Very light SUSY WIMPs

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Containing work done (and in progress) in collaboration with C. Muñoz, O. Seto, (M. Peiró, N. Fornengo)

Outline

Motivation: Direct DM Detection (hints of very light WIMPs?)

Very light neutralino DM in the MSSM

Very light neutralino DM in the Next-to-MSSM

Right-Handed Sneutrino as WIMP dark matter in the NMSSM

Predictions for direct detection

Very light sneutrinos

Conclusions

WHAT is the Dark Matter?

... WHAT DO WE KNOW...

- Good dark matter candidates must fulfil a number of requirements

- Neutral
- Stable on cosmological scales
- Reproduce the correct relic abundance
- Not excluded by direct or indirect searches
- No conflicts with BBN or stellar evolution

- Many candidates in Particle Physics

- Axions
- Weakly-Interacting massive particles:

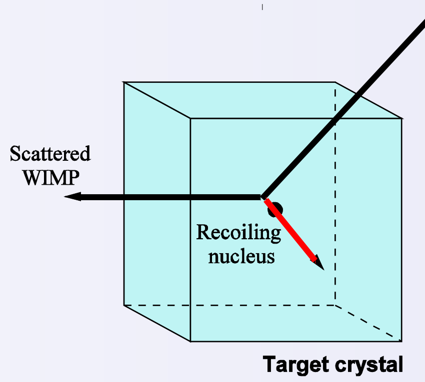
  WIMPs
- SuperWIMPs (gravitino, axino)
- SIMPs, CHAMPs, SIDMs, WIMPzillas, Scalar DM, Light DM, ...

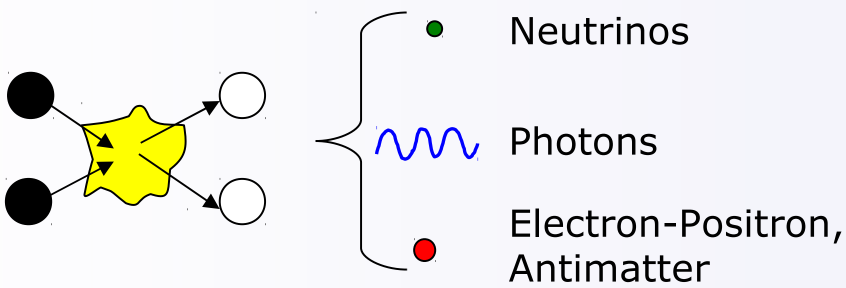
NEW PHYSICS BEYOND THE STANDARD MODEL OF PARTICLE PHYSICS

Detection of Dark Matter

- Direct Detection:

  Look for the elastic scattering of dark matter with nuclei



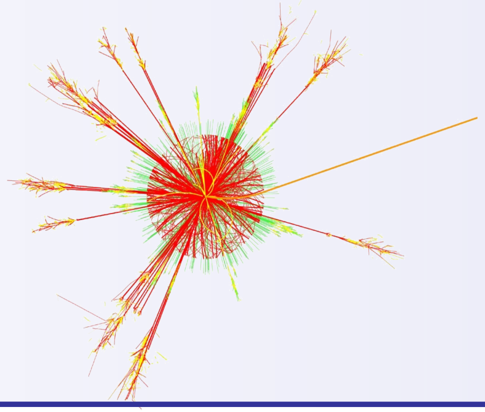


- Indirect Detection:

  Look for the annihilation products

- Accelerator Searches

  Look for signals of new physics



Direct detection of WIMPs

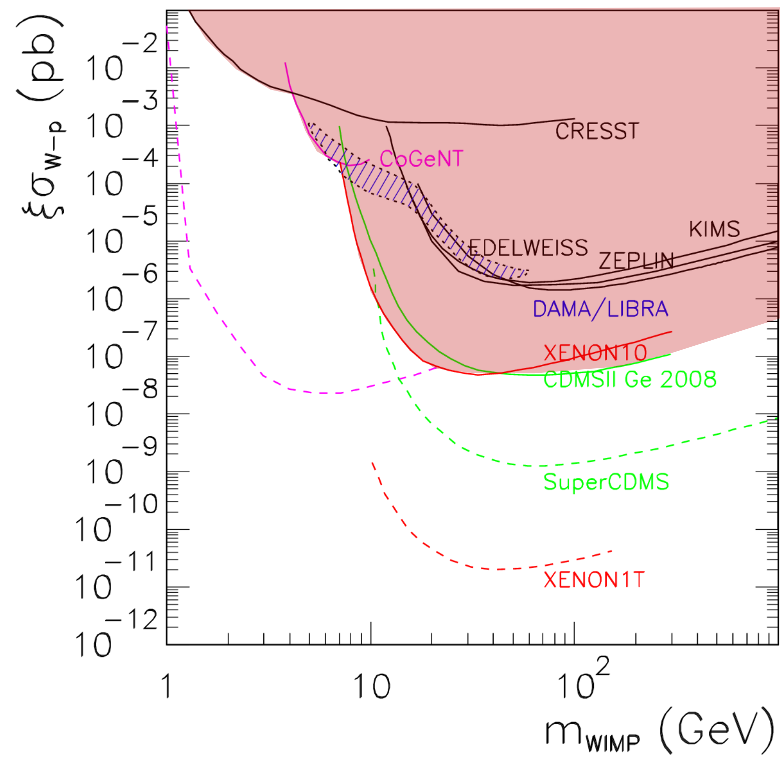
- Most of the experiments nowadays are mostly sensitive to the scalar (spin-independent) part of the WIMP-nucleon cross section

DAMA/LIBRA (based on NaI) claims a potential dark matter signal

Other experiments XENON10-100, CDMS(?) have not yet confirmed any WIMP in the DAMA region (maybe very light WIMPs? CoGeNT)

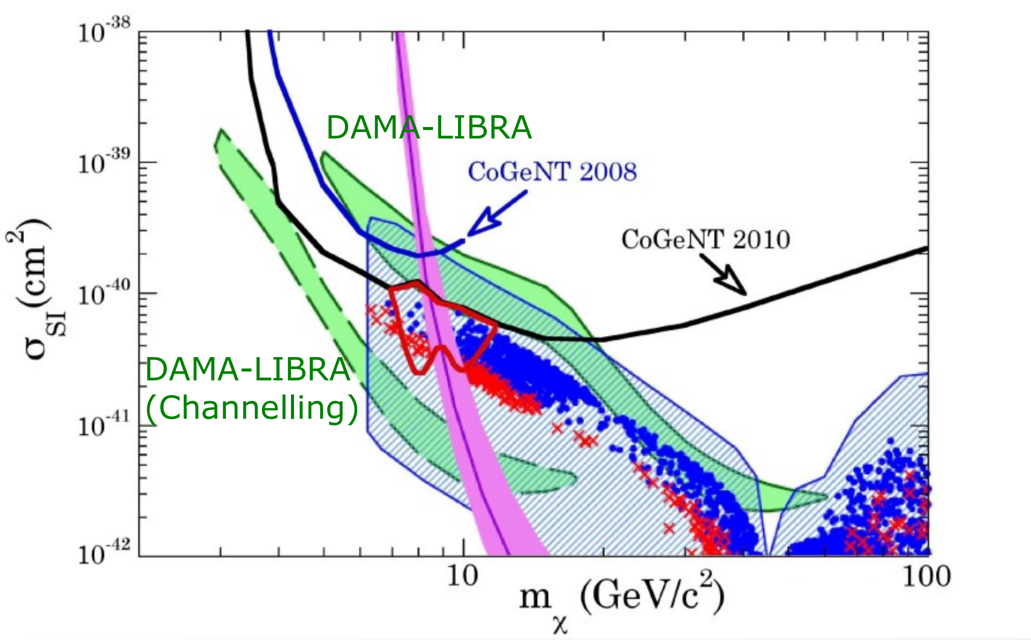
The current sensitivity and future predictions will allow to explore models for particle dark matter.

Need to compare with theoretical predictions for WIMP models



Recent results for light WIMPs

- Very light WIMPs might be motivated by experimental results from direct detection



(CoGeNT Coll. 2010)

Not excluded by other experiments (depending on the halo model)

Very light WIMPs (5-12 GeV) could account for the DAMA/LIBRA signal and be compatible with CDMS "events" (maybe not with recent reanalysis) and recent results from CoGeNT...

Incompatible with XENON10-100?

(Subtleties in the treatment of L_{eff})

(Aprile et al (XENON Coll) 2010)
(Savage et al. 2010)
(Collar, McKinsey 2010)

Signal in CRESST?

(Seidel @ IDM2010)

Are there theoretical models for these WIMPs?

Generic Problems of very light WIMPs

- Theoretical models for very light WIMPs generally face three complications

Naturalness of the very light mass

Normally requires a careful tuning of parameters and introducing deviations from simplest models

Low energy constraints

Some low-energy observables get too large contributions (e.g., Invisible Z decay width, and BR($B_s \rightarrow \mu^+\mu^-$))

Reproducing the correct relic abundance

SM annihilation products: $f\bar{f}$ (generally $b\bar{b}$) – Other SM particles kinematically forbidden

Supersymmetric Dark Matter

• The Lightest SUSY Particle is stable in theories with R-parity. Thus, it will exist as a remnant from the early universe and may account for the observed Dark Matter.

In the MSSM, the LSP can be…

Squarks	$\tilde{u}_{R,L}$, $\tilde{d}_{R,L}$ $\tilde{c}_{R,L}$, $\tilde{s}_{R,L}$ $\tilde{t}_{R,L}$, $\tilde{b}_{R,L}$
Sleptons	$\tilde{e}_{R,L}$, $\tilde{\nu}_e$ $\tilde{\mu}_{R,L}$, $\tilde{\nu}_\mu$ $\tilde{\tau}_{R,L}$, $\tilde{\nu}_\tau$
Neutralinos	$\tilde{B}^0$, $\tilde{W}^0$, $\tilde{H}^0_{1,2}$
Charginos	$\tilde{W}^\pm$, $\tilde{H}^\pm_{1,2}$
Gluino	$\tilde{g}$

Lightest sneutrino: They annihilate very quickly and the regions where the correct relic density is obtained are already experimentally excluded

(Ibáñez '84; Hagelin, Kane, Rabi '84)

Lightest neutralino: WIMP

(Goldberg '83; Ellis, Hagelin, Nanopoulos, Olive, Srednicki '83; Krauss '83)

Neutralino Dark Matter

- In the MSSM

The neutralino in the MSSM

- Neutralinos in the MSSM are physical superpositions of the bino and wino $(\tilde{B}^0,\ \tilde{W}_3^0)$ and Higgsinos $(\tilde{H}_d^0,\ \tilde{H}_u^0)$

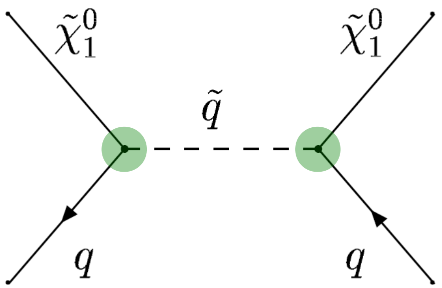
$$\mathcal{M}_{\tilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & -M_Z s_\theta c_\beta & M_Z s_\theta s_\beta \\ 0 & M_2 & M_Z c_\theta c_\beta & -M_Z c_\theta s_\beta \\ -M_Z s_\theta c_\beta & M_Z c_\theta c_\beta & 0 & -\mu \\ M_Z s_\theta s_\beta & -M_Z c_\theta s_\beta & -\mu & 0 \end{pmatrix}$$

The detection and annihilation properties of the neutralino depend on its composition

$$\tilde{\chi}_1^0 = \underbrace{N_{11}\,\tilde{B}^0 + N_{12}\,\tilde{W}_3^0}_{\texttt{Gaugino content}} + \underbrace{N_{13}\,\tilde{H}_d^0 + N_{14}\,\tilde{H}_u^0}_{\texttt{Higgsino content}}$$

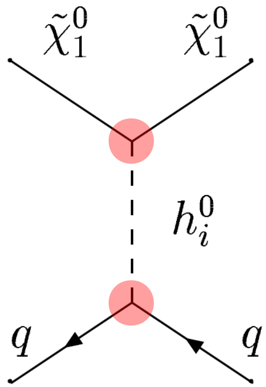
Spin-independent cross section

- Contributions from **squark-** and **Higgs-**exchanging diagrams:



Squark-exchange

$$\sigma_{\tilde{\chi}_1^0-p} \propto \frac{m_r^2}{4\pi}\left(\frac{g'^2 \sin\theta}{m_{\tilde{q}}^2 - m_{\tilde{\chi}_1^0}^2}\right)^2 |N_{11}|^4$$



Higgs-exchange

It is the leading contribution, and increases when

$$\sigma_{\tilde{\chi}_1^0-p} \propto \frac{m_r^2}{4\pi}\frac{\lambda_q^2}{m_h^4}\left|N_{13,\,14}\,(g' N_{11} - g N_{12})\right|^2$$

- The Higgsino components of the neutralino increase $\mu \downarrow$
- The Higgs masses decrease $m_h,\ m_{H^0}\ m_{A^0} \downarrow$

The neutralino in the MSSM

- The neutralino can be within the reach of present and projected direct DM detectors

Large cross section for a wide range of masses

Very light **Bino-like** neutralinos with masses ~10 GeV

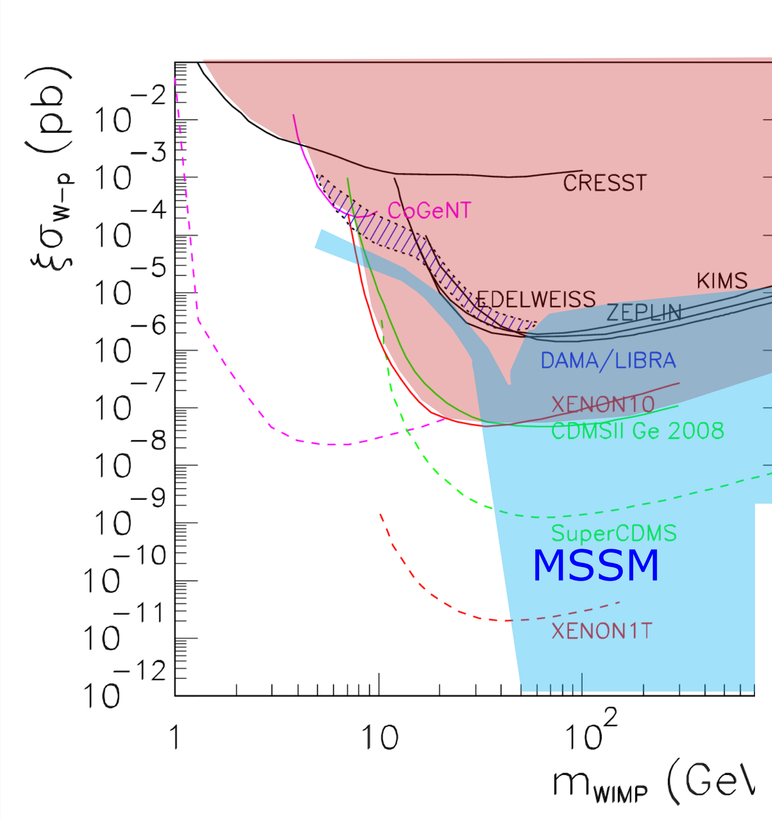
(Bottino, Donato, Fornengo, Scopel '04-'08)

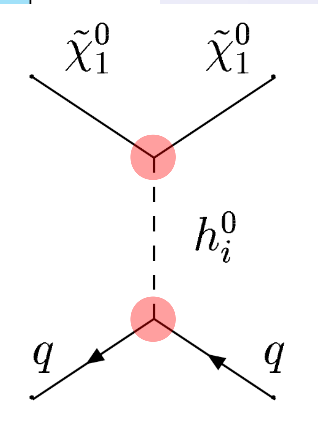
Bayesian analyses show preference for regions within the reach of CDMS and Xenon

(Roszkowski, Ruiz de Austri, Trotta '08)

A frequentist approach may favour different regions

(K. Olive et al.





Very light neutralinos in the MSSM

• Light neutralinos in the MSSM are possible

In order to avoid constraints on the chargino mass $M_2, \mu > 100 \quad GeV$

Therefore, these neutralinos are Bino-like $M_1 \ll M_2, M_3$

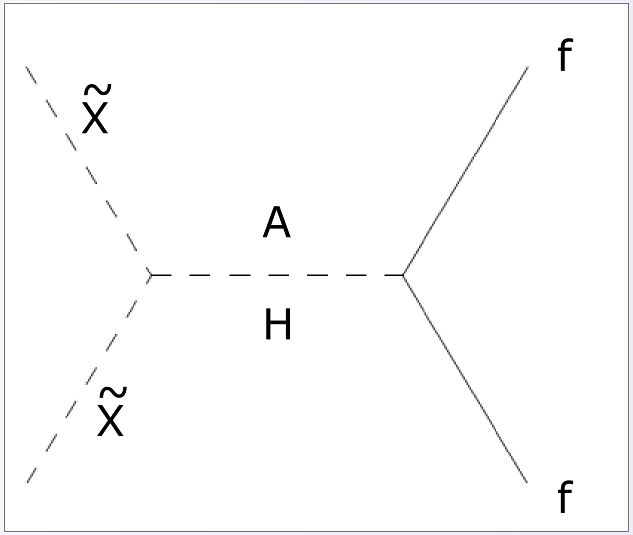
(this is crucial to reduce the contribution to the invisible Z decay width)

• The correct relic abundance is only possible due to an increase of the annihilation in bb through pseudoscalar Higgses

This requires

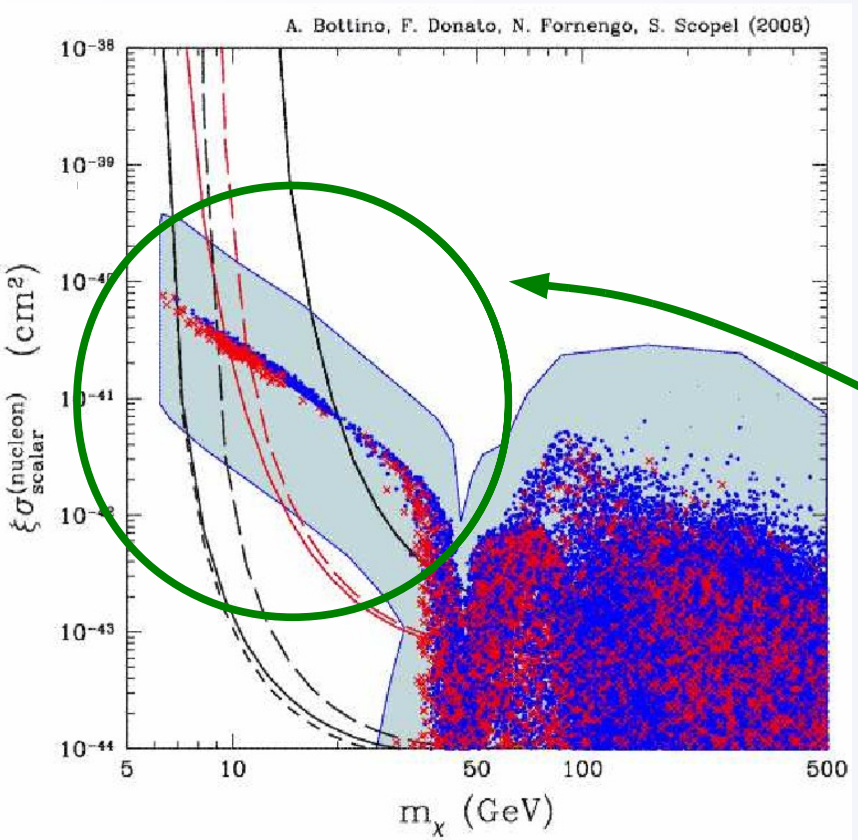
$$m_A \leq 200\, GeV$$

$$\tan\beta \geq 35$$

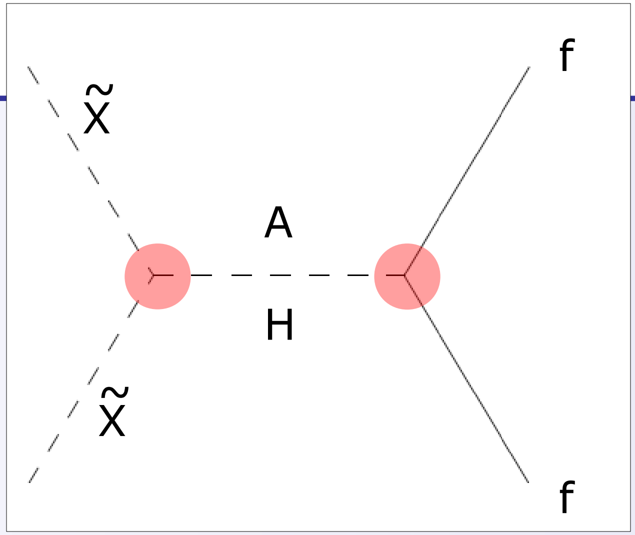


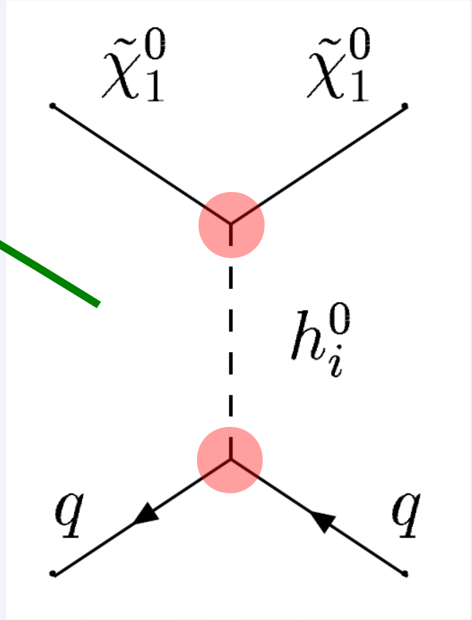
Very light neutralinos in the MSSM

- Direct detection correlated to annihilation diagram



(Bottino, Donato, Fornengo, Scopel '08)





Very light neutralinos in the MSSM

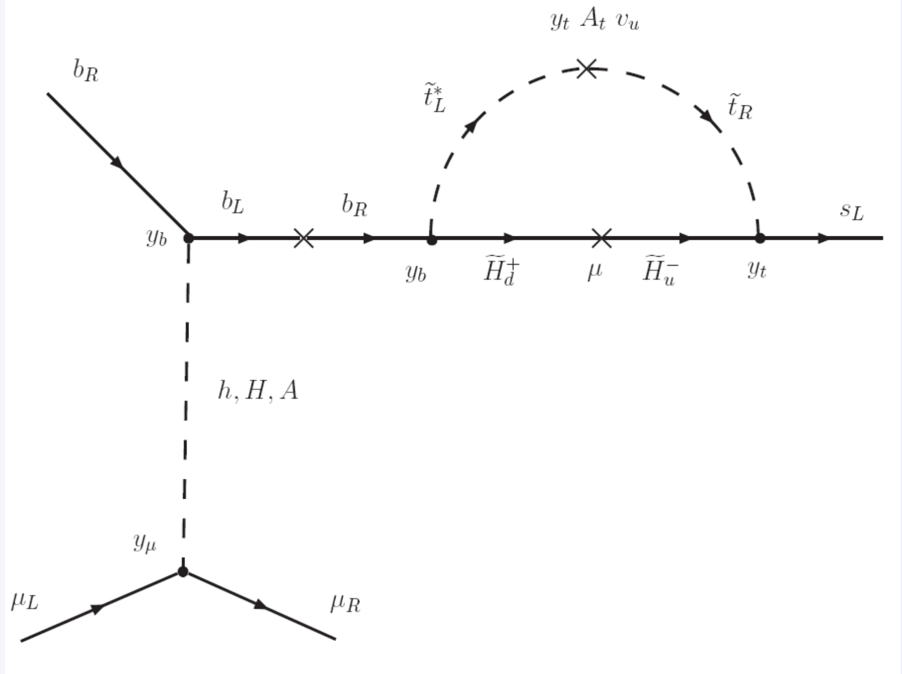
- The problem with **BR(Bs → μ+μ−)**

For large enough values of tan β

$$B(B_s^0 \to \mu^+\mu^-) \propto \frac{\tan^6\beta}{m_A^4}\left(\frac{\mu A_t}{m_{\tilde{t}_L}^2}\right)^2$$

$$m_A \leq 200\, GeV$$
$$\tan\beta \geq 40$$

The conditions for very light neutralinos are precisely the conditions for increasing the theoretical predictions of BR(Bs → μ+μ-)



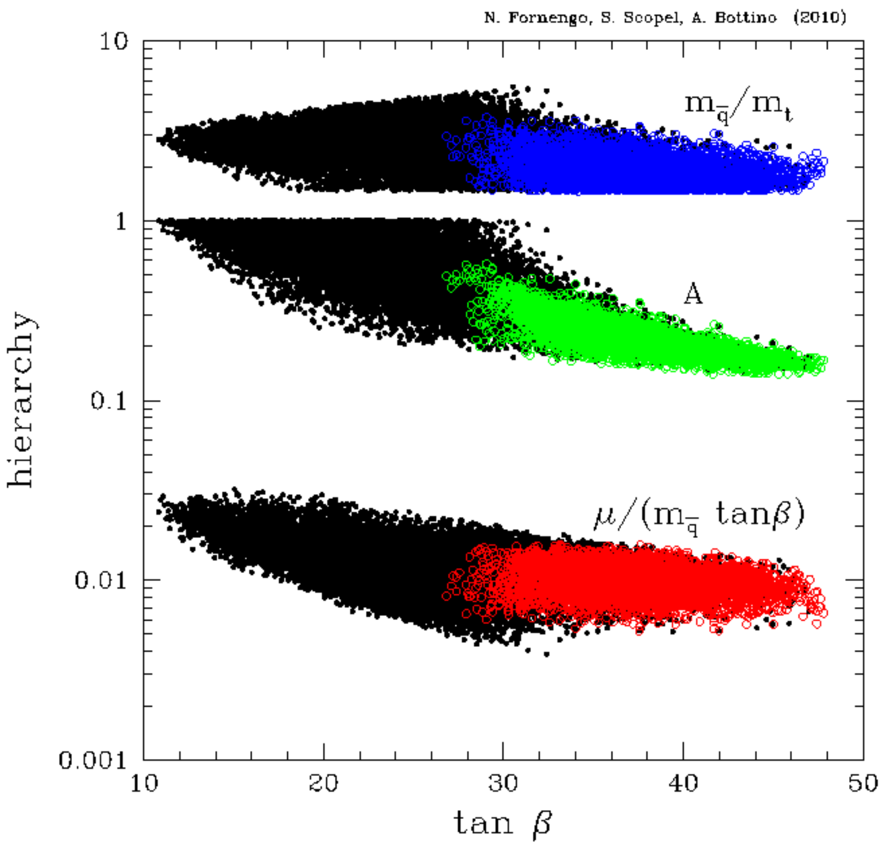
$$BR(B_s \to \mu^+\mu^-) < 5.8 \times 10^{-8}$$

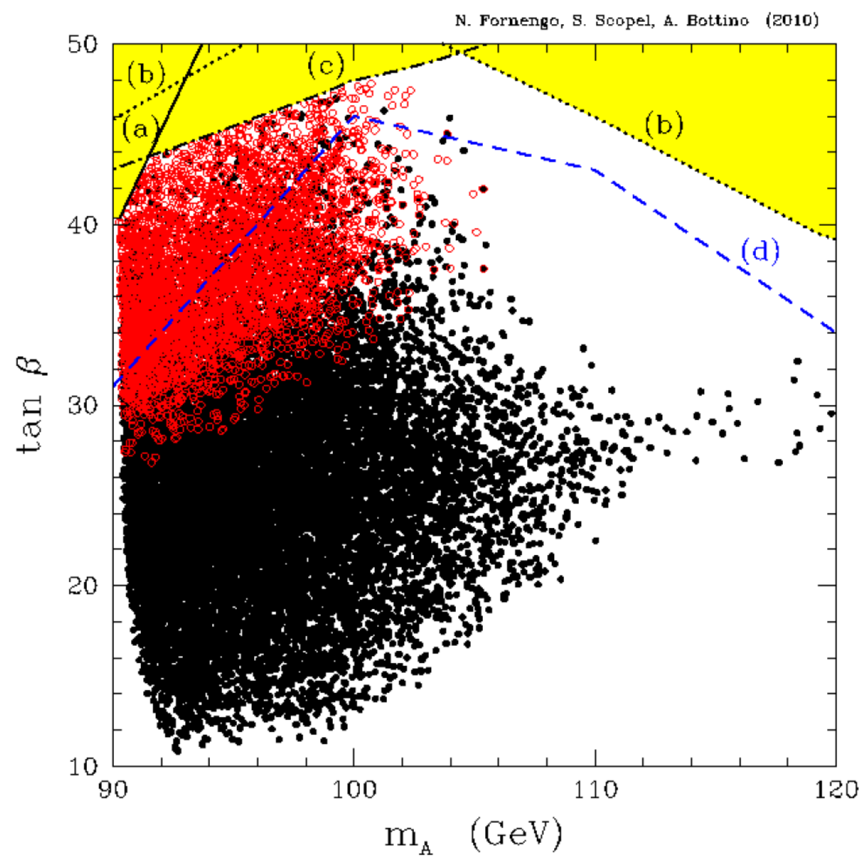
(CDF '07 – See also results from D0)

- A hierarchical structure at low energy (achieving a small trilinear parameter)

$$\frac{|\mu|}{m_{\tilde{q}}\ \tan\beta} \ll |A| \ll \frac{m_{\tilde{q}}}{m_t}$$

Tevatron Bounds on the pseudoscalar mass can be avoided



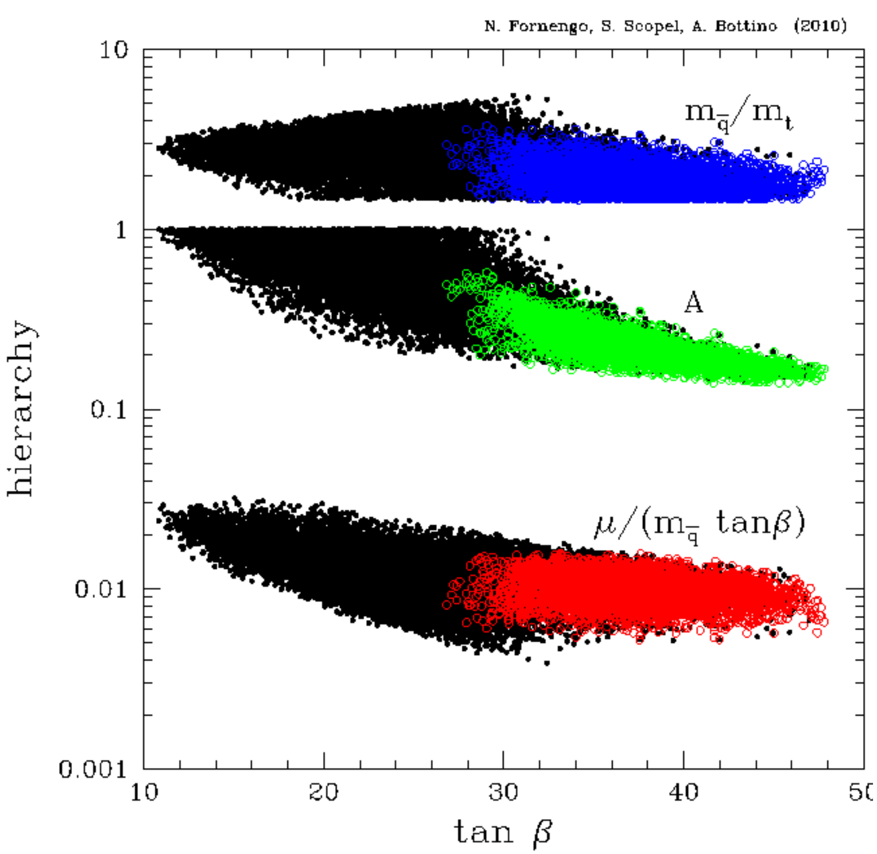


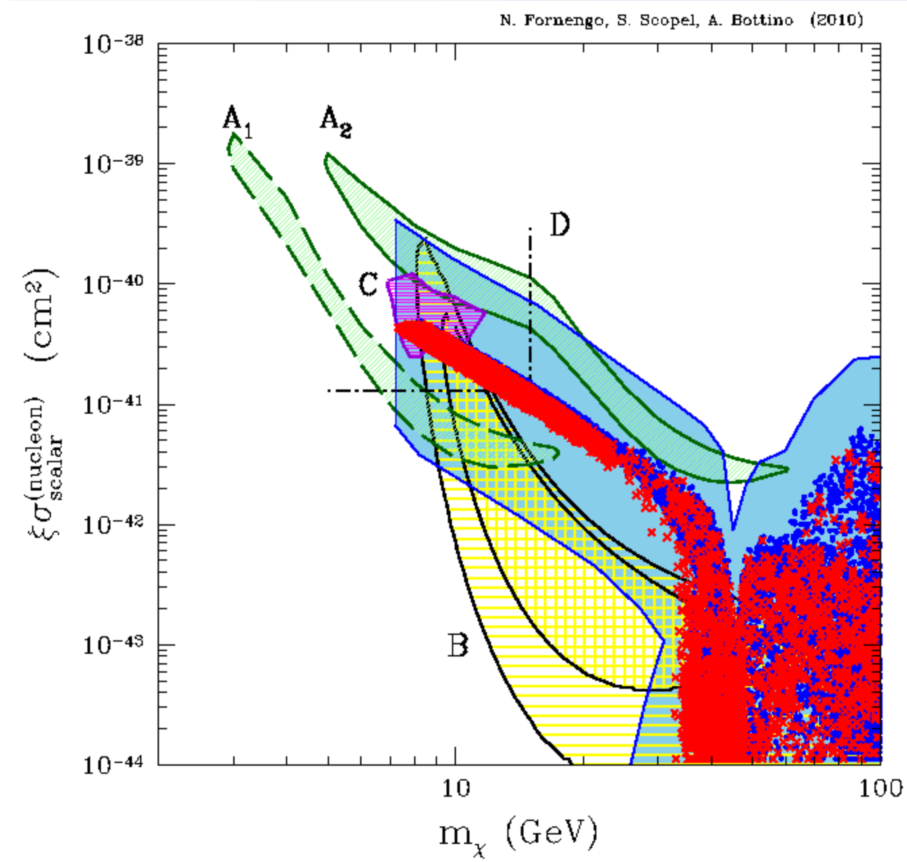
(Bottino, Donato, Fornengo, Scopel '10)

- A hierarchical structure at low energy (achieving a small trilinear parameter)

$$\frac{|\mu|}{m_{\tilde{q}}\ \tan\beta} \ll |A| \ll \frac{m_{\tilde{q}}}{m_t}$$

And the result is compatible with CoGeNT + (maybe) DAMA-LIBRA





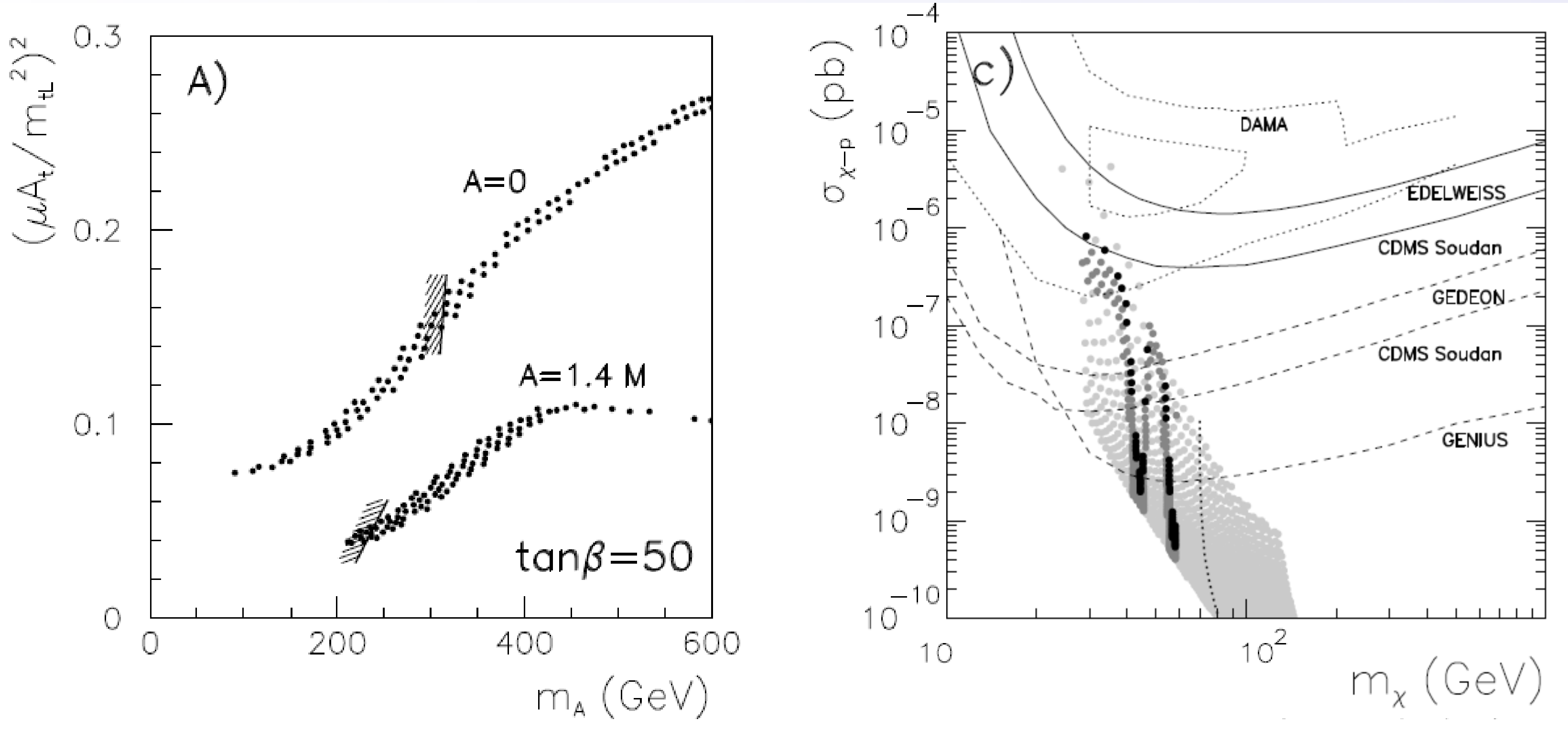
(Bottino, Donato, Fornengo, Scopel '10)

• Can these points be obtained with parameters given at the GUT scale (general SUGRA)

General SUGRA theory with non-universal gauginos and scalar masses

Careful tuning of the trilinear top parameter At

The pseudoscalar mass can be decreased and the conditions for very light WIMPs recovered.



(Baek, D.G.C., Kim, Ko, Muñoz 04)
(D.G.C., Fornengo, Muñoz, Peiró in progress)

Neutralino Dark Matter

- In the Next-to-MSSM

The Next-to-MSSM

- Offers an elegant solution to the μ problem of the MSSM

The superpotential of the MSSM contains a μ term with a naturalness problem

$$W(\mu) = \mu\, H_1\, H_2$$

Radiative Electroweak Symmetry-Breaking implies

$$\mu \approx \mathcal{O}(M_{\mathrm{EW}},\, M_{\mathrm{SUSY}})$$

Solution: Promote it to a trilinear term (including a new singlet field S)

$$W(\mu) = \lambda S\, H_1\, H_2; \qquad \rightarrow \qquad \mu_{\mathrm{eff}} = \lambda \langle S \rangle$$

The Next-to-MSSM

- Addition of a new superfield, ***S***, singlet under the SM gauge group

$$\mathrm{NMSSM} \quad = \quad \mathrm{MSSM} + \hat{S} \begin{cases} 2 \text{ extra Higgs (CP} - \text{even, CP} - \text{odd)} \\ 1 \text{ additional Neutralino} \end{cases}$$

- New terms in the superpotential

$$W = Y_u\, H_2\, Q\, u + Y_d\, H_1\, Q\, d + Y_e\, H_1\, L\, e - \lambda\, S\, H_1 H_2 + \frac{1}{3}\kappa S^3$$

- New terms in the Lagrangian

$$-\mathcal{L}_{\rm soft}^{\rm Higgs} = m_{H_i}^2\, H_i^* H_i + m_S^2\, S^* S + (-\lambda A_\lambda\, S H_1 H_2 + \frac{1}{3}\kappa A_\kappa\, S^3 + \mathrm{H.c.})$$

The Next-to-MSSM

- Addition of a new superfield, ***S***, singlet under the SM gauge group

$$\text{NMSSM} \quad = \quad \text{MSSM} + \hat{S} \left\{ \begin{array}{l} 2 \text{ extra Higgs } (\text{CP}-\text{even}, \;\; \text{CP}-\text{odd}) \\ 1 \text{ additional Neutralino} \end{array} \right.$$

- New terms in the superpotential

$$W = Y_u \, H_2 \, Q \, u + Y_d \, H_1 \, Q \, d + Y_e \, H_1 \, L \, e - \lambda \, S \, H_1 H_2 + \frac{1}{3} \kappa S^3$$

- New terms in the Lagrangian

$$-\mathcal{L}_{\text{soft}}^{\text{Higgs}} = m_{H_i}^2 \, H_i^* H_i + m_S^2 \, S^* S + (-\lambda A_\lambda \, S H_1 H_2 + \frac{1}{3} \kappa A_\kappa \, S^3 + \text{H.c.})$$

- After Radiative Electroweak Symmetry-Breaking

$$\langle H_1^0 \rangle = v_1 \quad ; \quad \langle H_2^0 \rangle = v_2 \quad ; \quad \langle S \rangle = s \, (= \frac{\mu}{\lambda})$$

The Next-to-MSSM

- In terms of physical fields, the addition of the singlet superfield, ***S***, implies

1 extra CP-odd Higgs $$P^0 = (A^0, S_I)$$

SINGLET

1 extra CP-even Higgs $$H^0 = (H_{1R},\, H_{2R},\, S_R)$$

1 extra Neutralino $$\tilde{\chi}^0 = (\tilde{B}^0, \tilde{W}_3^0,\, \tilde{H}_u^0,\, \tilde{H}_d^0, \tilde{S})$$ **SINGLINO**

- Rich Phenomenology

Very light Higgses and Neutralinos are experimentally viable

Neutralino in the NMSSM

$$\text{NMSSM} = \text{MSSM} + \hat{S} \begin{cases} 2 \text{ extra Higgs (CP} - \text{even, CP} - \text{odd)} \\ 1 \text{ additional Neutralino} \end{cases}$$

- In the Next-to-MSSM there is a fifth neutralino due to the mixing with the singlino

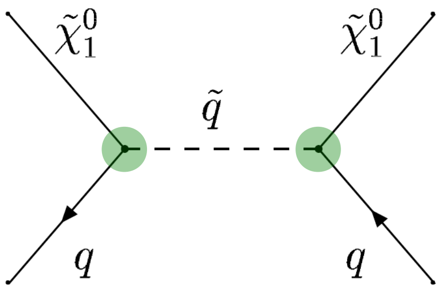
$$\mathcal{M}_{\tilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & -M_Z s_\theta c_\beta & M_Z s_\theta s_\beta & 0 \\ 0 & M_2 & M_Z c_\theta c_\beta & -M_Z c_\theta s_\beta & 0 \\ -M_Z s_\theta c_\beta & M_Z c_\theta c_\beta & 0 & -\mu & -\lambda v_2 \\ M_Z s_\theta s_\beta & -M_Z c_\theta s_\beta & -\mu & 0 & -\lambda v_1 \\ 0 & 0 & -\lambda v_2 & -\lambda v_1 & 2\kappa \frac{\mu}{\lambda} \end{pmatrix}$$

The lightest neutralino has now a singlino component

$$\tilde{\chi}_1^0 = \underbrace{N_{11}\,\tilde{B}^0 + N_{12}\,\tilde{W}_3^0}_{\text{Gaugino content}} + \underbrace{N_{13}\,\tilde{H}_d^0 + N_{14}\,\tilde{H}_u^0}_{\text{Higgsino content}} + \underbrace{N_{15}\,\tilde{S}}_{\text{Singlino content}}$$

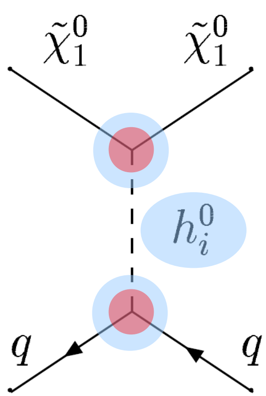
Spin-independent cross section

- Contributions from **squark-** and **Higgs-**exchanging diagrams:



Squark-exchange

$$\sigma_{\tilde{\chi}_1^0 - p} \propto \frac{m_r^2}{4\pi} \left(\frac{g'^2 \sin\theta}{m_{\tilde{q}}^2 - m_{\tilde{\chi}_1^0}^2} \right)^2 |N_{11}|^4$$



Higgs-exchange It is the leading contribution, and increases when

In the NMSSM very light Higgses ($m_h \geq$ 20 GeV) can be obtained in the NMSSM. These have a large singlet component and avoid experimental constraints.

- The Higgs masses decrease $m_h,\ m_{H^0}\ m_{A^0} \downarrow$

Neutralino in the NMSSM

- Different predictions from the MSSM (extensions with extra U(1) are also possible)

The detection cross section can be larger (through the exchange of light Higgses)

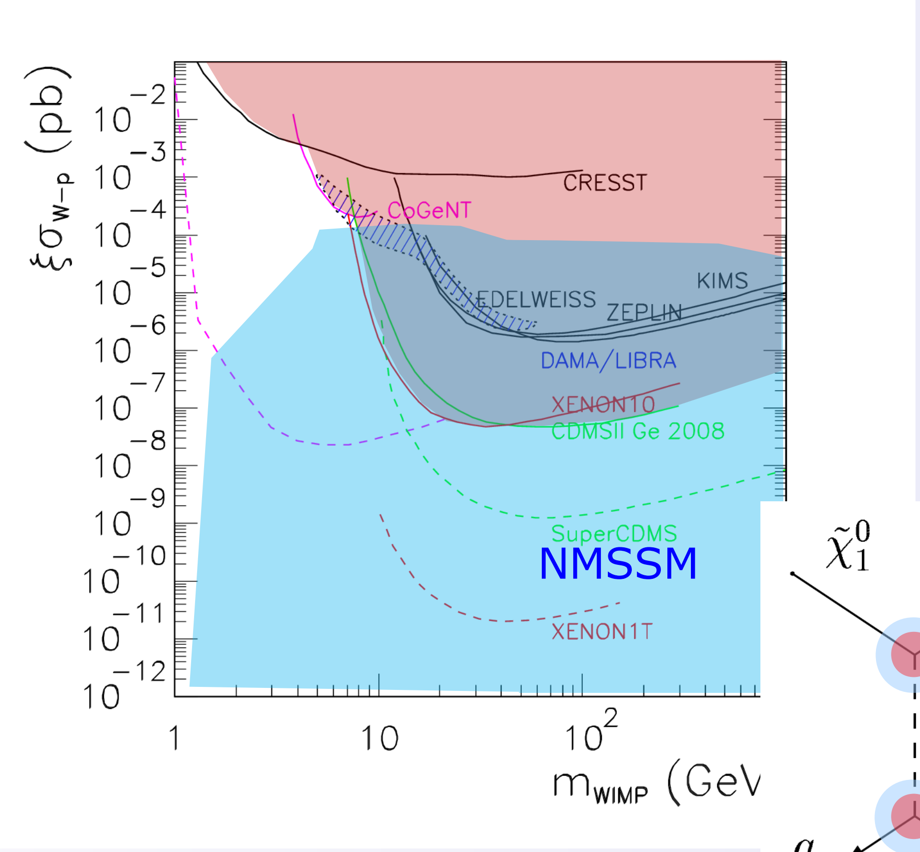
(D.G.C., E. Gabrielli, D.López-Fogliani, A.Teixeira, C.Muñoz ´07)

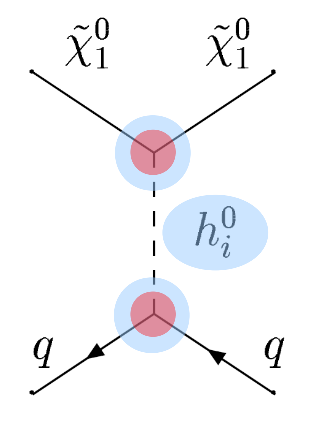
Very light **Bino-singlino** neutralinos are possible

(Gunion, Hooper, McElrath '05)

And their detection cross section significantly differs from that in the MSSM

(D.G.C, with CoGeNT '08)





Very light neutralinos in the NMSSM

- Light neutralinos in the NMSSM with a new possibility

1) MSSM-like light neutralinos are still possible: **BINO-LIKE**

In order to avoid constraints on the chargino mass $M_{2,}\mu > 100 \quad GeV$

Therefore, these neutralinos are Bino-like $M_1 \ll M_{2,} M_3$

(this is crucial to reduce the contribution to the invisible Z decay width)

2) Another possibility: **SINGLINO-LIKE (OR BINO-SINGLINO)**

$$\kappa \to 0 \quad ; \quad \kappa \frac{\mu}{\lambda} \to 0$$

In this limit a Peccei-Quinn type symmetry is restored and the mass of one of the pseudoscalars (which plays the role of a pseudo-Goldstone boson) also goes to zero.

(optimal to avoid constraints from invisible Z decay width)

Very light neutralinos in the NMSSM

- Correct relic abundance through the Higgs properties

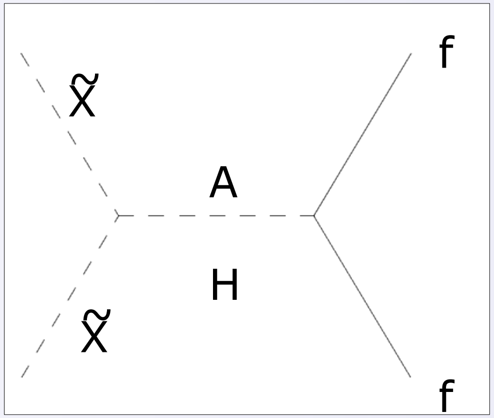
Same as in the MSSM but now

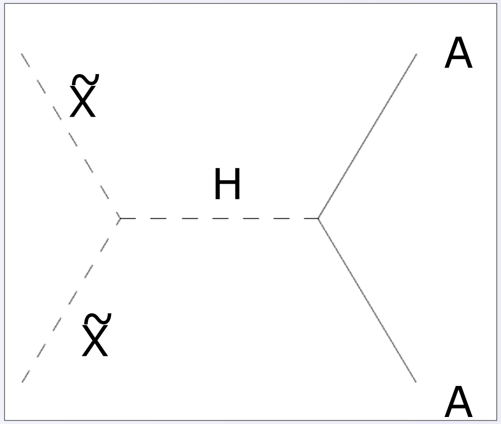
Lighter Higgses are possible (i.e., larger contribution, easier)

Possibility of resonant annihilation through pseudoscalar

$$2 \quad m_X = m_A$$

Annihilation into pseudoscalars (only for very light A)

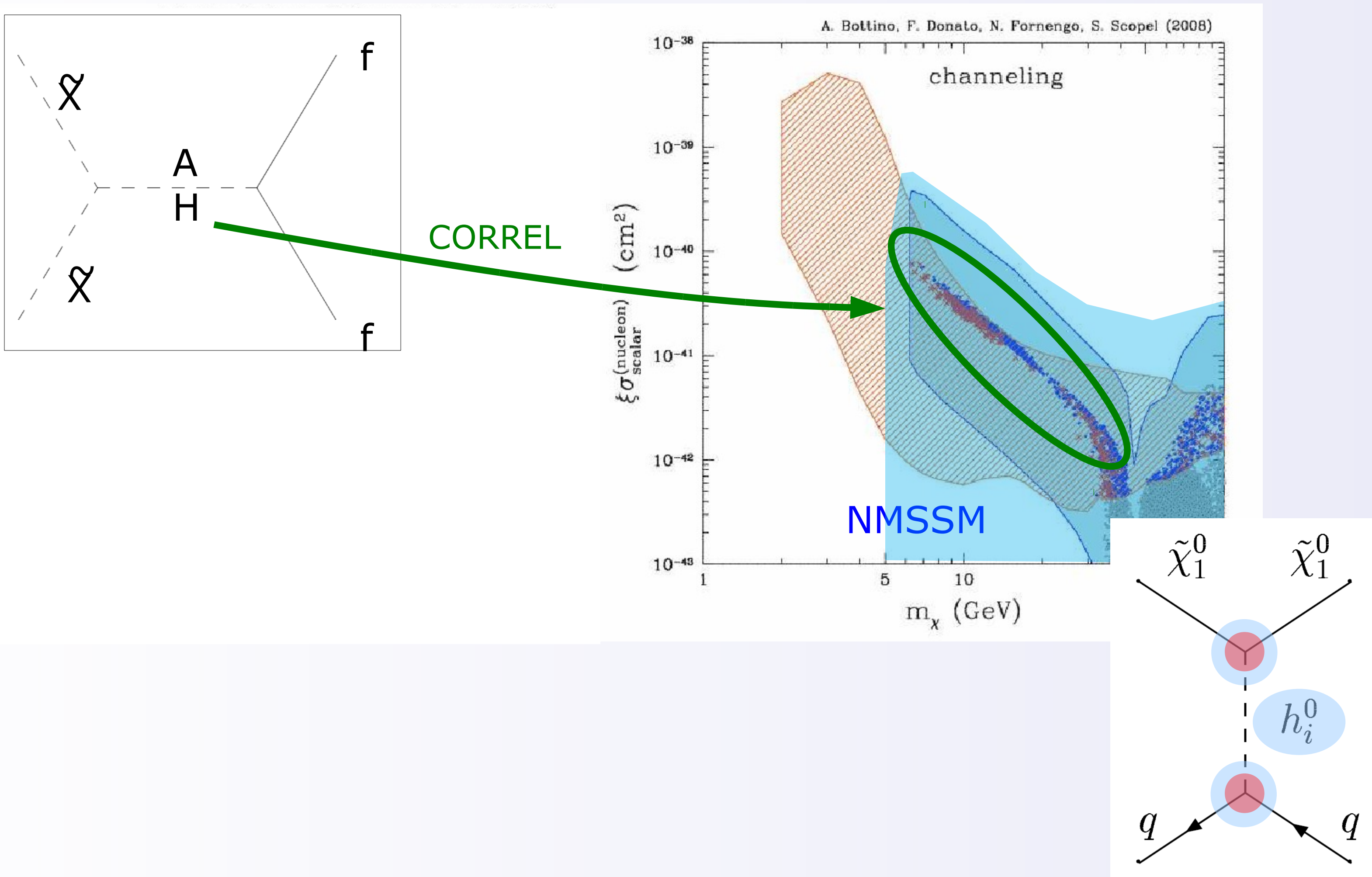




Very light neutralinos in the NMSSM

- Direct detection is now not always correlated

(D.G.C. With CoGeNT '08)



Very light neutralinos in the NMSSM

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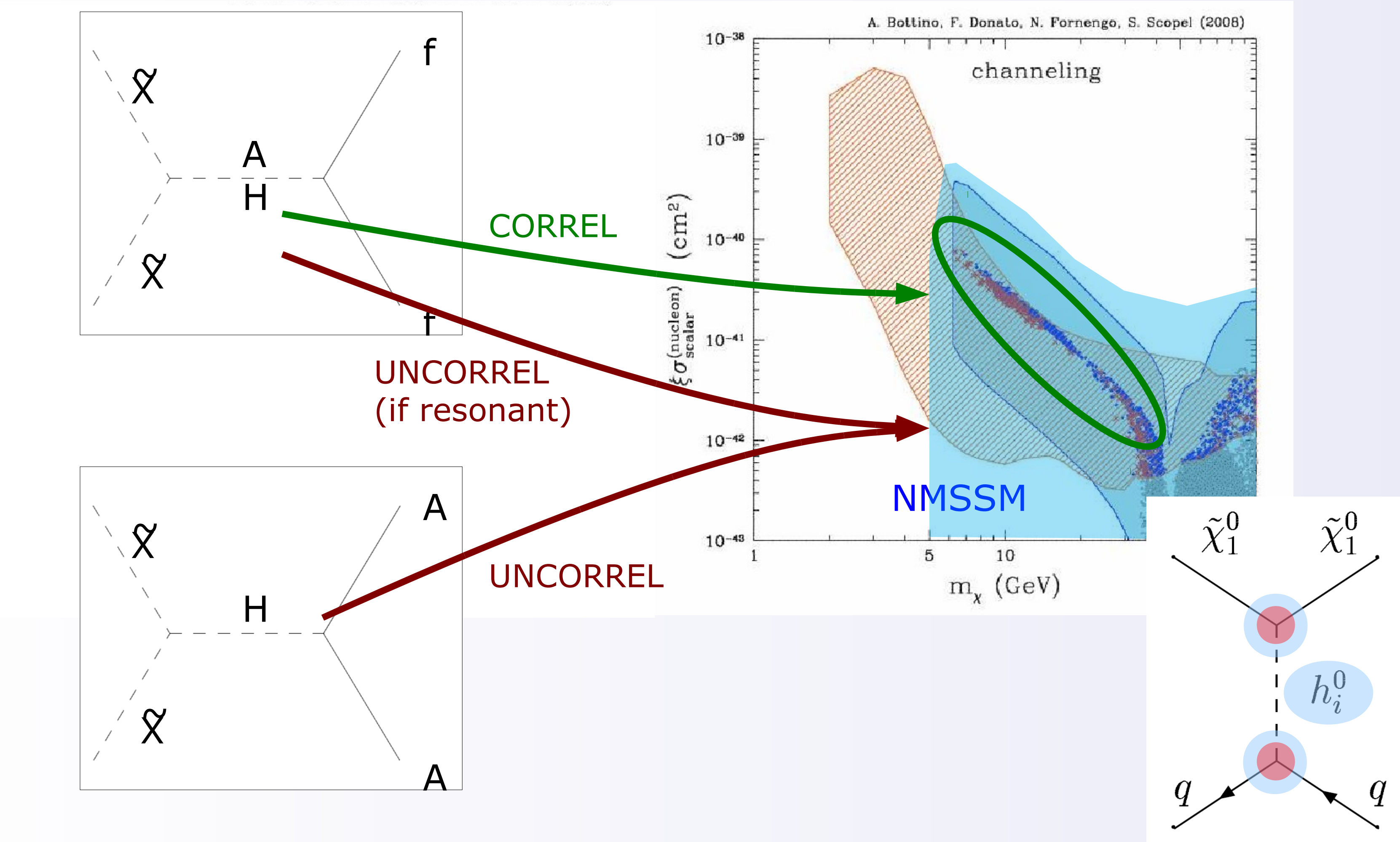


Very light neutralinos in the NMSSM

- Direct detection is now not always correlated

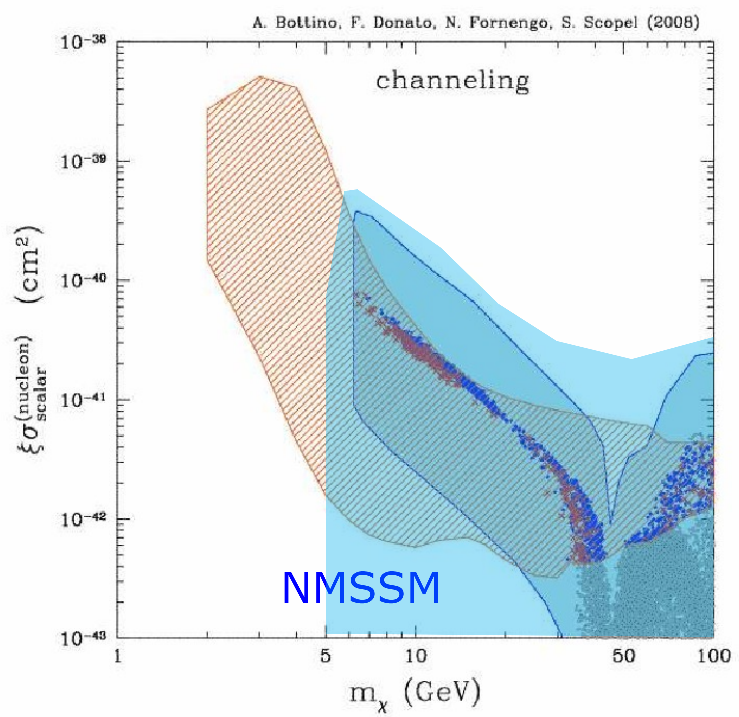
(D.G.C. With CoGeNT '08)

- Better fit of low-energy observables (e.g., smaller contribution to BR(b→sγ))

Higgses can have a large singlet component

- Wider regions of the parameter space

Pseudoscalar can be much lighter without the need of large tan β



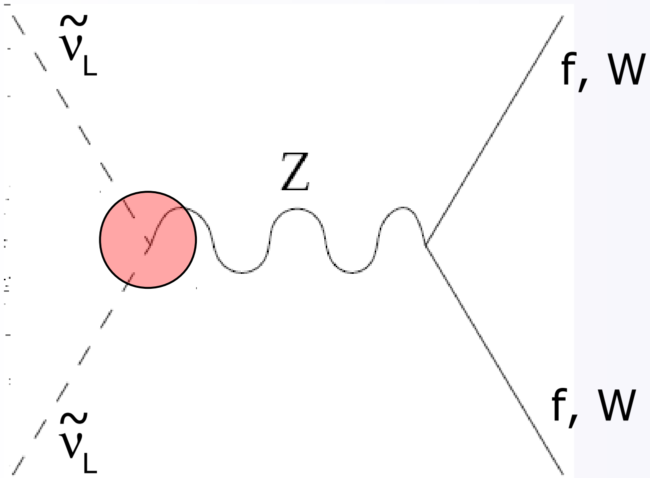
- Less constrained if the observation of light WIMPs is not confirmed

Other SUSY WIMPs?

- Sneutrino dark matter in the NMSSM

Sneutrino DM in the MSSM

- On the Standard MSSM: Pure left-handed sneutrino, faces some problems



Sizable coupling with Z boson, leading to

- Too large annihilation cross section (implying too small relic density)

(Ibáñez '84; Hagelin, Kane, Rabi '84; Goodmann, Witten'85; Freese '86)

- Too large direct detection cross section (already disfavoured by current experiments)

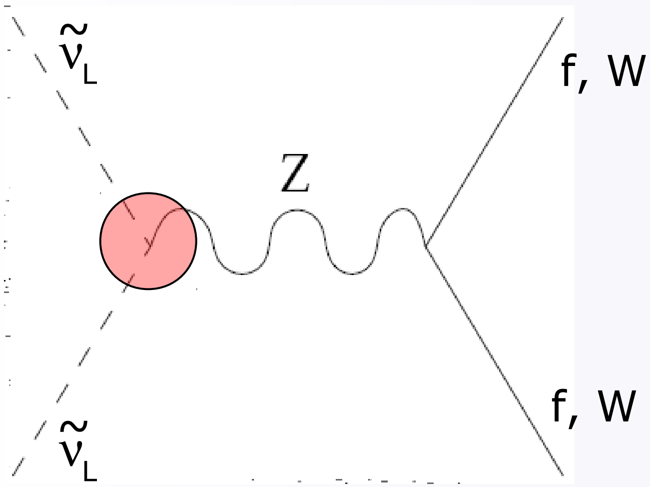
(Falk, Olive, Srednicki '94)

Sneutrino DM in the MSSM

- These problems alleviated by reducing the Zνν coupling

Including a "sterile" (e.g., right-handed) component → mixed left-right mass eigenstates

(Arkani-Hamed et al. '91; Hooper et al. '05)



$$\tilde{\nu}_i = N^{\tilde{\nu}}_{i\tilde{\nu}_L}\tilde{\nu}_L + N^{\tilde{\nu}}_{i\tilde{N}}\tilde{N}$$

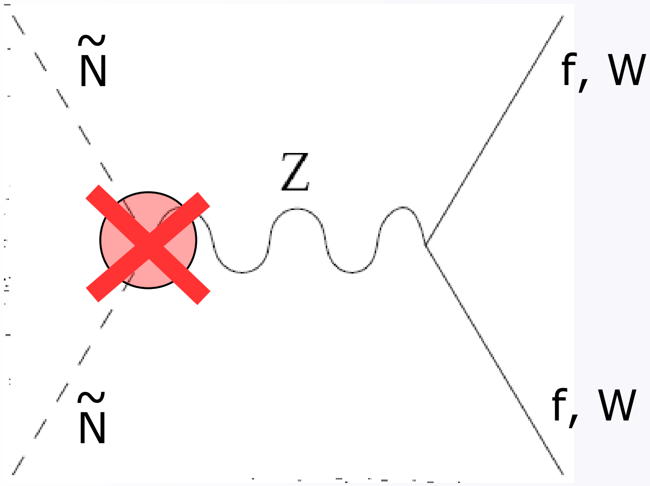
- Smaller annihilation cross section
- Smaller detection cross section

BUT: sneutrino mixing proportional to neutrino Yukawa → a large mixing is difficult to reconcile with see-saw generation of neutrino masses

Sneutrino DM in the MSSM

- Alternatively, a pure right-handed neutrino → no coupling with Z boson

(Asaka et al. '06; Gopalakrishna et al. '06; McDonald '07)



$$\tilde{\nu} = \tilde{N}$$

- Non-thermally produced

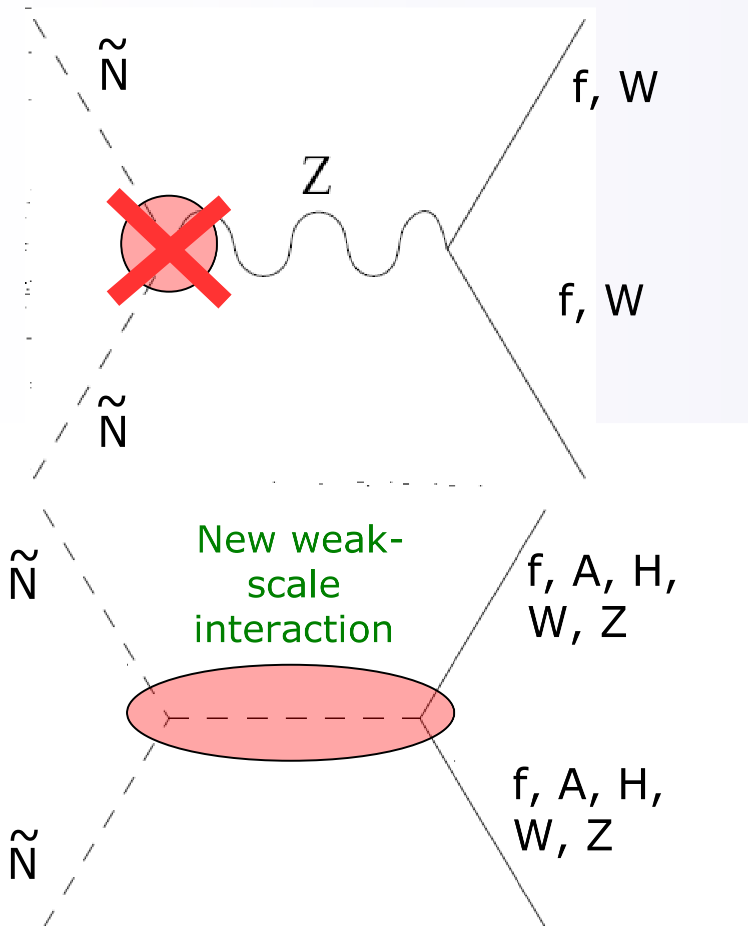
NOT WIMPS

BUT: very small detection cross section (would not account for a WIMP observation)

Sneutrino DM beyond the MSSM

- Solution? Coupling the RH sneutrino to the observable sector WEAKLY (e.g., extending gauge or Higgs sectors)

(Lee et al. ‘07; Garbrecht et al. '06)



$$\tilde{\nu} = \tilde{N}$$

WIMP

This can be accommodated in a well-motivated extension of the MSSM:

the Next-to-Minimal SUSY SM (NMSSM)

(D.G.C., Muñoz, Seto ‘08; D.G.C. Seto '09)

The NMSSM with right-handed neutrinos

- Addition of TWO new superfields, ***S***, ***N***, singlets under the SM gauge group

$$\mathrm{NMSSM} \quad = \quad \mathrm{MSSM} + \hat{S} \left\{ \begin{array}{l} 2 \text{ extra Higgs } (\mathrm{CP-even},\ \mathrm{CP-odd}) \\ 1 \text{ additional Neutralino} \end{array} \right.$$

$$+ N \left\{ \begin{array}{l} 1 \text{ additional (right-handed) Neutrino} \\ \text{and sneutrino} \end{array} \right.$$

S cures the μ problem

N provides right-handed neutrinos (see-saw)

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$$\text{NMSSM} = \text{MSSM} + \hat{S} \begin{cases} 2 \text{ extra Higgs (CP-even, CP-odd)} \\ 1 \text{ additional Neutralino} \end{cases}$$

$$+ N \begin{cases} 1 \text{ additional (right-handed) Neutrino} \\ \text{and sneutrino} \end{cases}$$

- New terms in the superpotential

$$W = Y_u\, H_2\, Q\, u + Y_d\, H_1\, Q\, d + Y_e\, H_1\, L\, e - \lambda\, S\, H_1 H_2 + \frac{1}{3}\kappa S^3$$

$$W = W_{\text{NMSSM}} + \lambda_N S N N + y_N L\, H_2 N$$

- After Radiative Electroweak Symmetry-Breaking

$$\langle H_1^0 \rangle = v_1 \quad ; \quad \langle H_2^0 \rangle = v_2 \quad ; \quad \langle S \rangle = s \qquad \begin{cases} \mu\, H_1\, H_2 \\ m_N\, N\, N \end{cases}$$

- Neutrino masses (low-scale see-saw)

$$M_N = 2\lambda_N v_s \quad \text{(EW scale)} \qquad m_{\nu_L} = \frac{y_N^2 v_2^2}{M_N}$$

y_N constrained to be ~O(10[-6])

- Sneutrino masses:

$$\tilde{\nu}_L \equiv \frac{1}{\sqrt{2}}(\tilde{\nu}_{L1} + i\tilde{\nu}_{L2}) \qquad \tilde{N} \equiv \frac{1}{\sqrt{2}}(\tilde{N}_1 + i\tilde{N}_2)$$

$$\frac{1}{2}(\tilde{\nu}_{L1}, \tilde{N}_1)\begin{pmatrix} m^2_{L\bar{L}} & m^2_{LR} + m^2_{L\bar{R}} \\ m^2_{LR} + m^2_{L\bar{R}} & m^2_{R\bar{R}} + 2m^2_{RR} \end{pmatrix}\begin{pmatrix} \tilde{\nu}_{L1} \\ \tilde{N}_1 \end{pmatrix} + \frac{1}{2}(\tilde{\nu}_{L2}, \tilde{N}_2)\begin{pmatrix} m^2_{L\bar{L}} & -m^2_{LR} + m^2_{L\bar{R}} \\ -m^2_{LR} + m^2_{L\bar{R}} & m^2_{R\bar{R}} - 2m^2_{RR} \end{pmatrix}\begin{pmatrix} \tilde{\nu}_{L2} \\ \tilde{N}_2 \end{pmatrix}$$

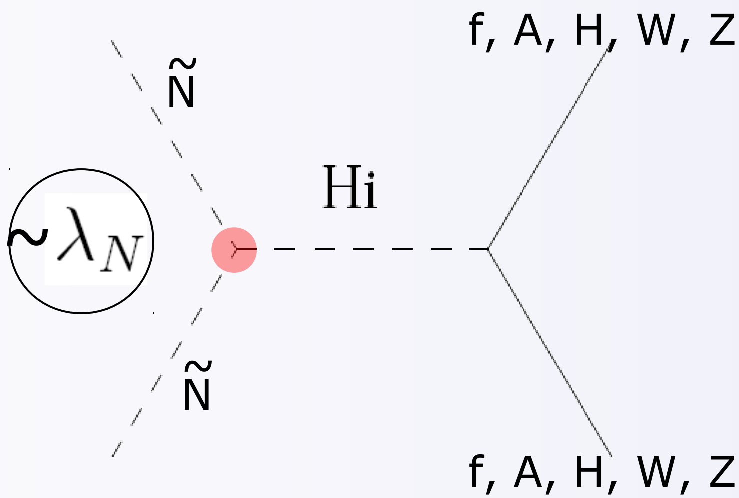
Proportional to y_N ➡ NEGLIGIBLE MIXING

$$\tilde{\nu}_i = N^{\tilde{\nu}}_{i\tilde{\nu}_L}\tilde{\nu}_L + N^{\tilde{\nu}}_{i\tilde{N}}\tilde{N} \quad \Rightarrow \quad \tilde{\nu} = \tilde{N}$$

PURE RH-SNEUTRINO

Sneutrino Interactions

$\tilde{\nu} = \tilde{N}$ PURE RH-SNEUTRINO (LR mixing proportional to very small Yukawa)



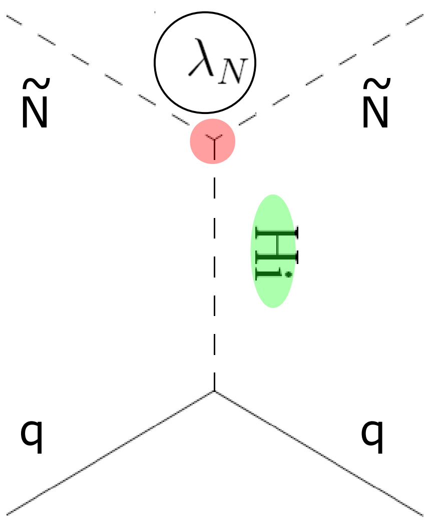
BUT COUPLED TO THE HIGGS (and therefore to SM particles)

WIMP

(D.G.C., Muñoz, Seto '08; D.G.C. Seto '09)

Spin-independent cross section

- Contributions from **Higgs-**exchanging diagrams:



$$\sigma \sim \frac{m_p^2 \, C^2_{H_i \nu \nu}}{(m_p + m_N)^2 \, m^4_{H_i}}$$

- No spin-dependent contribution: potential discrimination from neutralino

RH-Sneutrino DM overview

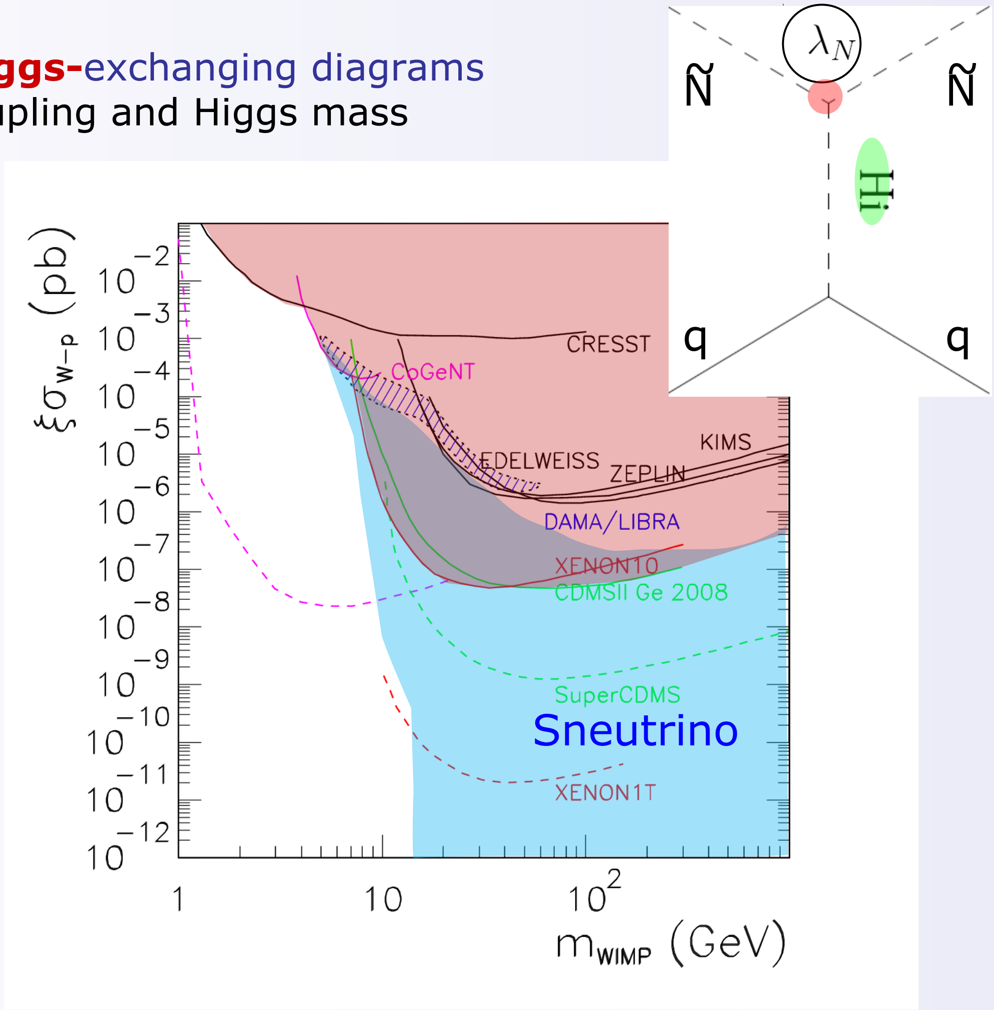
- (Right-handed) sneutrinos in the NMSSM: Predictions for direct detection

Main contribution from **Higgs-**exchanging diagrams
dependent on the new coupling and Higgs mass

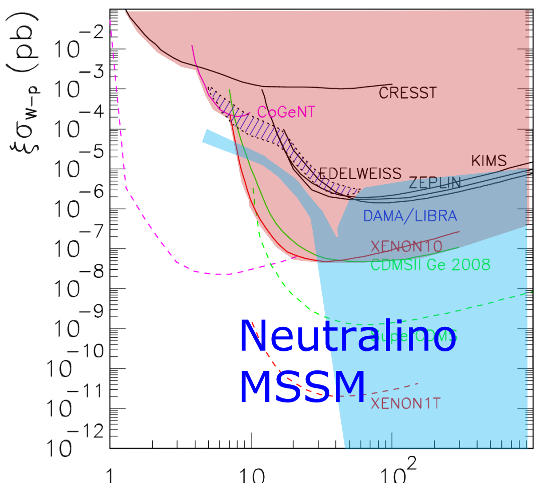
○ Viable, accessible and not yet excluded
(D.G.C., Muñoz, Seto '08)

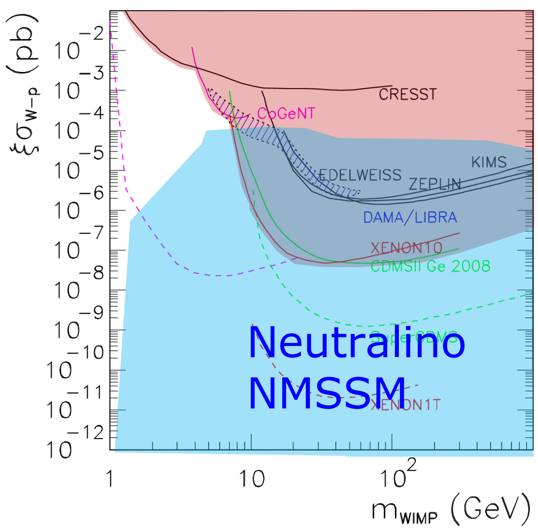
○ Light sneutrinos are viable and distinct from MSSM neutralinos

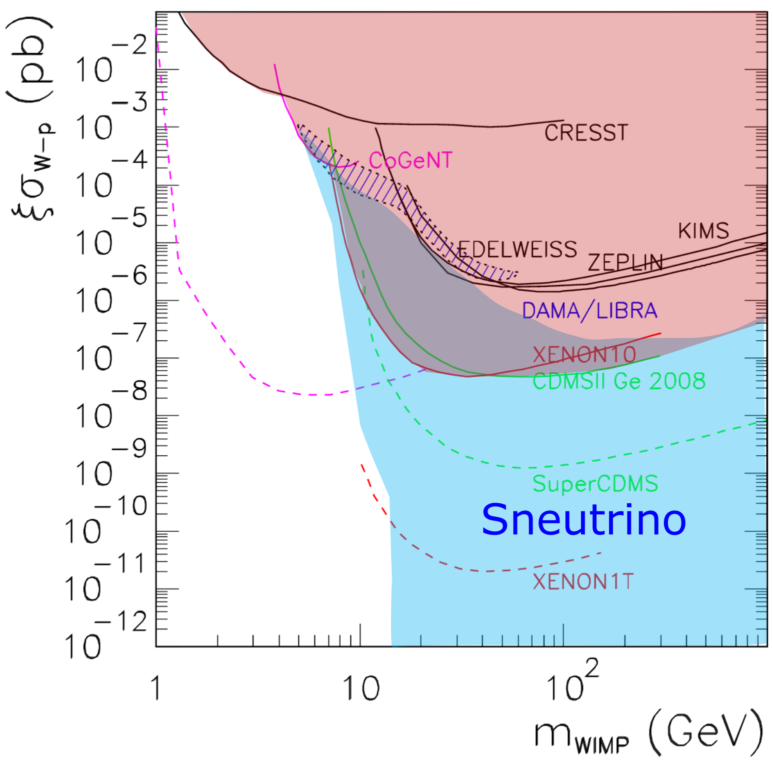
(D.G.C., Seto '09)



Comparison with other SUSY WIMPs (neutralinos)

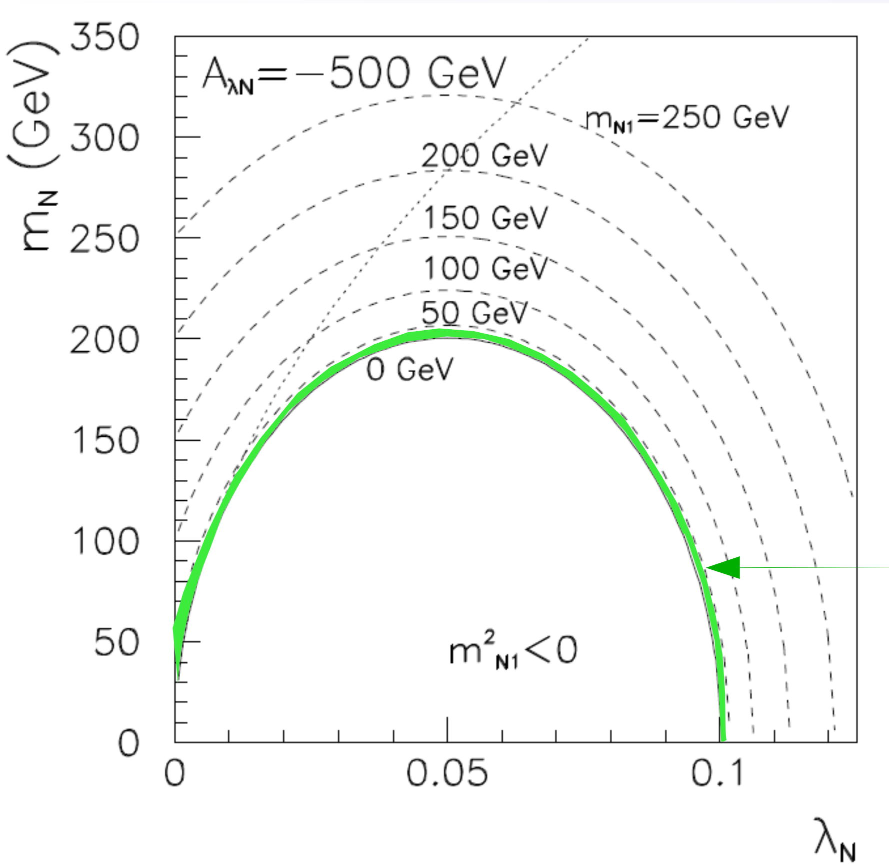






- For which choice of parameters are very light sneutrinos possible?

Varying the extra parameters within a reasonable range very light sneutrinos can be obtained for almost any choice of NMSSM parameters



E.g, for a "reasonable" choice

$$\lambda=0.1$$
$$\kappa=0.05$$
$$\tan\beta=5$$
$$\mu=200\,GeV$$
$$A_\lambda=500\,GeV$$
$$A_\kappa=0$$

$$7\,GeV<m_{N1}<12\,GeV$$

Analysis with parameters defined at the GUT scale is in process (sneutrino LSP with universal conditions? - seems reasonable).

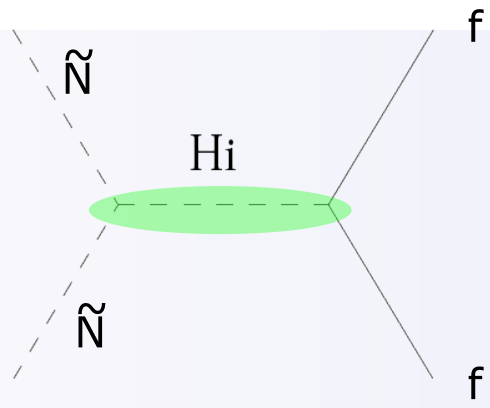
- The correct relic abundance for very light sneutrinos can be recovered in two ways

- Annihilation $\tilde{N}\tilde{N} \to ff$

Large coupling to fermions

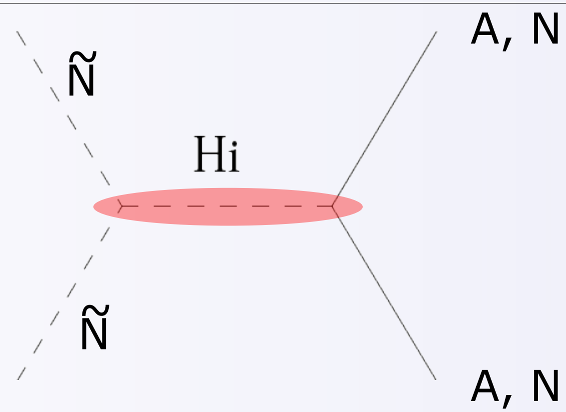
Easier than MSSM due to freedom with new coupling and small Higgs masses

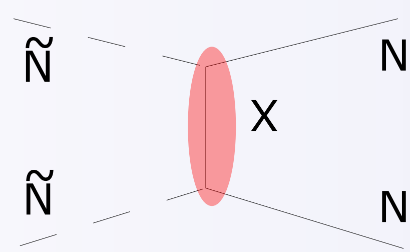
Better low-energy phenomenology



- Annihilation $\tilde{N}\tilde{N} \to AA, NN$

Requires very light pseudoscalars (singlet-like) or very light RH-neutrinos





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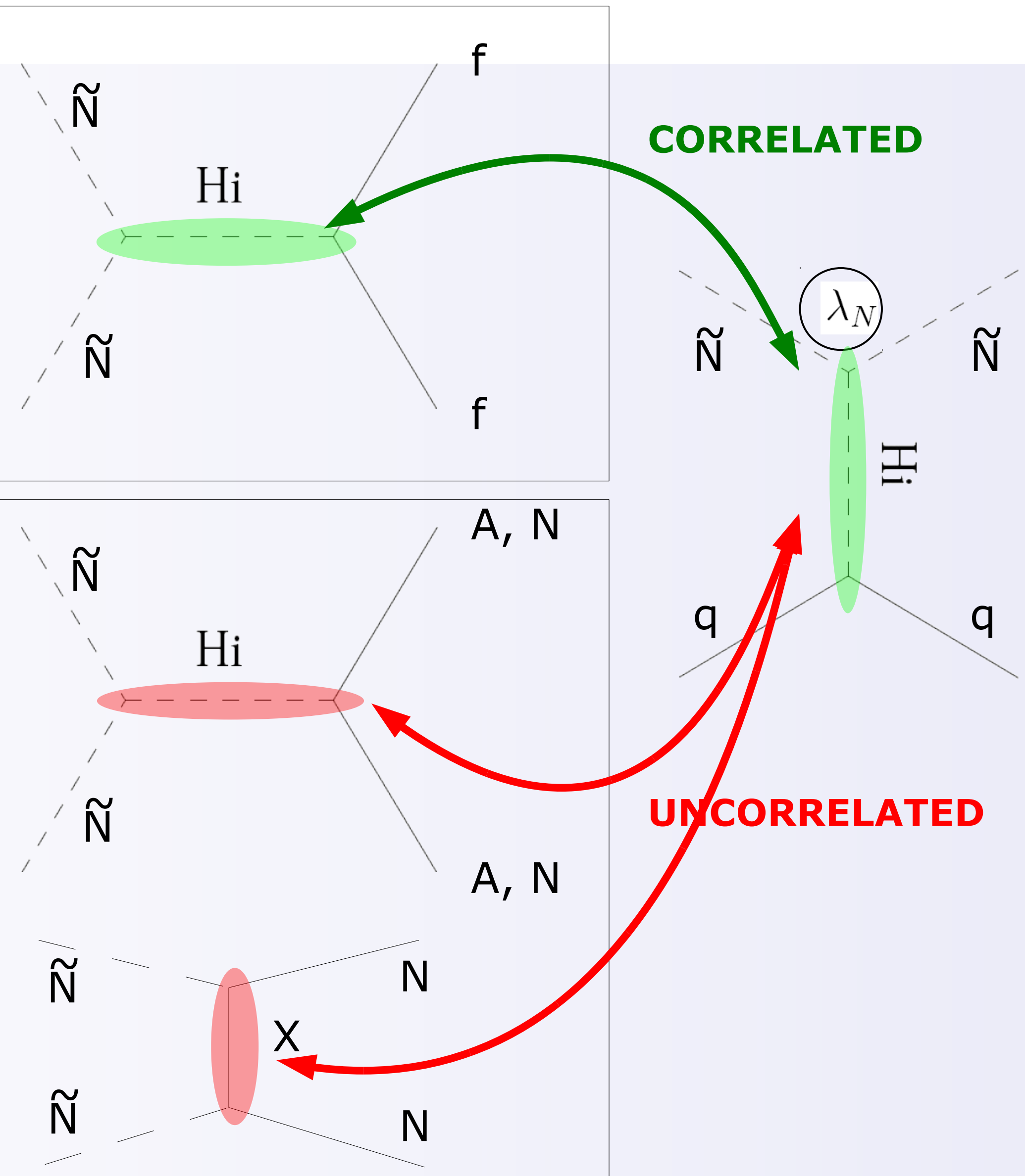
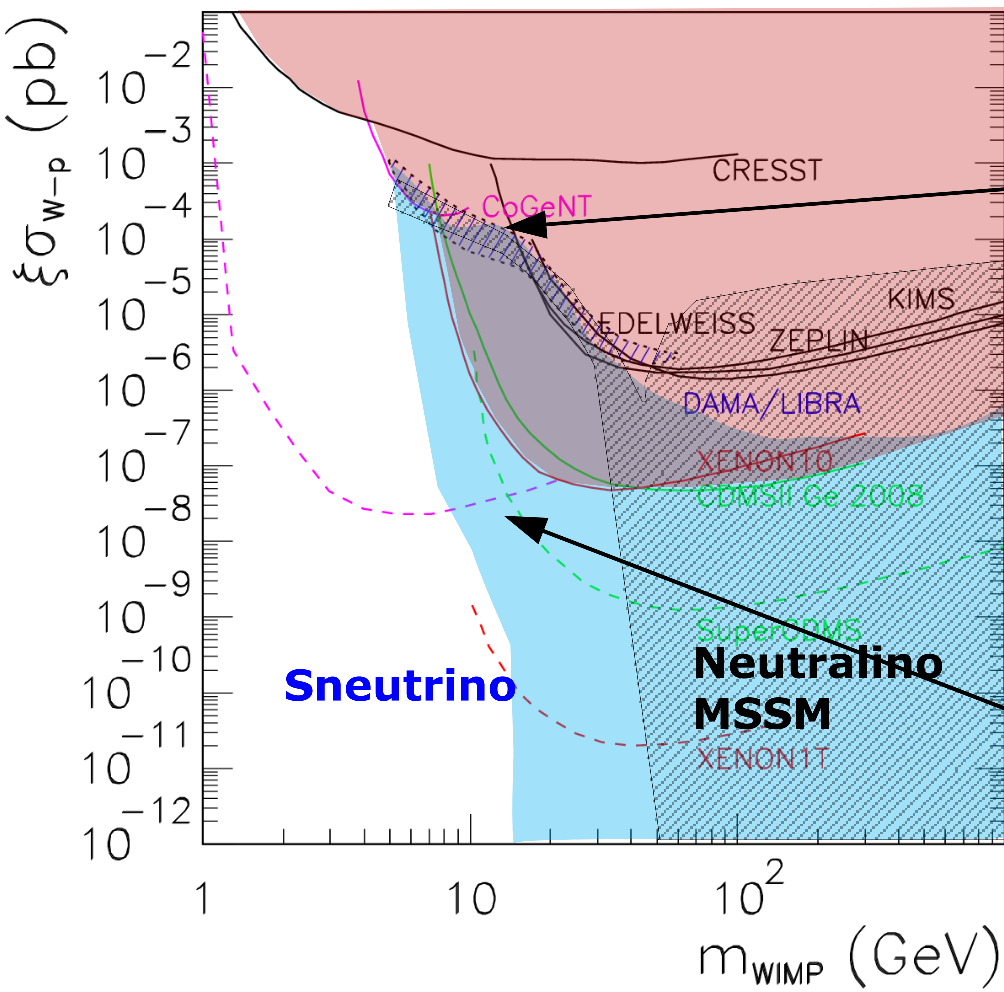


This gives rise to different properties under direct detection and might be crucial if CoGeNT results are (ore are not) confirmed



ÑÑ → ff

Similar to Neutralino in MSSM

ÑÑ → AA

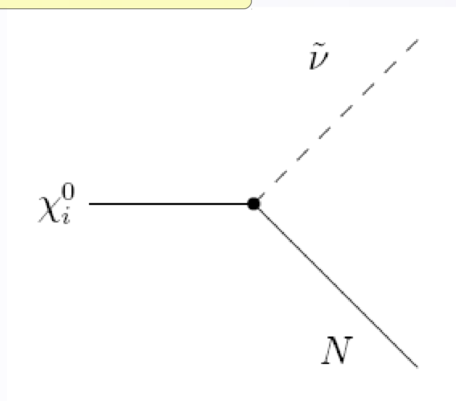
ÑÑ → NN

Can be similar to Neutralino in NMSSM

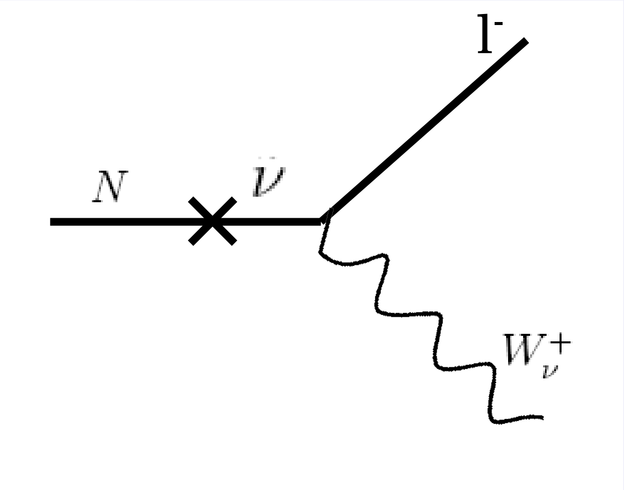
Collider signals

- (Right-handed) sneutrinos in the NMSSM: Signals at colliders?

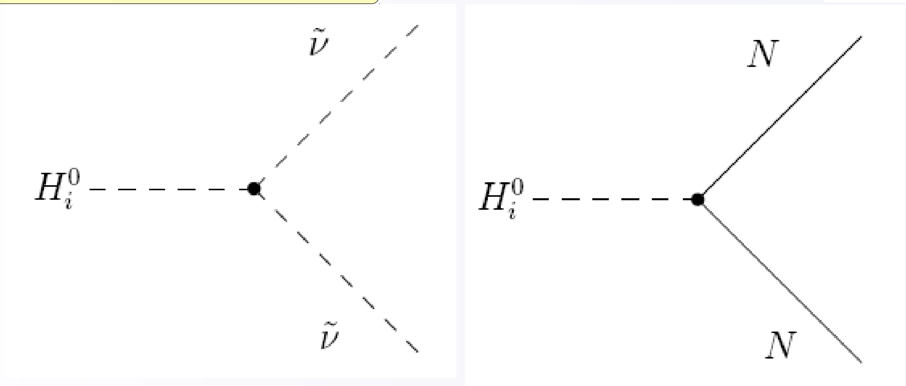
  - Missing energy



  - Displaced vertices of RH-neutrino decay



  - Invisible Higgs decays



with M.Peiró and O. Seto

Conclusions

Light SUSY WIMPs:

Neutralino (MSSM and NMSSM) and **RH-Sneutrino** (in the NMSSM)

Right-Handed Sneutrino can be a **viable WIMP DM candidate**

Very light RH-Sneutrinos are possible

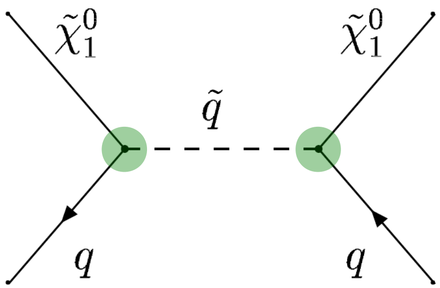
- Annihilation $\tilde{N}\tilde{N} \rightarrow ff$ (similar to neutralino in the MSSM)
- Annihilation $\tilde{N}\tilde{N} \rightarrow AA$ or NN (resembles neutralinos in the NMSSM)

Distinguishable with combined DD experiments or with LHC signals?

Complementary material

Spin-dependent cross section

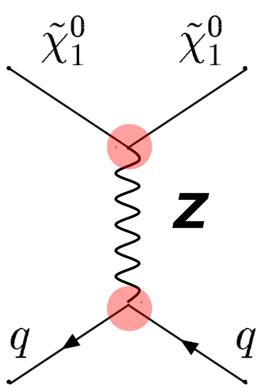
- Contributions from **squark-** and **Z-**exchanging diagrams:



Squark-exchange

$$\alpha_{2i}^{\tilde{q}} = \frac{1}{4(m_{1i}^2 - m_\chi^2)}\left[|Y_i|^2 + |X_i|^2\right] + \frac{1}{4(m_{2i}^2 - m_\chi^2)}\left[|V_i|^2 + |W_i|^2\right]$$

- Typically very small unless $m_q \sim m_\chi$



Z-exchange

$$\alpha_{2i}^{Z} = -\frac{g^2}{4m_Z^2\cos^2\theta_W}\left[|N_{13}|^2 - |N_{14}|^2\right]\frac{T_{3i}}{2}$$

Leading contribution but has an upper bound: $\sigma \leq 6.2\times 10^{-2}$ pb

- It also increases with the neutralino Higgsino components: $\mu \downarrow$

Spin-dependent searches

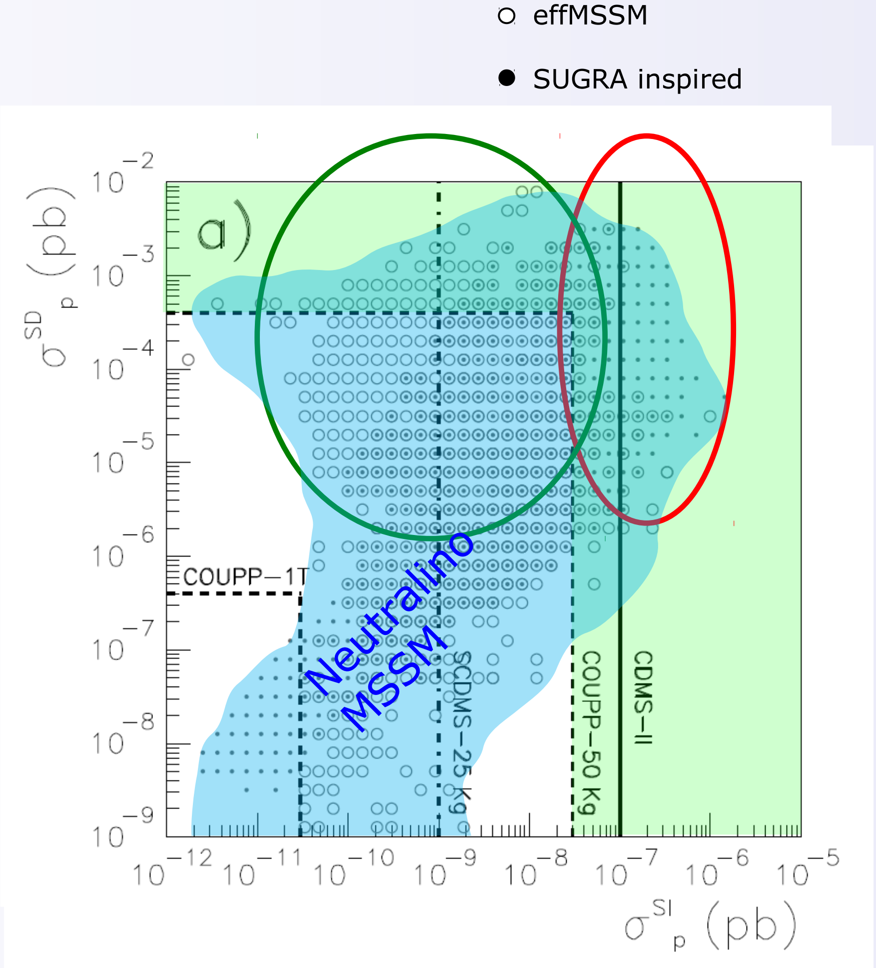
- Overall theoretical predictions in the MSSM:

Enhancement of Z-exchange

Through a decrease in the μ parameter

Enhancement of q̃-exchange

$$(m_{\tilde{u},\tilde{d},\tilde{s}} - m_{\tilde{\chi}_1^0})/m_{\tilde{\chi}_1^0} \lesssim 0.1$$

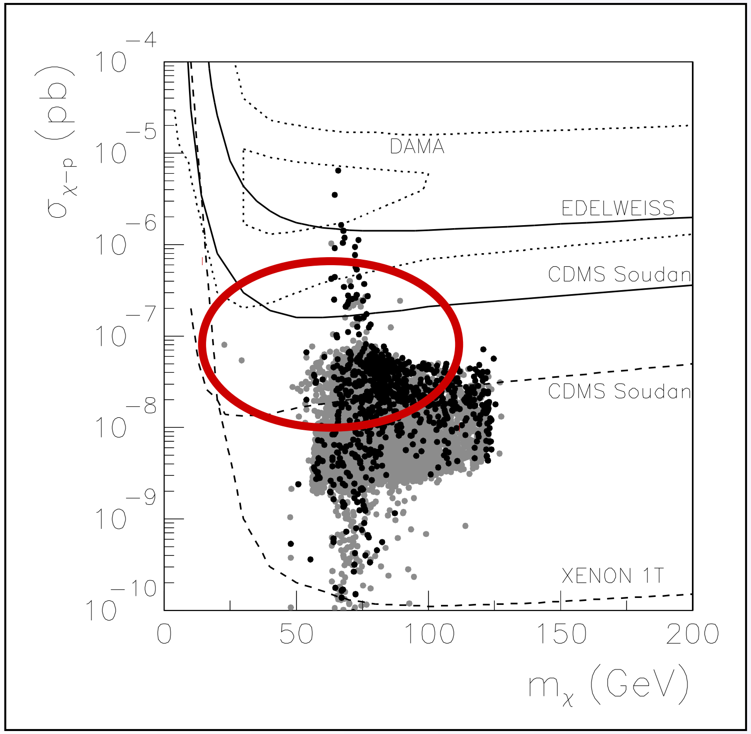


(G.Bertone, D.G.C., J.I.Collar, B.Odom´07)

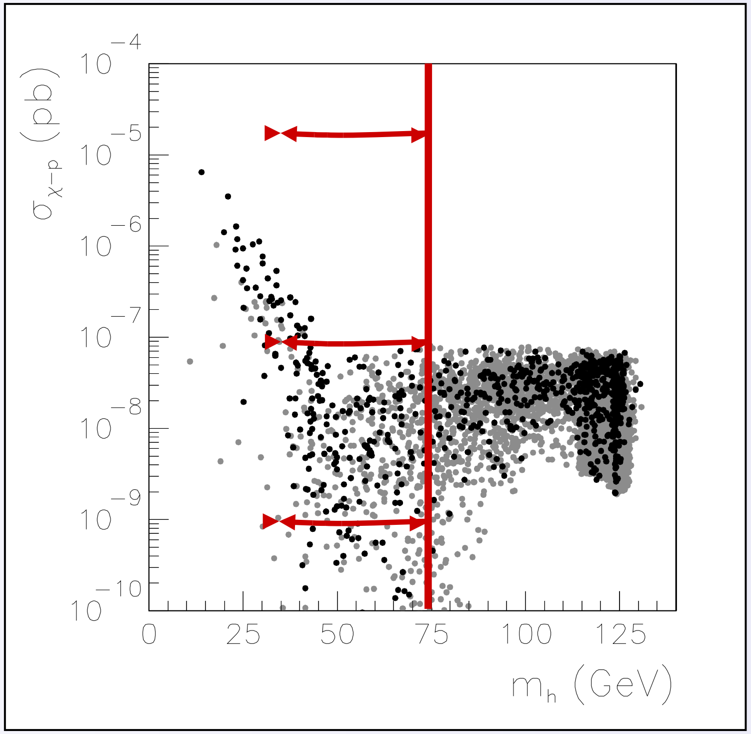
Neutralino

Neutralino in the NMSSM

- Very large detection cross sections can be obtained for singlino-line neutralinos



Higgses lighter than 70 GeV and mostly singlet-like



(D.G.C., C.Hugonie, D.López-Fogliani, A.Teixeira, C.Muñoz ´04)
(D.G.C., E. Gabrielli, D.López-Fogliani, A.Teixeira, C.Muñoz ´07)

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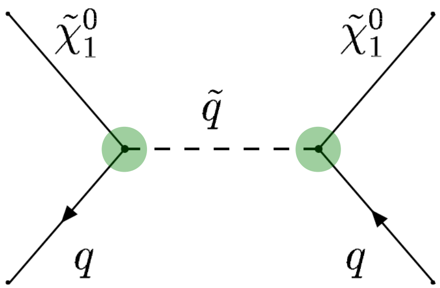

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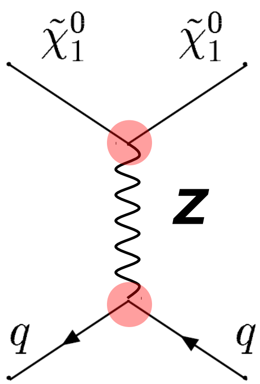

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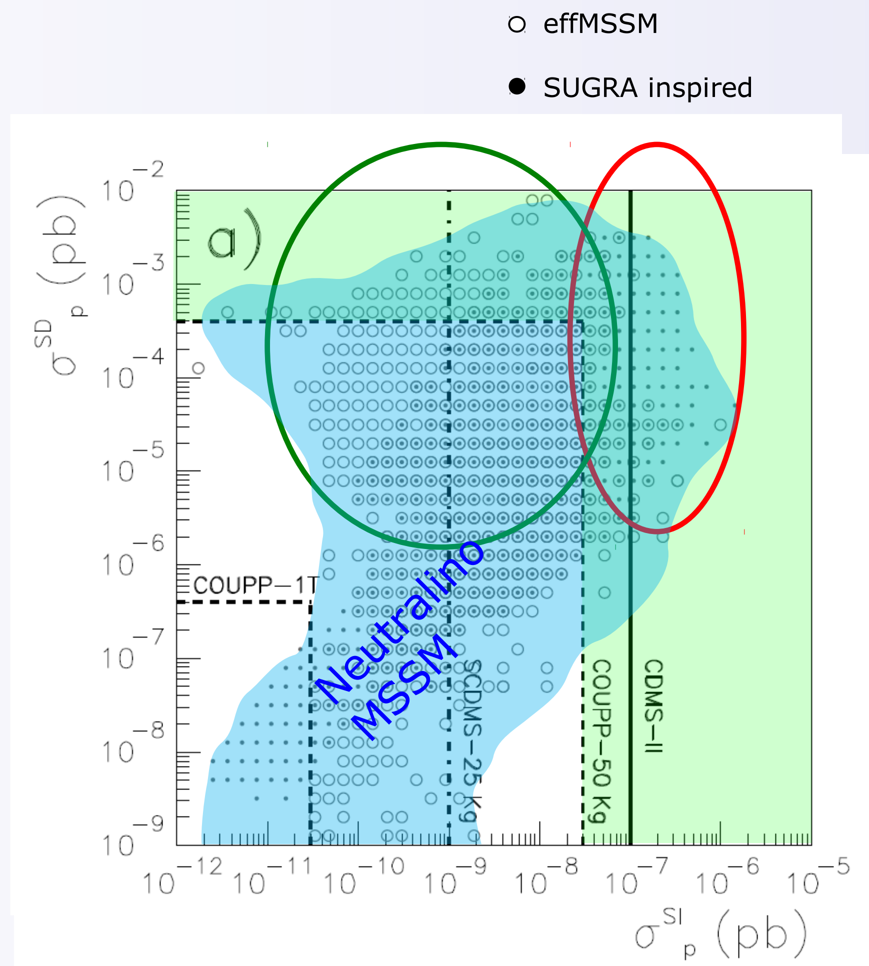

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