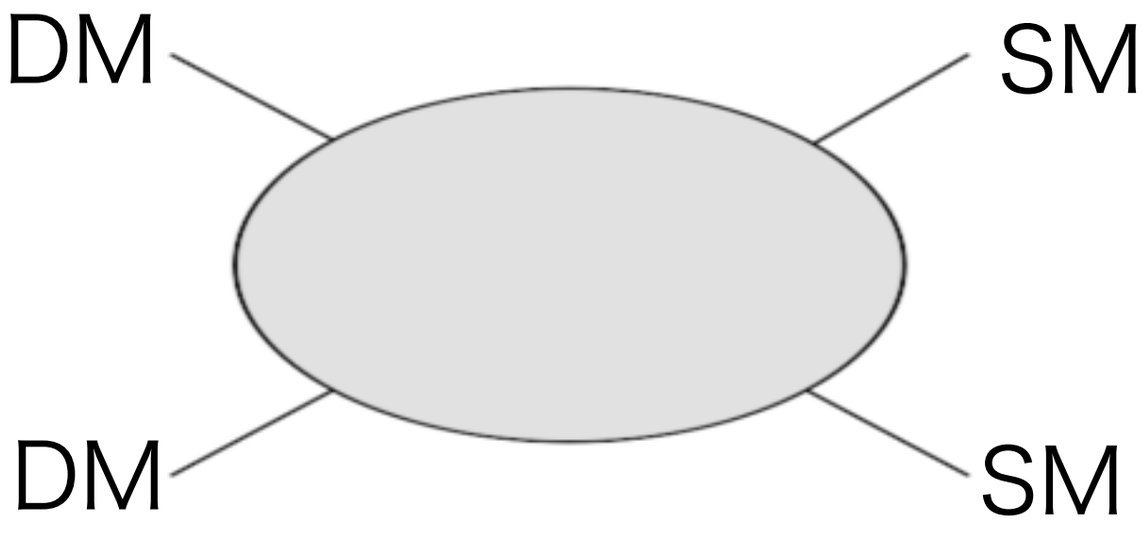
- The DM, neutrino mass, and hierarchy problems can be solved simultaneously
- The light sneutrino DM case with the gaugino mass universality is excluded

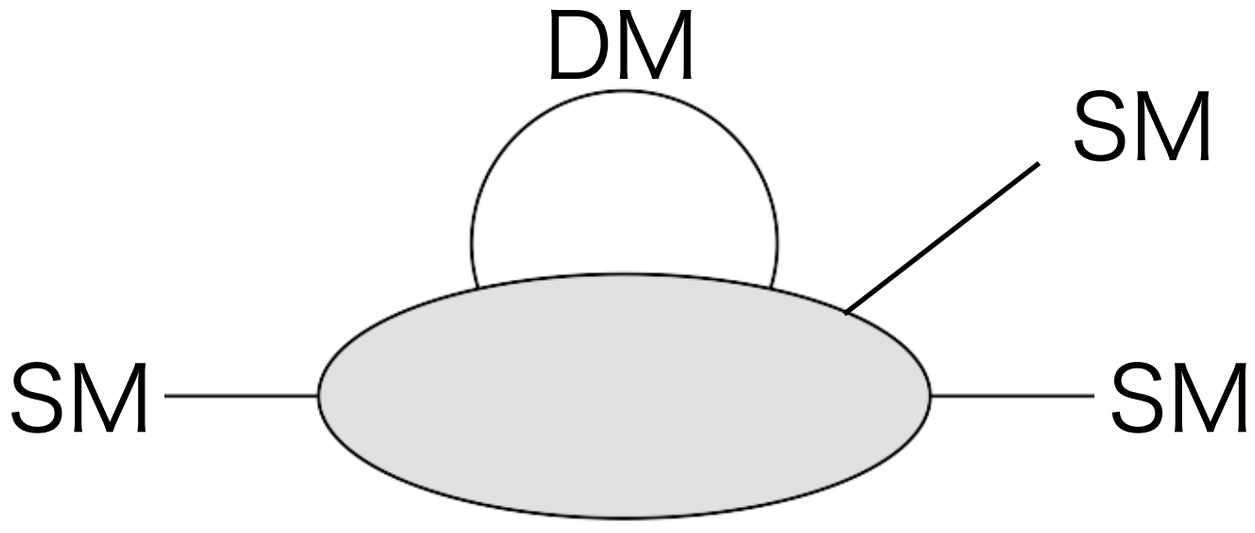
B.Dumont et.al (2012)

Analysis of GeV-mass mixed sneutrino DM

- **New !** Impose the vacuum meta-stability bound
  => not serious
- **New !** There is an allowed region **without** the gaugino mass universality
  - Direct, indirect detections are insensitive to the region
  - The allowed region $(0.1\ \mathrm{GeV} \leq m_{\tilde{\nu}_1} \leq 3\ \mathrm{GeV})$ can be covered at future colliders !!

Future Works

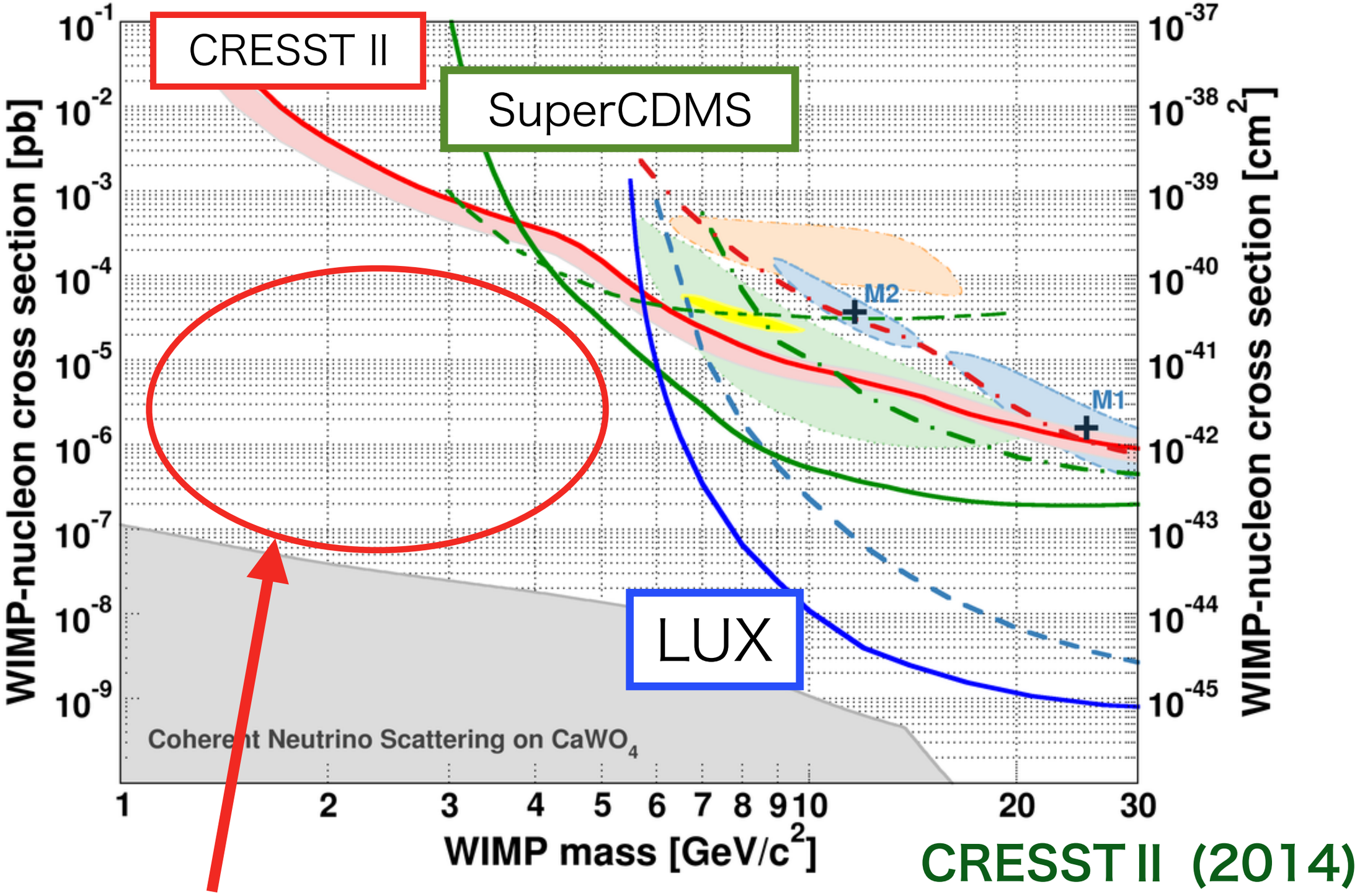




- GeV-mass sneutrino and neutralino
  => The magnetic dipole moment of the muon
  => The large difference from the SM is expected
- **Complementary analysis**
  - Neutralino WIMP scenarios
    in mixed sneutrino model
  - Asymmetric Dark Matter (ADM) scenarios
    in inert model
  - Mixed sneutrino ADM scenarios

Back up

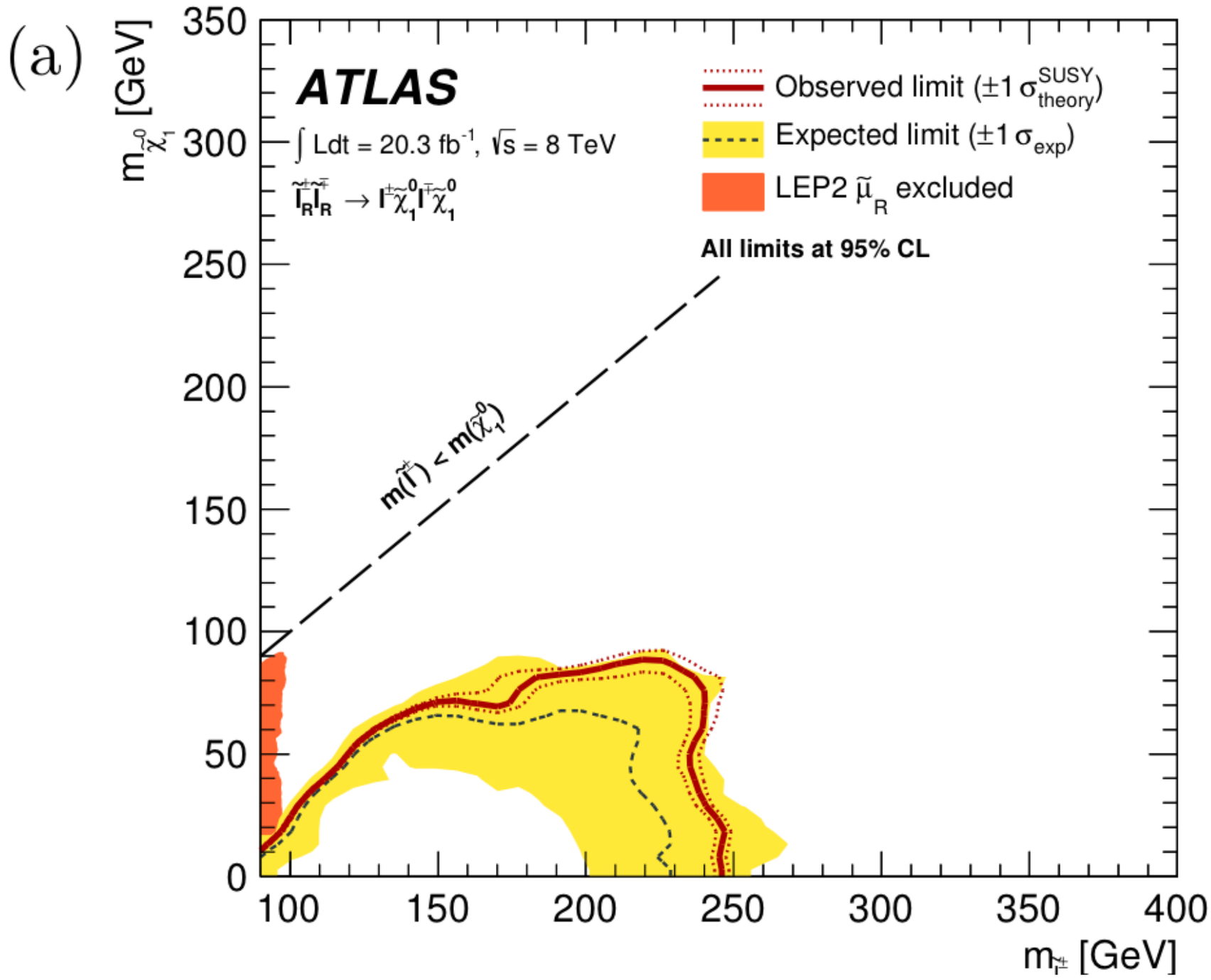
Direct detections for GeV-mass DM



CRESST II (2014)

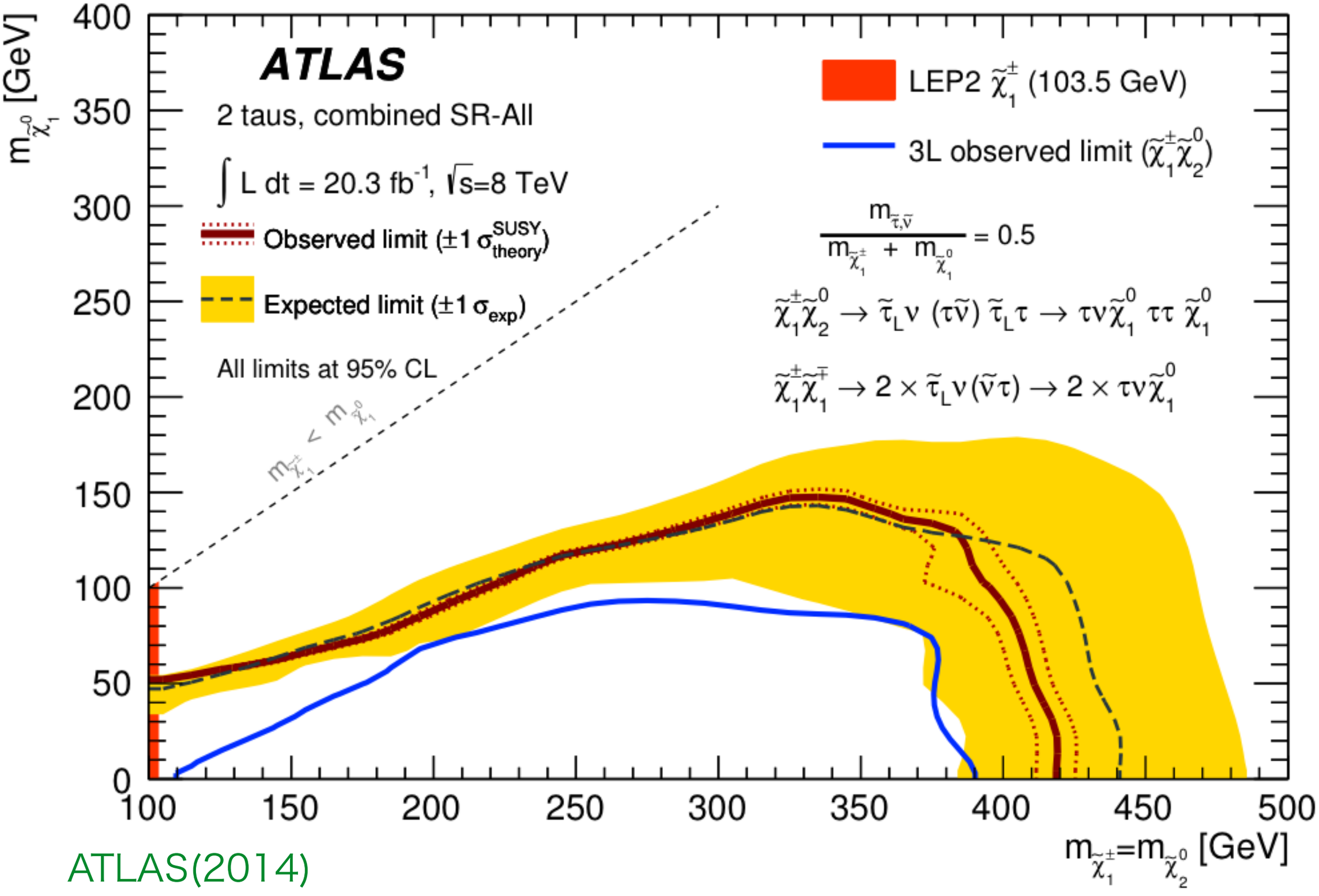
How to probe this region?

Selectron and smuon search at LHC



ATLAS(2014)

2, 3 tau search at LHC



ATLAS(2014)