Recoil Detection of the Lightest Neutralino in MSSM Singlet Extensions

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Outline

- Introduction
- Overview of Models
- Relic Density results
- Direct Detection experiment overview
- Spin Independent scattering calculation
- Spin Independent scattering results
- Conclusions

Introduction

- Calculated relic density and scattering cross section for various supersymmetric models.
- Modified DarkSUSY [P. Gondolo *et al.*, astro-ph/0406204] code to incorporate additional states of investigated models
- Investigate the correlated predictions for direct detection and observed relic density bounds.

Model Overview

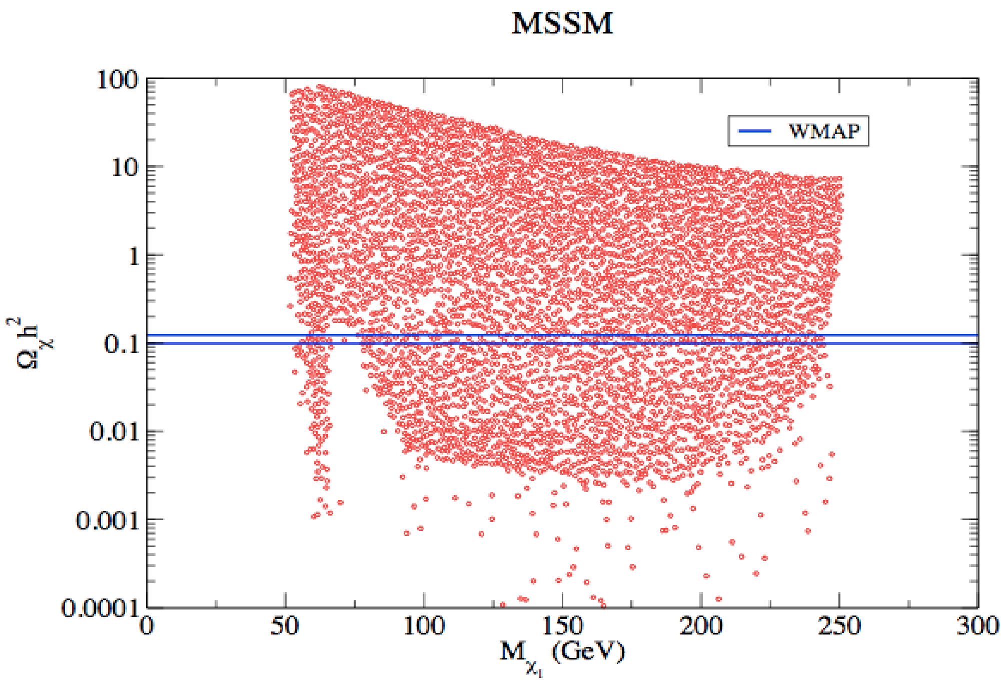
- We investigated singlet extensions of the Minimal Supersymmetric Standard Model (MSSM)
  - Next-to-Minimal Supersymmetric SM (NMSSM) with an additional cubic singlet term
  - Nearly-Minimal Supersymmetric SM (nMSSM) with a tadpole term
  - U(1)’-extended MSSM (UMSSM) with an extra Z’ gauge Boson
- The secluded U(1)’-extended MSSM (sMSSM) with three singlets in addition to UMSSM is equivalent to nMSSM if additional singlet vevs are large.
- sMSSM and nMSSM collectively called n/sMSSM

Additional States

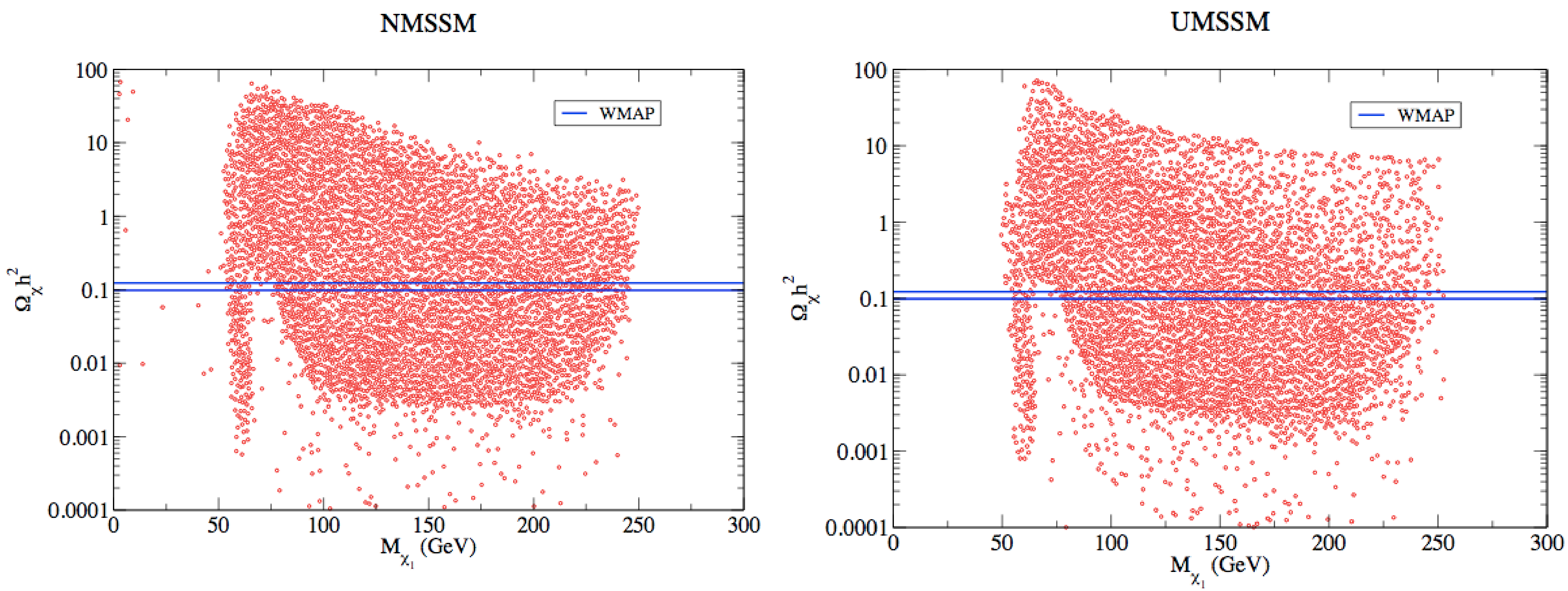
Model:	MSSM	NMSSM	nMSSM	UMSSM	sMSSM
Symmetry:	–	$\mathbb{Z}_3$	$\mathbb{Z}_5^R, \mathbb{Z}_7^R$	$U(1)'$	$U(1)'$
Extra	–	$\frac{\kappa}{3}\hat{S}^3$	$t_F \hat{S}$	–	$\lambda_S S_1 S_2 S_3$
superpotential term	–	(cubic)	(tadpole)	–	(trilinear secluded)
χ_i^0	4	5	5	6	9
H_i^0	2	3	3	3	6
A_i^0	1	2	2	1	4

MSSM relic density

- Points within WMAP correspond to focus point
- Lightest Higgs pole near $m_{\chi_1^0} \sim M_{H_1}/2 \sim 60\ \mathrm{GeV}$
- Similar effect from second lightest Higgs, giving sporadic points below populated region.



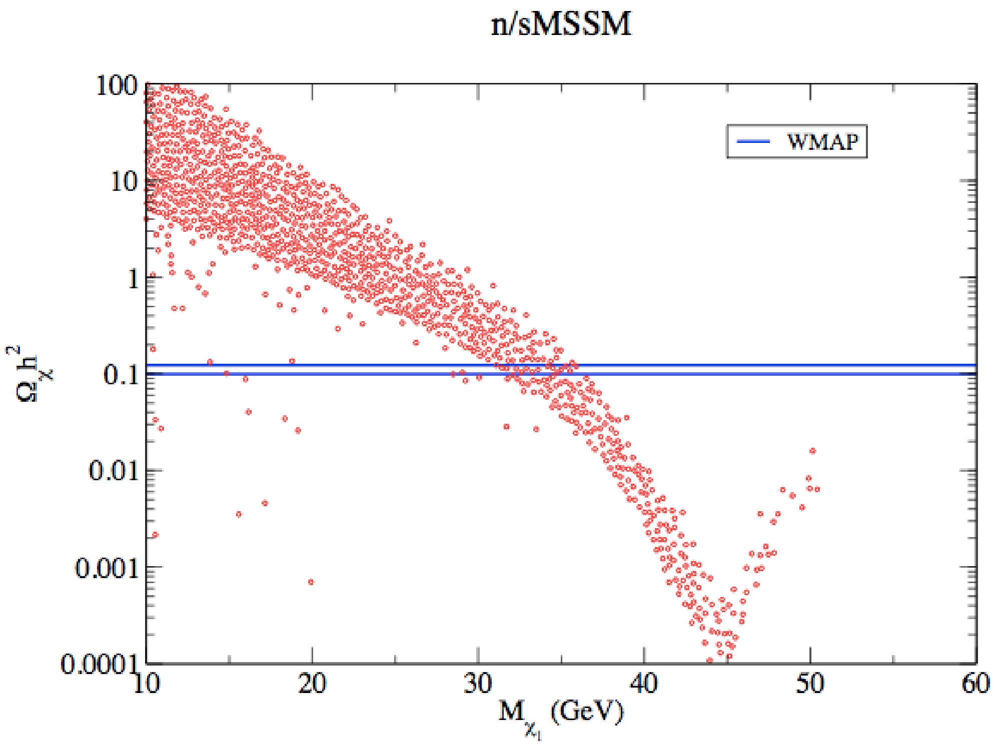
NMSSM and UMSSM relic density



- Similar to MSSM
- These models contain more Higgs resonances, so there are more points below populated region.

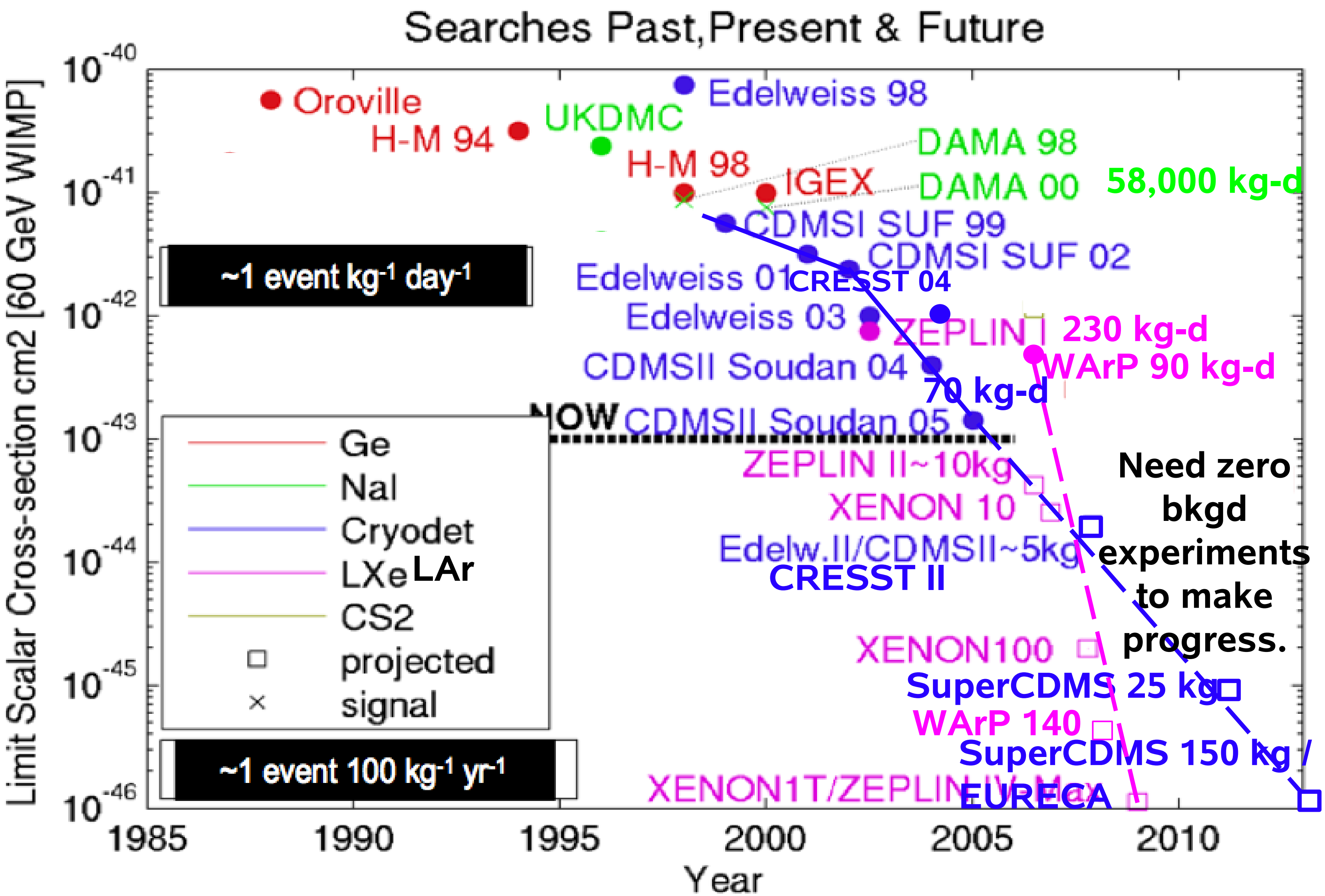
n/sMSSM relic density

- Relic density strongly dependent on neutralino mass
- Annihlation rate suppressed by Z propagator for low neutralino mass
- Annihilation through Higgs pole gives sporadic points for lighter neutralino masses.
- Lightest neutralino mass escapes LEP bound since it is dominately singlino.



Direct Detection Experiments

- Present experiment much more sensitive to spin independent scattering (SI), than spin dependent (SD) scattering.
  - SI processes scatter coherently
  - Scattering is enhanced by large target nuclei



Plot updated from that in DM Review Article: Gaitskell, Ann. Rev. Nucl. and Part. Sci. 54 (2004) 315-359

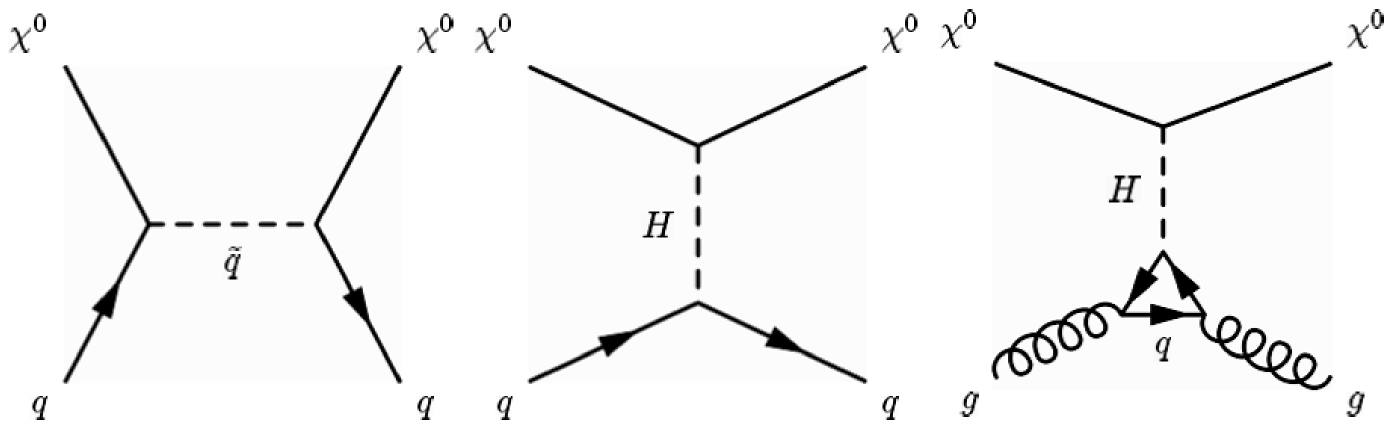
- Richard Schnee, Status of Direct Searches for WIMP Dark Matter, SUSY06

Direct Detection Experiments

- For a summary of cryogenic dark matter searches see W. Seidel, Nucl. Phys. (Proc. Suppl.) B138 (2005) 130
- For a summary of non-cryogenic dark matter searches see A. Morales, Nucl. Phys. (Proc. Suppl.) B238 (2005) 135

Spin Independent Scattering

- Diagrams contributing to spin independent scattering cross section:



SI scattering ct'd

- SI cross section [P. Gondolo et al., astro-ph/0406204]:

$$\sigma^{SI}_{\chi_i} = \frac{\mu^2_{\chi_i}}{\pi}|ZG^p_s + (A-Z)G^n_s|^2$$

.

  - $\mu_{\chi^i} = \frac{m_{\chi^0_1} m_N}{m_{\chi^0_1} + m_N}$ is the nucleon-neutralino reduced mass
  - G^p_s (G^n_s) is the proton (neutron) hadronic mixing matrix
- Scattering off neutrons and protons very similar, so focus on proton scattering:

$$\sigma^{SI}_{\chi p} = \frac{\mu^2_{\chi p}}{\pi}|G^p_s|^2$$

SI scattering ct'd

- In terms of the hadronic mixing elements and couplings

$$G_s^p = \sum_{q=u,d,s,c,b,t} \langle N|\bar{q}q|N\rangle \frac{1}{2}\sum_{k=1}^{6}\frac{g_{\bar{q}_{L_k}\chi q}\, g_{\bar{q}_{R_k}\chi q}}{m^2_{\tilde{q}_k}}$$

$$-\sum_{q=u,d,s}\left(\langle N|\bar{q}q|N\rangle \sum_{h=H_1,H_2,H_3}\frac{g_{h\chi\chi}\, g_{hqq}}{m_h^2}\right) - \frac{2}{27}\sum_{q=c,b,t}\left(f_{TG}^{(p)}\frac{m_p}{m_q}\sum_{h=H_1,H_2,H_3}\frac{g_{h\chi\chi}\, g_{hqq}}{m_h^2}\right)$$

- The first term is from the squark exchange
- The second term from the Higgs exchange
- The last term from the quark loop.

SI scattering ct'd

- The updated hadronic matrix elements are [J. R. Ellis, A. Ferstl, and K. A. Olive, hep-ph/0001005]

$$\langle N|\overline{q}q|N\rangle = f^p_{Tq}\frac{m_p}{m_q}$$

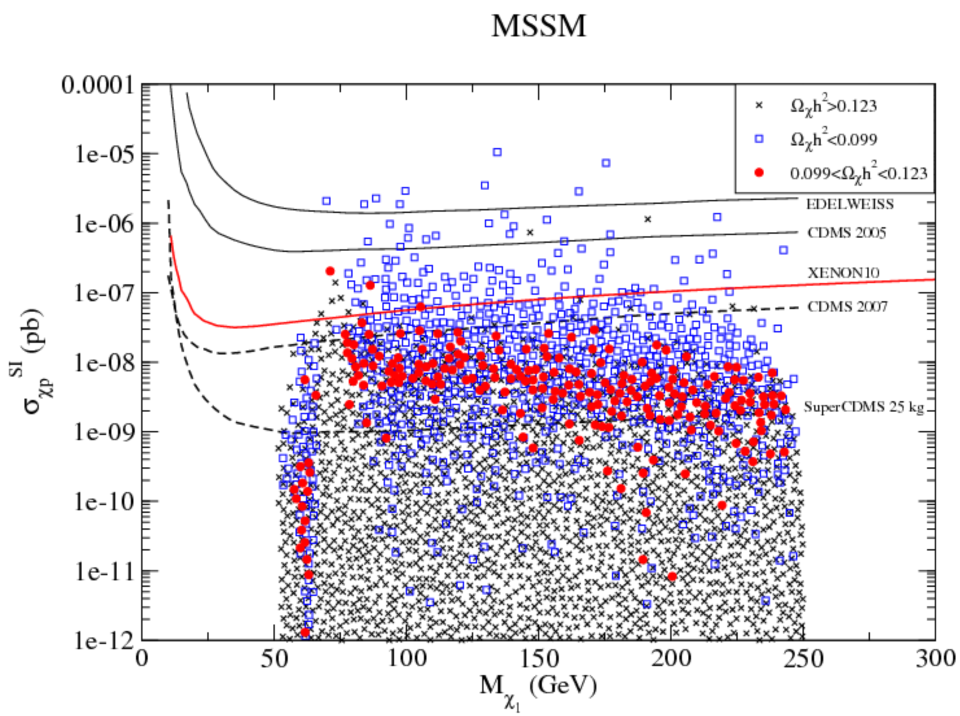
$$f^p_{Tu} = 0.020 \pm 0.004,\ f^p_{Td} = 0.026 \pm 0.005, \quad f^p_{Ts} = 0.118 \pm 0.062$$

$$f^p_{TG} = 0.84 \pm 0.06$$

- Uncertainty in SI cross sections on order of 60% due to uncertainty in hadronic matrix elements.

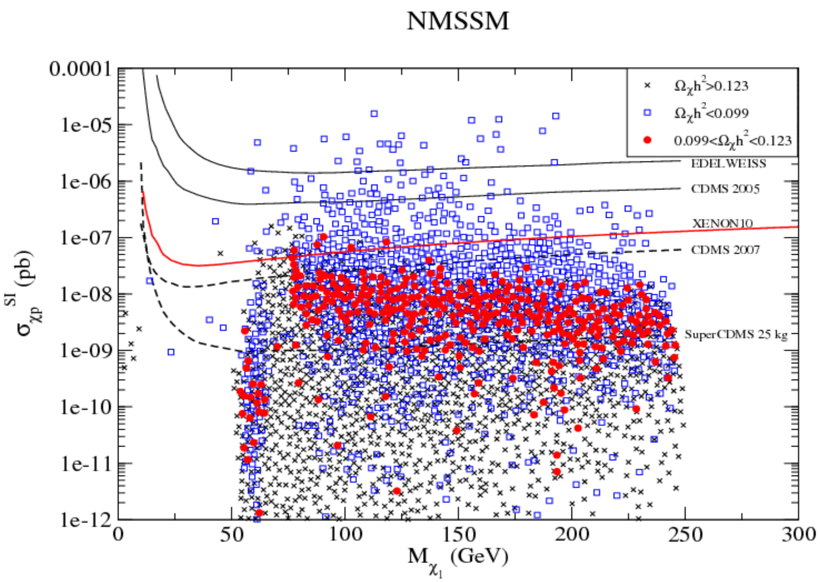
MSSM SI Scattering Results

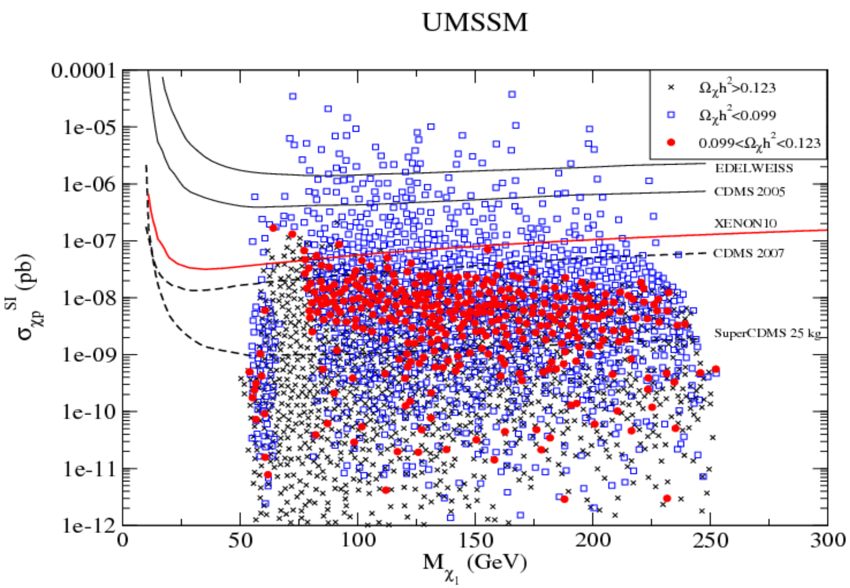
- Many points with observed relic abundance within reach of SuperCDMS
- A small neutralino-Higgs coupling is needed at the Higgs pole to obtain observed relic density



- With small neutralino-Higgs coupling the Higgs pole contribution to the SI scattering cross section is suppressed

UMSSM and NMSSM SI scattering results

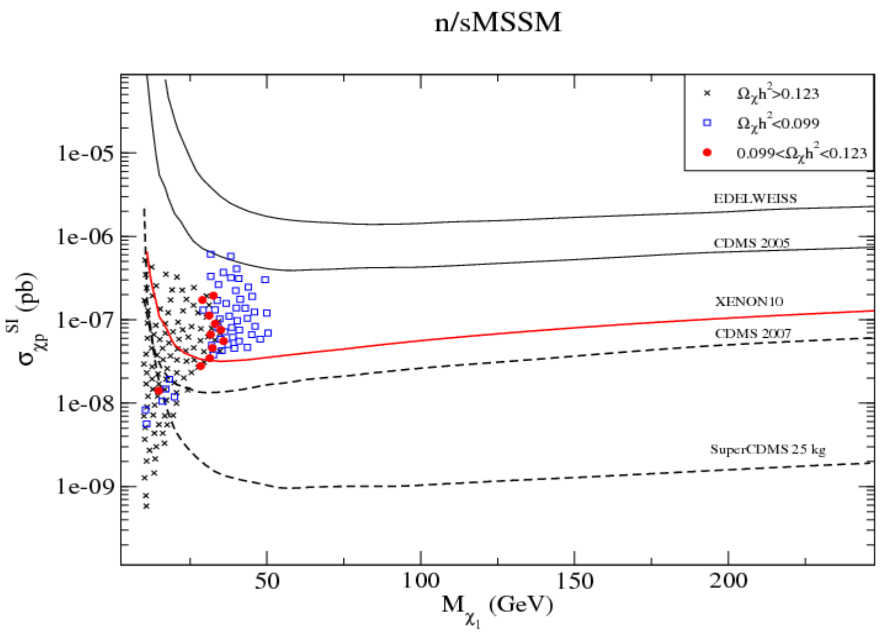




- Results similar to MSSM
- More points below SuperCDMS reach due to more Higgs resonances

n/sMSSM SI scattering

- Strict mass limit can be used to find direct detection lower limit
- XENON 10 has eliminated nearly all of the n/sMSSM parameter space
- CDMS 2007 should be able to put even stronger constraints on model.



Conclusions

- MSSM, NMSSM, an UMSSM predict SI proton scattering cross sections that may be detectable at SuperCDMS and consistent with observed relic density
- XENON 10 has eliminated most of the n/sMSSM parameter space that is compatible with the SI scattering cross section and observed relic density
- n/sMSSM SI proton scattering cross sections are highly favored to be detectable at CDMS 2007 and compatible with measured relic density

Other Studies

- nMSSM:
  - Balazs, Carena, Freitas, Wagner, hep-ph/0705.0431
- NMSSM:
  - Cerdeno, Hugonie, Lopez-Fogliani, Munoz, Teixeira, JHEP 12, 048 (2004), hep-ph/0408102
  - Cerdeno, Gabrielli, Lope-Fogliani, Munoz, Teixeira, (2007), hep-ph/0701271

Direct Detection Experiments

- Future Experiments
  - CDMS II [D. S. Akerib et al., Nucl. Instrum. Meth. **A559**, 390 (2006)]
  - CRESST2 [Astrophys. J. 12 (1999) 107]
  - ZEPLINII, III [Dawson et al., Nucl. Phys. B (Proc. Suppl.) 110 (2002) 109]
  - Majorana [Aalseth set al., Nucl. Phys. B (Proc. Suppl.) 110 (2002) 392]
  - Cuore [Arnaboldi et al., hep-ex/0212053]
  - DAMA II [Bernabei et al., Riv. N. Cim. 26 (2003) 1]

Direct Detection Experiments

- SuperCDMS, WARP,
- GENIUS [Nuc. Phys. 123 (Proc. Suppl.) (2003) 209],
- ZEPLIN4 [hep-ph/0008296]
- XENON [hep-ph/0008296]
- Heidelberg Moscow Experiment [Baudis et al., Phys. Rev. D59 (1999) 022001]
- Igex [Irastorza et al., astro-ph/0211535]
- GTF [Baudis et al., Astropart. Phys. 17 (2002) 383]
- ZEPLIN I [Luscher et al., astro-ph/0305310]
- CRESST I [Angloher et al., Astropart. Phys. 18 (2002) 43],

Direct Detection Experiments

- Tokyo LiF/NaF [Takeda et al., Phys. Lett. B572 (2003) 145]
- Rosebud [Cebrian et al., Astropart. Phys. 15 (2001) 79]
- EDELWEISS [astro-ph/0503265 (2005)]
- CDMS [astro-ph/0509269 (2006)]