

# Sneutrino dark matter :

G. Bélanger  
LAPTH

## Outline

- Motivation and model
- Light sneutrino scenario
- Signatures

GB, M. Kakizaki, S. Kraml, E.K. Park, A. Pukhov, arXiv:1008.0580

# Introduction

- Strong evidence for dark matter
- CMB (WMAP+SDSS) gives precise information on the amount of dark matter,  $\Omega h^2 = 0.1109 \pm 0.0056$
- Most attractive explanation for dark matter: new weakly interacting particle
- Extensions of SM which address hierarchy problem naturally provide wimp DM candidate (MSSM, UED...)
- Neutrino oscillation : non zero neutrino mass requires extension of SM , e. g. RH neutrino.
- Neutrino+hierarchy+DM
  - Supersymmetry MSSM+ $v_R$
- $\sim v_R$  can be DM candidate

# Sneutrino DM

- LH sneutrino : not a good DM candidate (Falk, Olive, 1999)
  - Much too large elastic scattering cross section :  $\sigma \sim 10^{-4}$  pb
- Singlet RH sneutrino : suppress coupling to Z
  - Sterile : tiny mixing with LH , not thermal equilibrium – non thermal DM candidate
    - Asaka et al . hep-ph/0512118, Gopalakrishna et al hep-ph/0602027
  - Extend gauge symmetry : couple to Z'
    - Annihilation through Z'
    - Suppress DD rate high mass of Z'
    - Lee, Matchev, Nasri, hep-ph/0702223
- RH sneutrino with large L/R mixing : enough for thermal equilibrium
  - Dirac sneutrino
    - Arkani-Hamed et al hep-ph/0006312
  - Majorana sneutrino: lepton number violation, possable small mass splitting, inelastic DM scattering
    - Arina Fornengo 0708.4477

# Model

- Neutrino mass in susy model with global symmetry  $G + R$ -parity
  - N: RH neutrino field
  - X: spontaneous breaking SUSY and global symmetry
  - Arkani-Hamed et al hep-ph/0006312
  - Borzumati et al hep-ph/000708
- Effective theory
  - Dirac neutrino  $\frac{1}{M_{Pl}^2} [X^\dagger L N H_u]_D$
  - Weak scale :  $M_\nu = v^2/M_{Pl}$ .
  - Coupling to Higgs  $\frac{1}{M_{Pl}} [X L N H_u]_F \supset v \tilde{l} \tilde{n} h_u.$
  - Also possible to write operators with Majorana mass-see saw mechanism

# Model

- 2 new soft parameters (per generation)

$$\mathcal{L} \supset -\tilde{m}_N^2 \tilde{\nu}_R^* \tilde{\nu}_R - A_\nu h_2 l \tilde{\nu}_R^* + \text{h.c.}$$

- A term is not related to the neutrino Yukawa coupling – can be weak scale
- Sneutrino mass matrix

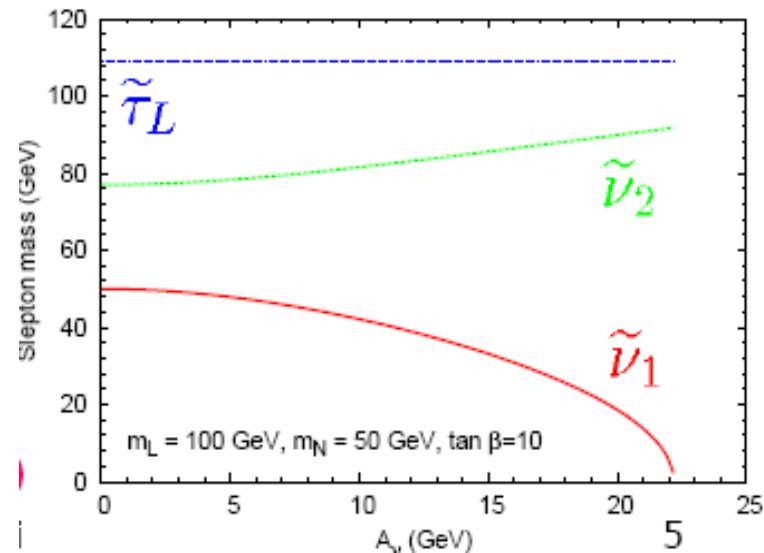
$$m_{\tilde{\nu}}^2 = \begin{pmatrix} m_L^2 + \frac{1}{2} m_Z^2 \cos 2\beta & \frac{1}{\sqrt{2}} A_{\tilde{\nu}} v \sin \beta \\ \frac{1}{\sqrt{2}} A_{\tilde{\nu}} v \sin \beta & m_N^2 \end{pmatrix}$$

# Sneutrino

- When  $m_{\tilde{N}} < m_{\tilde{L}}$  sneutrino is lightest slepton
- Natural when embedding in GUT scale model: running of  $m_L$  driven by  $M_2$ , running of  $m_N$  by  $A$  term (SM singlet)
- Large  $A$  term (TeV scale)  $\rightarrow$  large mixing, large splitting singlet/doublet

$$\tilde{\nu}_1 = -\sin \theta \tilde{\nu}_L + \cos \theta \tilde{\nu}_R$$

- Sneutrino naturally lighter neutralino
- Sneutrino can be lighter than  $M_z/2$



# Mixed sneutrino

- Mixing

$$\theta = \frac{1}{2} \tan^{-1} \left( \frac{\sqrt{2} A_{\tilde{\nu}} v \sin \beta}{\tilde{m}_{\tilde{L}}^2 - m_{\tilde{N}}^2 + \frac{1}{2} m_Z^2 \cos 2\beta} \right)$$

- Constraint from Z width (assume one light sneutrino=tau) :  $\sin\theta < 0.4$

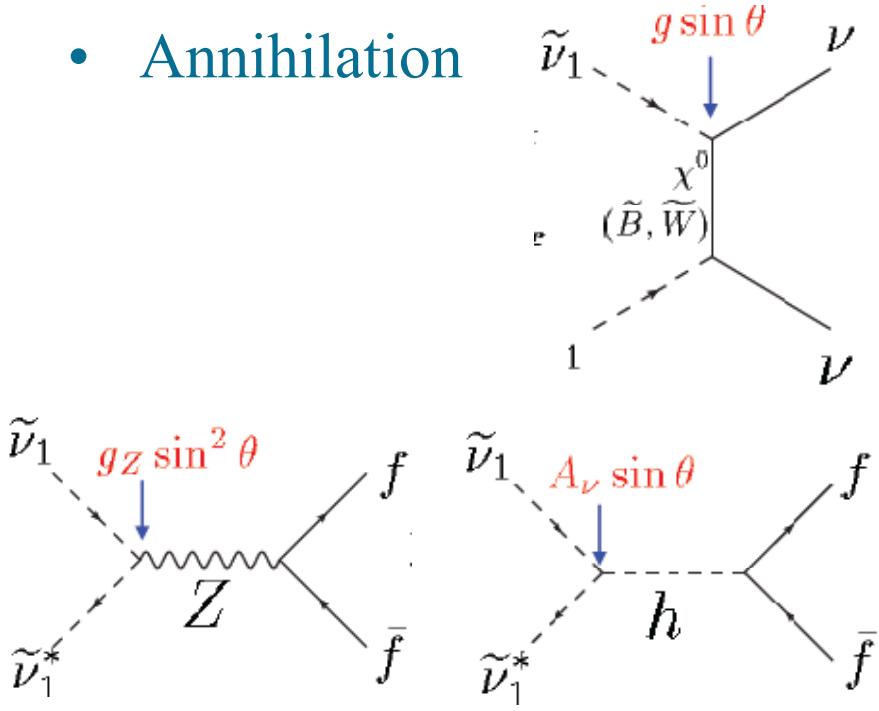
$$\Delta\Gamma_z = \Gamma_\nu \frac{\sin^4 \theta}{2} \left( 1 - \left( \frac{2m_{\tilde{\nu}}}{m_Z} \right)^2 \right)^{3/2} < 2 \text{ MeV}$$

- Mixed sneutrino : same couplings as LH sneutrino X  $\sin\theta$
- Higgs coupling

$$H \tilde{\nu}_1^* \tilde{\nu}_1 : i e m_W \frac{\sin(\alpha + \beta)}{2 c_W^2 s_W} \sin^2 \theta + i \sqrt{2} A_{\tilde{\nu}} \cos \alpha \cos \theta \sin \theta$$

# RH sneutrino DM

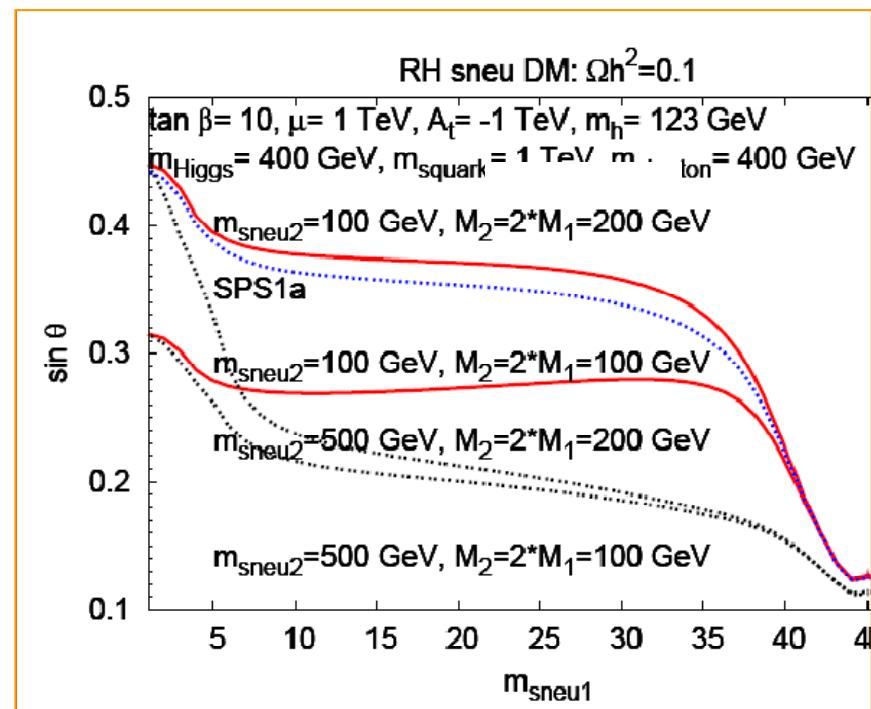
- Annihilation



Above W threshold  $\rightarrow WW$

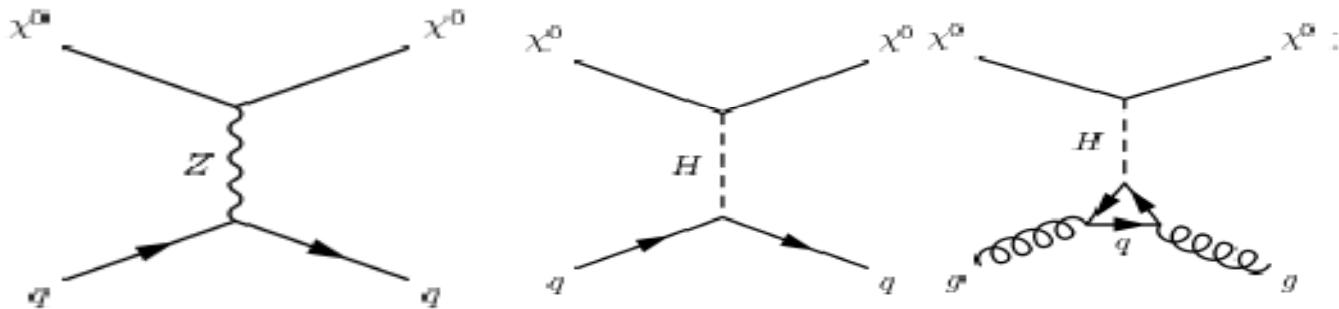
- Relevant parameters:

- $m_{\nu 1}, \sin \theta, m_{\nu 2}$  or  $A_\nu$  or  $m_L$
- $M_1, M_2$



# *Direct detection*

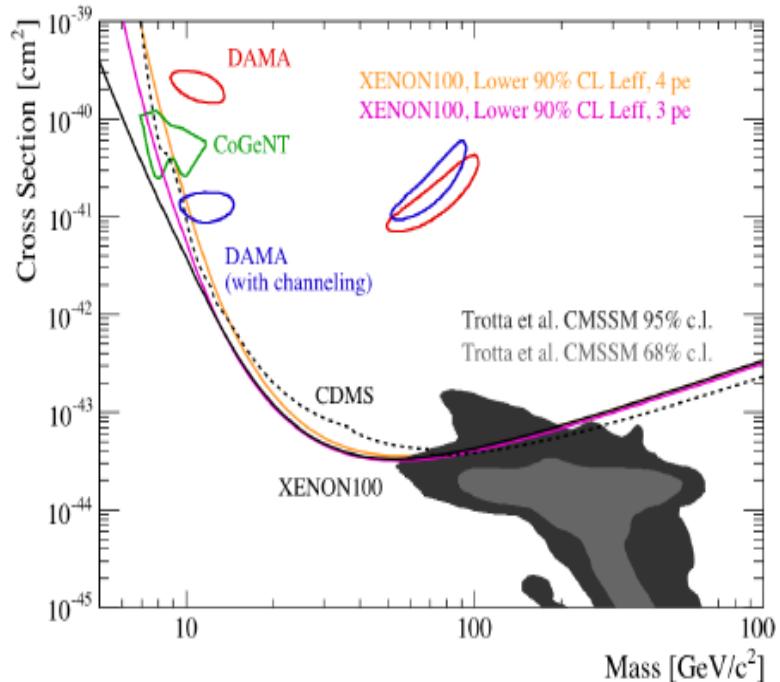
- Elastic scattering of WIMPs off nuclei in a large detector - nuclear recoil energy,  $E_R$
- Spin independent interactions: coherent scattering on A nucleons - dominant for heavy nuclei
- Typical diagrams



- Dirac fermions or complex scalar: Z exchange contributes to SI and SD
- Higgs exchange important contribution
- Scalar DM- no SD interactions
- *DD strongly constrain Dirac or complex scalar dark matter candidates*

# Direct Detection

- DAMA : signal in annual modulation compatible with light DM
- CoGent and CDMS also reported some signals compatible with ‘light’ DM
- Some of the favoured regions are excluded by Xenon10, Xenon100
- Sneutrino has large DD cross sections: compatible with observations



# The light sneutrino

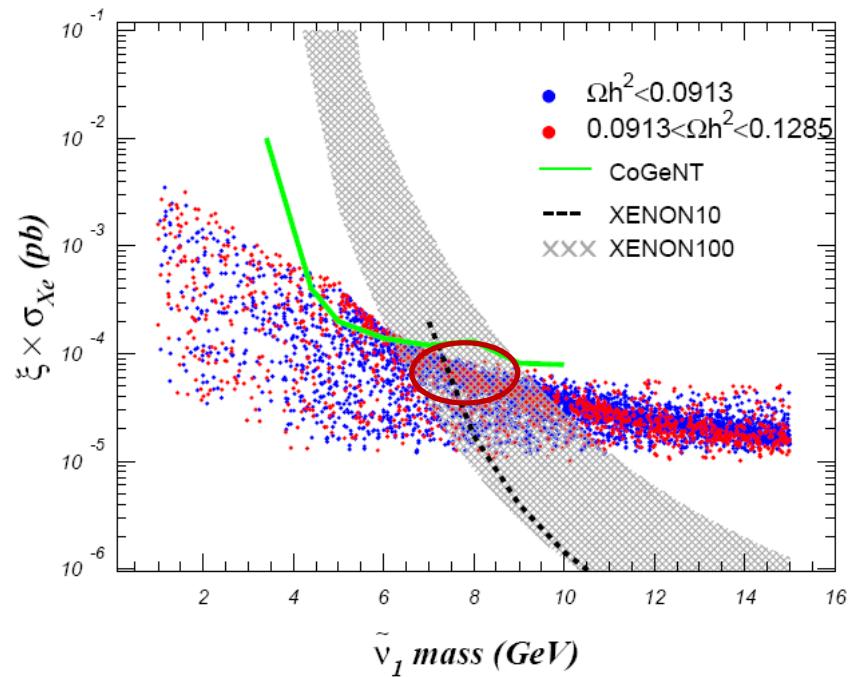
- Z exchange :  $\sigma_p \ll \sigma_n$

$$\sigma_{\tilde{\nu}_1 N}^{SI} = \frac{G_F^2}{2\pi} \mu_\chi^2 \left( (A - Z) - (1 - 4 \sin^2 \theta_W) Z \right)^2 \sin^4 \theta$$

- Higgs exchange  $\sigma_p = \sigma_n$
- Compare with expt:

$$\sigma_{\tilde{\nu}_1 N}^{SI} = \frac{(Z + (A - Z)f_n/f_p)^2}{A^2} \sigma_p^{SI}$$

- Average  $\nu, \nu^*$
- Scan over parameter space
  - $m_{\nu_1}, \sin\theta, m_{\nu_2}, M_2 = 2M_1$ ,
  - $\tan b = 10$ , soft terms = 1 TeV



Xenon10 0706.0039  
 Cogent 1002.4703  
 Xenon 100 1005.0380

# Uncertainties

- Rates depend on nuclear form factors, quark coefficient in nucleon (only for Higgs contribution) WIMP velocity distribution of WIMPs + local density (0.3 but range 0.1-0.7)

$$\frac{dN^{SI}}{dE} = \frac{2M_{det}t}{\pi} \frac{\rho_0}{M_\chi} F_A^2(q) (\lambda_p Z + \lambda_n(A - Z))^2 I(E)$$

- Velocity distribution : large effect for light DM

• Bottino et al hep-ph/0508270, A. Green 1004.2383

– Simplest Isothermal sphere-> Maxwellian velocit,

$$I(E) = \int_{v_{min}(E)}^{\infty} \frac{f(v)}{v} dv$$

$$v_{min}(E) = \left( \frac{EM_A}{2\mu_\chi^2} \right)^{1/2}$$

$$f(v) = c_{norm} \left[ \exp \left( -\frac{(v - v_1)^2}{\Delta V^2} \right) - \exp \left( -\frac{\min(v + v_1, v_{max})^2}{\Delta V^2} \right) \right]$$

–  $v_1$ : Earth velocity with respect to galaxy

$$498 \text{ km/s} < v_{max} < 608 \text{ km/s}$$

–  $v_{max}$ : escape velocity

–  $v_0$ : measured velocity of Sun and nearby objects

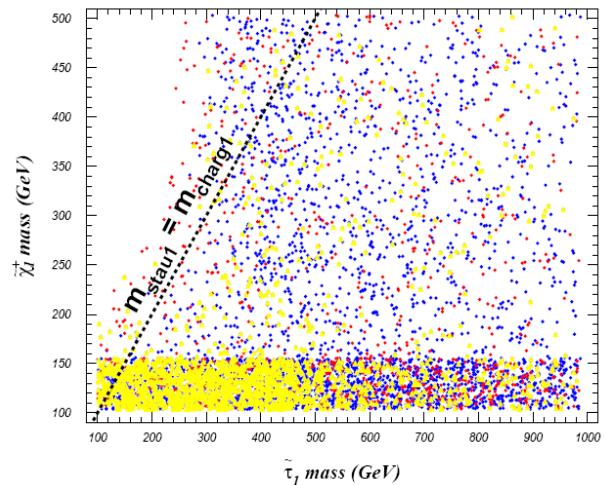
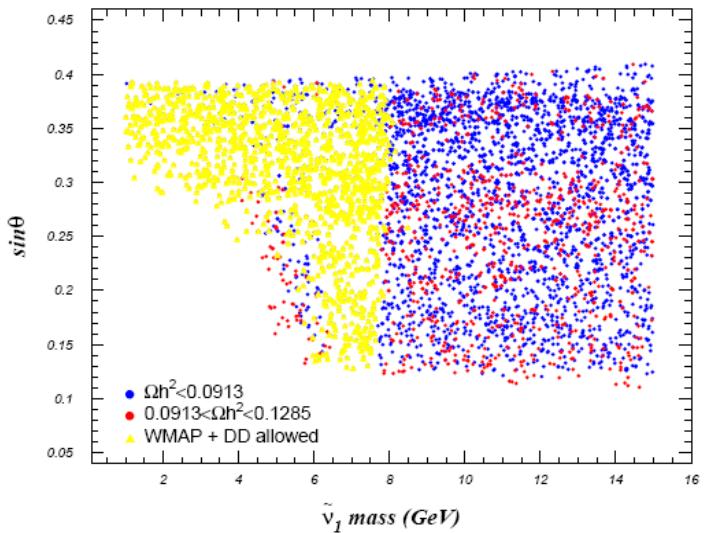
$$v_0 = 220 \pm 20 \text{ km/s}$$

- Relax the constraint from DD by 1-2GeV or factor 3 on  $\sigma$ .
- Scintillation factor in Xenon (assume decrease with energy – conservative)

# Allowed scenarios

- Mass range 1-8GeV
- Sneutrino  $\sim 2$  GeV large mixing- constraint WMAP,Z
- 5GeV : strongest DD constraint- need light chargino
- 6-8 GeV can afford smaller mixing
- Higgs contribution needed
  - large A ( heavy  $v_2$ )
  - stau usually heavier than chargino
  - chargino decay

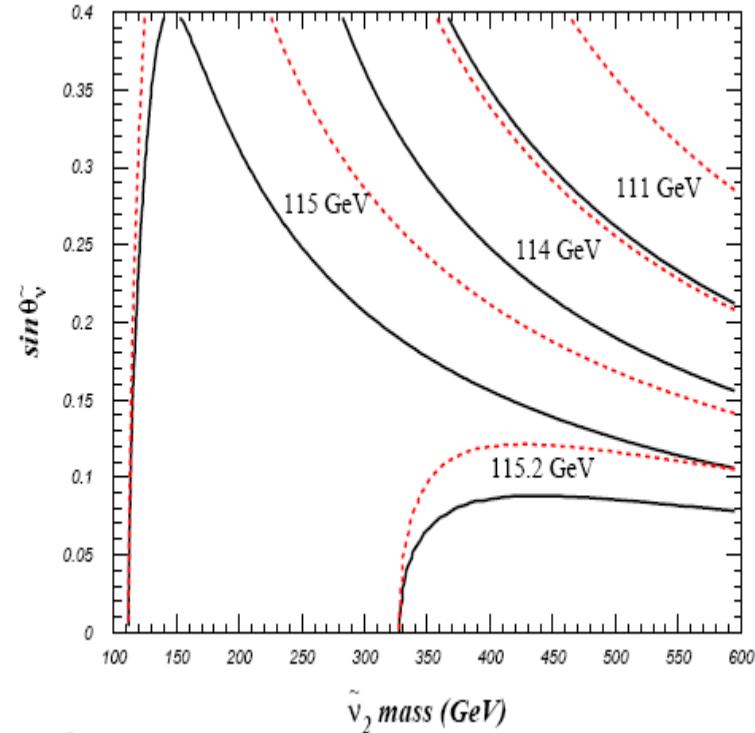
$$\chi^+ \rightarrow \tilde{\nu}_1 l$$



# Higgs mass

- New operator induces corrections to light Higgs mass

$$\begin{aligned} m_h^2 = & m_Z^2 \sin^2(\alpha + \beta) + m_A^2 \cos^2(\alpha - \beta) \\ & + v^2 [(\Delta\lambda_1 s_\alpha^2 c_\beta^2 + \Delta\lambda_2 c_\alpha^2 s_\beta^2 - (\Delta\lambda_3 \cdot \\ & + \dots) \end{aligned}$$



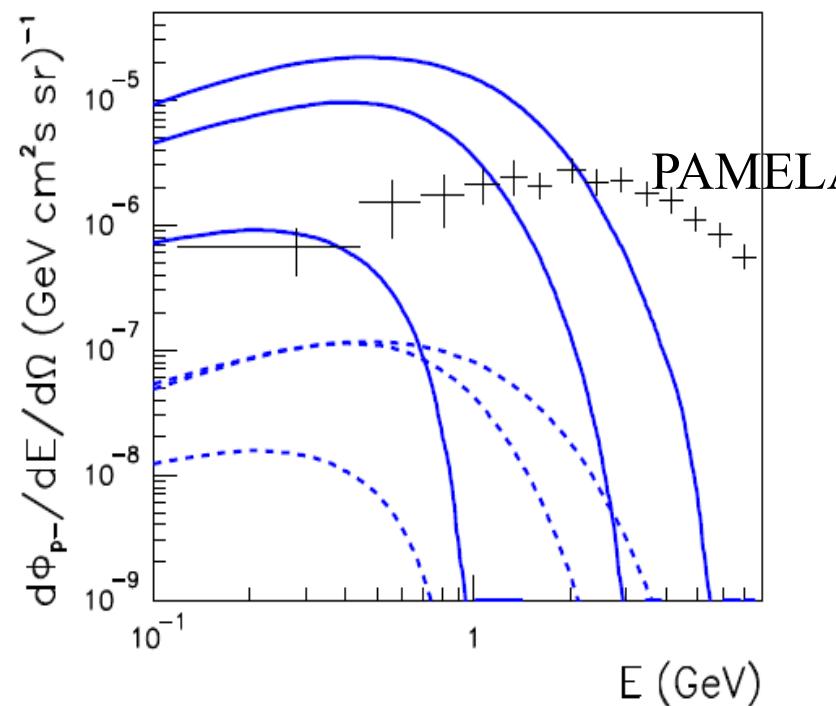
- Large splitting  $\rightarrow$  decrease light Higgs mass

$$\Delta\lambda_2^{(\tilde{\nu})} = -\frac{1}{16\pi^2} \sum_{i=1}^{N_f} \frac{|A_\nu|^4}{(m_{\tilde{\nu}_2}^2 - m_{\tilde{\nu}_1}^2)^2} \left( \frac{m_{\tilde{\nu}_2}^2 + m_{\tilde{\nu}_1}^2}{m_{\tilde{\nu}_2}^2 - m_{\tilde{\nu}_1}^2} \log \frac{m_{\tilde{\nu}_2}^2}{m_{\tilde{\nu}_1}^2} - 2 \right)$$

# Signatures of light sneutrino DM

- Direct detection best way to test light sneutrino
  - Need good sensitivity to low masses
- Indirect detection:
  - Annihilation  $bb, \tau\tau \rightarrow$  low energy photons, positrons, antiprotons
  - in region where background is uncertain
  - T. Delahaye et al 0809.5268
  - Some scenarios lead to large distortion of spectrum

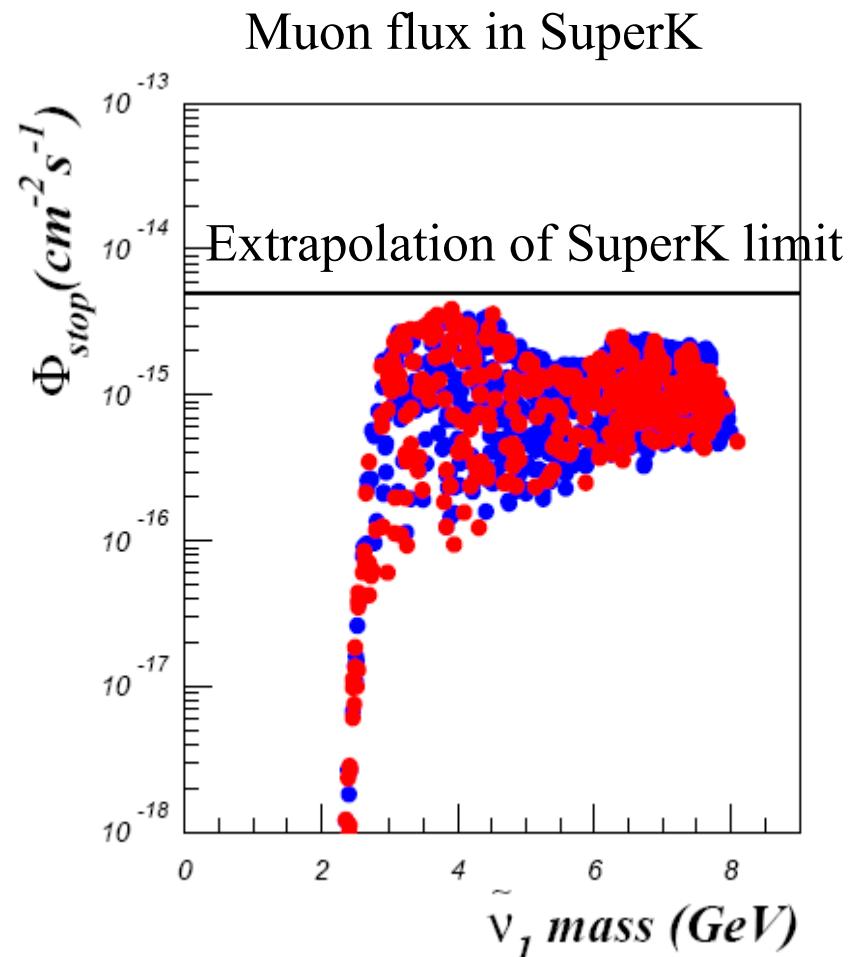
Antiproton signal for some benchmarks



# Signatures of light sneutrino DM

- Often dominant annihilation into neutrinos : signature in neutrino telescope
  - Solar capture – large flux but low energy neutrino
  - Antares, Icecube have cutoff ~ 25GeV
  - SuperK best limit from through going muons – mass > 18GeV
  - Light sneutrino imply only contained events in SuperK

$$\begin{aligned}\dot{N}_\chi &= C_\chi - 2A_{\chi\chi}N_\chi^2 - A_{\chi\bar{\chi}}N_\chi N_{\bar{\chi}}, \\ \dot{N}_{\bar{\chi}} &= C_{\bar{\chi}} - 2A_{\bar{\chi}\bar{\chi}}N_{\bar{\chi}}^2 - A_{\chi\bar{\chi}}N_\chi N_{\bar{\chi}},\end{aligned}$$

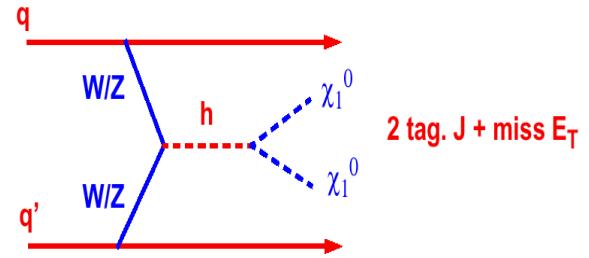


# Signatures of sneutrino DM

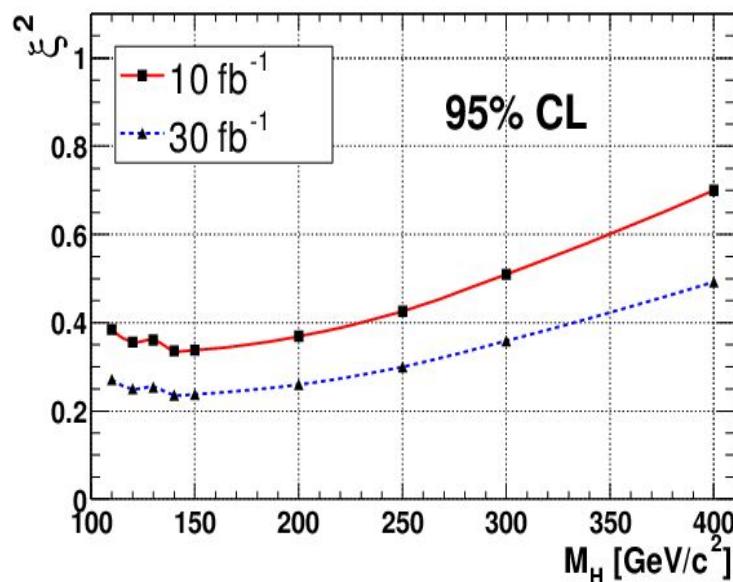
- Colliders:
  - Invisible Higgs (almost 100% B.R)
  - Other predictions more dependent on the complete spectrum ( $\sim eL$ ,  $\sim eR$ ,  $\sim q ..$ )
  - Characteristic signatures?

# LHC

- Invisible Higgs
- SUSY  $\tilde{\chi}_2^0 \rightarrow \tilde{\nu}_1 \nu$  or  $\chi^+ \rightarrow \tilde{\nu}_1 l^-$  fer
- MSSM:  $\chi_2^- \rightarrow l^+ l^- \chi_1^0, \chi^+ \rightarrow \sim l \nu$
- Trilepton suppressed ( $pp \rightarrow \chi^+ \chi_2^0$ )
- Gluino production as in MSSM, decay  $\tilde{g} \rightarrow q(\tilde{q}) \rightarrow q(\chi^+ q') \nu$  (invisible)  
neu  $\tilde{g} \rightarrow q\tilde{q}'(\chi^+) \rightarrow q\tilde{q}'(\tilde{\nu}_1 l^-)$

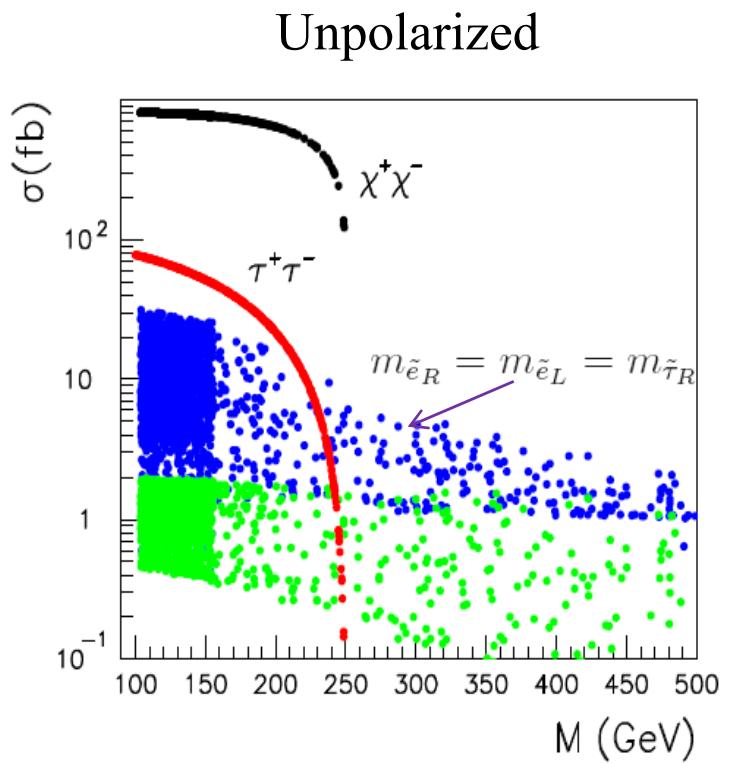


$$\xi^2 = \frac{\sigma(Hjj)}{\sigma(Hjj)_{SM}} \times \text{Br}(H \rightarrow \text{inv})$$



# ILC

- Invisible Higgs  $e^+e^- \rightarrow Z^* \rightarrow Zh$
- Chargino, stau pair (if kinematic accessible)
- Invisible particles + single photon
- $e^+e^- \rightarrow \chi_1\chi_1\gamma, \chi_1\chi_2\gamma, \chi_2\chi_2\gamma, \gamma\nu_1\nu_1$
- Model independent search for DM at ILC -
  - Bartels, List ..
- Reach with  $500\text{fb}^{-1} \sim 1\text{-}2\text{fb}$



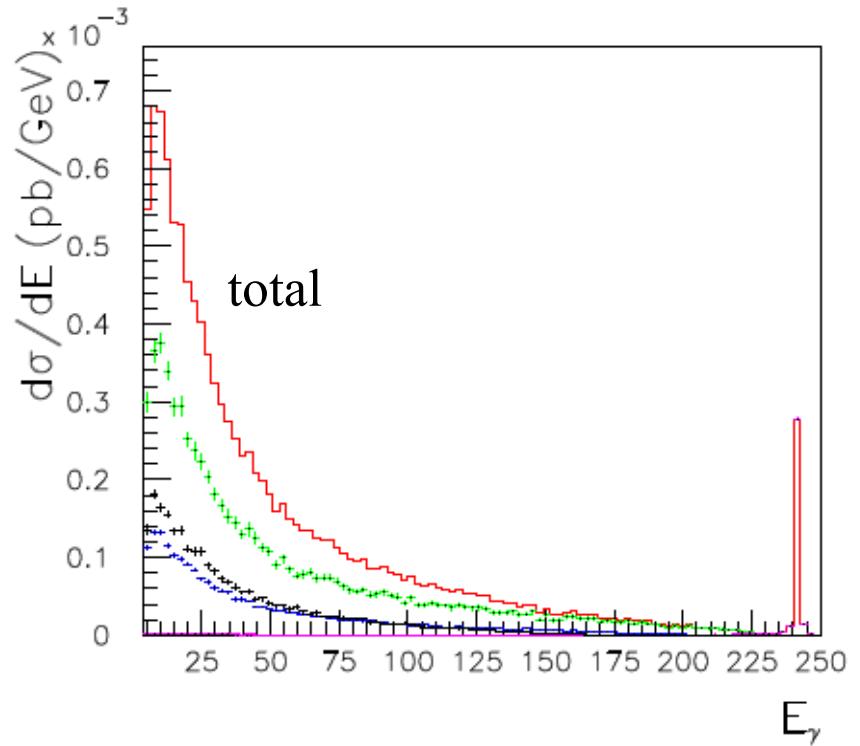
Allowed scenarios with light  
Sneutrinos

# ILC

- While for DM properties only sneutrino sector + gaugino was relevant for collider searches strong dependence on full spectrum (e.g. selectron mass)
- One scenario with

$$m_{\tilde{e}_R} = m_{\tilde{e}_L} = m_{\tilde{\tau}_R}$$

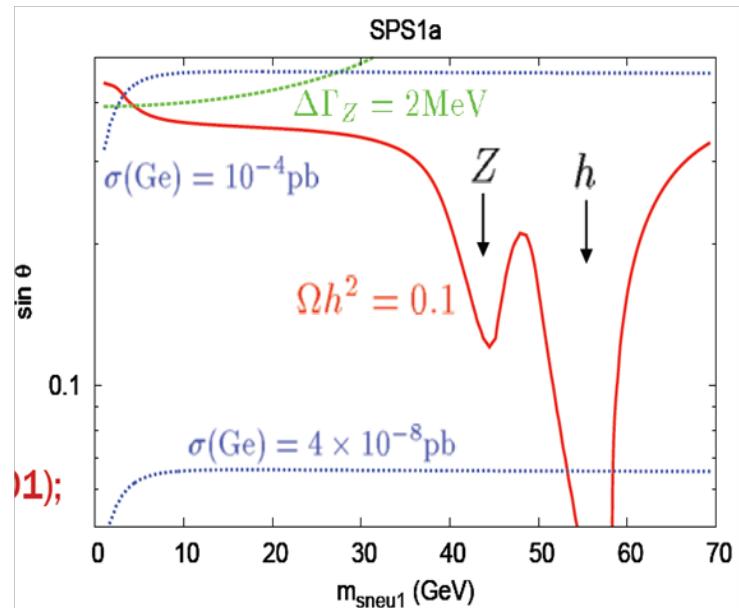
- Photoc... spectrum at high energy from light sneutrino ( $Z$ )



Sneutrino masses 3.5,200 GeV  
mixing= 0.34  
 $M_2 : 140$  GeV

# Not so light sneutrino

- Sneutrino does not have to be very light
- Example : SPS1a + sneutrino LSP
- Annihilation near Higgs resonance
- Hard to distinguish from neutralino LSP
  - No invisible Higgs
  - Neutralino NLSP invisible decay
  - Chargino production via squark decay
    - >kinematic endpoint in jet-lepton invariant mass distribution,
  - Thomas, Tucker-Smith, Weiner  
arXiv:0712.4146



Measure SUSY spectrum use  
this to make collider  
prediction of  $\Omega h^2$  – mismatch  
WMAP

# Conclusion

- Sneutrino with large mixing is viable thermal DM candidate and can be a light candidate
- Link neutrino masses, hierarchy, DM
- Best way to test is direct detection, also distinctive signatures at LHC and ILC